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A DEVELOPMENT OF KNOWLEDGE-BASED MODELS FOR CHECKING DESIGN ERRORS IN BUILDING CONSTRUCTION PROJECTS IN CAMBODIA

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Civil Engineering
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งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาโมเดลองค์ความรู้เพื่อช่วยวิศวกรตรวจสอบความผิดพลาดในงานออกแบบก่อสร้างที่อาจเกิดขึ้นในช่วงการก่อสร้าง งานวิจัยนี้แบ่งการศึกษาออกเป็น 2 ส่วน งานวิจัยส่วนแรกเป็นการระบุความผิดพลาดในงานออกแบบที่มีความสำคัญ ซึ่งเกิดขึ้นระหว่างส่วนประกอบของงานโครงสร้างกับส่วนประกอบงานประเภทอื่นๆ ของงานก่อสร้างอาคารในประเทศกัมพูชา โดยงานวิจัยเก็บข้อมูลจากวิศวกรโครงการในประเทศกัมพูชาด้วยแบบสอบถาม โอกาสเกิดความผิดพลาดจากงานออกแบบถูกวิเคราะห์โดยใช้การคำนวณค่าเปอร์เซ็นต์ และค่าความรุนแรงของความผิดพลาดจากงานออกแบบถูกวิเคราะห์โดยใช้ค่าเฉลี่ย ผลการพิจารณาโอกาสการเกิดและความรุนแรงของความผิดพลาดในงานออกแบบจะถูกใช้ในการจัดลำดับความสำคัญของความผิดพลาดโดยการวิเคราะห์ความเสี่ยงด้วยการแบ่งพื้นที่ความสำคัญ ผลการวิเคราะห์ความสำคัญที่ได้เป็นประโยชน์ต่อวิศวกรในการตระหนักถึงข้อผิดพลาดจากงานออกแบบที่อาจเกิดขึ้นในช่วงการก่อสร้าง จากการวิเคราะห์พบว่ามี 48 กรณีของงานออกแบบที่ผิดพลาดที่ควรให้ความสำคัญ งานวิจัยในส่วนที่สองเป็นการพัฒนาโมเดลองค์ความรู้สำหรับตรวจสอบความผิดพลาดในงานออกแบบ โดยกรณีศึกษาของงานออกแบบที่ผิดพลาดเก็บข้อมูลจากการสัมภาษณ์วิศวกรที่มีประสบการณ์ทำงานในหน่วยงานผู้รับเหมาก่อสร้าง ข้อมูลกรณีศึกษาที่เก็บมาจะถูกวิเคราะห์ร่วมกันเพื่อหาคุณลักษณะและเงื่อนไขที่ทำให้เกิดความผิดพลาด คุณลักษณะและเงื่อนไขดังกล่าวจะถูกใช้เป็นข้อมูลในการพัฒนาแบบจำลองแผนผังการตัดสินใจ (Decision tree) หลังจากนั้นแบบจำลองแผนผังการตัดสินใจจะถูกใช้ในการพัฒนาระบบด้วยภาษา Visual Basic ใน โปรแกรม Microsoft Excel โดยระบบต้นแบบที่พัฒนาขึ้นสามารถช่วยให้วิศวกรสามารถตรวจสอบความผิดพลาดในงานออกแบบที่สามารถเกิดขึ้นก่อนดำเนินงานก่อสร้าง

ภาควิชา วิศวกรรมโยธา ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมโยธา ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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KEYWORDS: DESIGN ERRORS / STRUCTURAL ELEMENTS / BUILDING COMPONENTS / KNOWLEDGE-BASED MODELS / DECISION TREES / RISK ANALYSIS / VISUAL BASIC

ROTHMONY LY: A DEVELOPMENT OF KNOWLEDGE-BASED MODELS FOR CHECKING DESIGN ERRORS IN BUILDING CONSTRUCTION PROJECTS IN CAMBODIA. ADVISOR: ASST. PROF. VACHARA PEANSUPAP, Ph.D., 275 pp.

This research aims to develop the knowledge-based models for helping the engineers to check the design errors which possibly occur throughout the construction practices. This research is divided into two main parts. The first part attempts to identify the critical cases of design errors between structure and other building components in building construction projects. The questionnaires were distributed to the engineers of contractors in Cambodia. The percentage formulas were applied to determine the percentage occurrence of each case of design errors whereas impact value of each case was calculated by average mean score. The combination of percentage occurrence and impact was used to rank the cases of design errors with the priority zones of risk analysis. This ranking is useful for engineers to concern about the most critical cases of design errors during construction phase. 48 cases were found as the critical design errors that should be concerned. The second part of this research is the development of knowledge-based models for checking design errors. The cases of critical design errors were collected from interviewing the engineers of contractors based on their previous experience and knowledge. The cross-case analysis revealed the main attributes and conditions of each case, which were then used as the inputs in the decision tree of the models. Last, it was proposed to code these decision trees into a system by using Visual Basic programming in Microsoft Excel. This prototype system can help the engineers to check the conditions of attributes that can lead to problems of design errors before construction begins.

Department:	Civil Engineering	Student's Signature	....
Field of Study:	Civil Engineering	Advisor's Signature	....
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CHAPTER I
INTRODUCTION

1.1 Significance of Research

In general, design errors in construction field are inevitable (Love et al., 2012). These errors can increase more complexity in the control and management of building construction projects. Without any considerations on design errors, building construction projects are already complicated because the projects themselves consist of many processes influencing and interacting with each other at any stages (Parvan et al., 2012). Thus, various types of design errors become very significant and should be carefully managed to ensure the success of construction projects and reduce the project's complexity.

Most design errors are prevalent among construction projects. These errors can occur both during design and construction (Haydl and Nikiel, 2000). For instance, design change is the design errors from owners. Obviously, design changes simply occur in any construction projects. In real practice, other parties or stakeholders involved in the project never made their decision only once in engineering design. Along the processes in construction projects, they may want to change the design more than one time according to various conditions. This is because they have different interests to design a project (Suther, 1998). These differences certainly can lead to design errors which can arise at any time and are inevitable (Han et al., 2013).

Actually, these design errors are associated with the lack of basic engineering methods' understanding, inadequate development of details, or immediate changes (Haydl and Nikiel, 2000). Design errors can result from the problems during design processes such as insufficient reviews of design, verifications and checks, re-use of details and specifications, design incompleteness, poor project governance, unrealistic schedules, and lack of staff (Love et al., 2011b, Love et al., 2012). Regarding the problems of these processes, the term of design errors has been defined and identified in several articles.

Several researchers have provided the definition of design errors in different ways. For example, Suther (1998) raised that design errors refer to the deviations from drawings or specification in which omissions and ambiguities are also included. According to Reason and Hobbs (2003), the failure of planned actions to attain the desired goal is called design errors. Another definition explains that design errors focus on the unexpected occurrences which have to be solved (Busby, 2001). Moreover, other definitions are also suggested due to various situations and conditions of each research and researchers' interest. These definitions are already explained in the previous researches. Although design errors are defined in many different contexts, there is no change of its common meaning and concept. Generally, design errors are the mistakes which actually can drive to the concern of design errors' impact on the performance of construction projects because they can jeopardize the construction performance and can contribute to failures, accidents, and loss of life (Love et al., 2011b, Lopez and Love, 2012, Love et al., 2012). Furthermore, design errors can reduce the safety practices and result in failures in construction and engineering projects (Love et al., 2013b). In this case, schedule delays and cost overruns are the main issues since design errors can dominate the project cost and schedule (Love et al., 2012).

Therefore, researchers further discussed about the influences and impact of design errors on construction projects. The impact of design errors was noticed and studied. Concerning about cost, the influences of organizational and project practices on design error costs was analyzed. The analysis revealed that the occurrences of design errors can incur more costs of the original contract value of sample projects (Lopez and Love, 2012, Love et al., 2014c, Love et al., 2014d). In addition, the significant difference between mean value of design error costs and project types was also found (Love et al., 2014d).

In response to the impact of design errors as mentioned above, researchers have studied on design errors' impact and causes in order to develop a systemic model and learning framework for better understanding and reducing design errors. In order to reduce the project cost and time, reduction of design errors is one of the major concerns (Suther, 1998). From the previous research studies, many authors tried to identify the impact, causes, or factors of design errors to develop a model so that it can be used to mitigate design errors in various types of construction projects based on their case studies. Furthermore, the utilization of building information modeling (BIM) is also beneficial and very effective for reducing the amount of errors in design (Love et al., 2011a).

Although there have been many researches that have examined design error reduction, little is known about the cases and problems resulting from design errors. The critical cases of those design errors should be also identified; otherwise the practitioners still do not know what cases of design errors are critical. Thus, studying about the problems due to those critical design errors remains highly significant in order to help the practitioners to check the possible occurrence of design errors in construction projects.

1.2 Problem Statement

Many approaches have been applied into construction and engineering projects in order to mitigate design errors. Some examples of those approaches are discussed.

First of all, most of the previous researches examined design error causation to propagate a systemic model for reducing design errors. Design errors are classified based on their causes according to three different levels: people, organization, and project (Lopez et al., 2010, Love et al., 2012, Love et al., 2013a, Love et al., 2014b).

Besides, the impact of design errors is also discovered so that the practitioners can better understand design errors and learn how to reduce them effectively. As studied in the previous research, the mean value of design error costs in construction projects are found 14.2% of the project’s contract value (Lopez and Love, 2012, Love et al., 2014c, Love et al., 2014d).

Later on, Love et al. (2014c) applied another approach in their research by considering on the influence of organizational and project practices on design error costs. The organizational and project factors influencing design error costs are revealed. Those factors include inadequate training for employees and unrealistic design and documentation schedules required by clients. From the findings, the key strategies for mitigating design errors derived from organization and project practices are the benchmarking of errors for tasks and process, integrated procurement method, and building information modeling (BIM). Actually, BIM still needs other key tools for solving the problems because BIM cannot detect all design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing). This is because BIM is not empirical (Love et al., 2011a). In short, the empirical methods and tools for checking design errors are absolutely needed to be developed.

Although the considerable amount of researches has focused on various different methods for design error reduction, the only ideal approach to error reduction is to view errors as symptoms of underlying problems that become sources of information to understand how the systems work (Busby, 2001, Homsma et al., 2007, Love et al., 2009). Despite the causes and impact of design errors that have been already addressed, design errors still remain a frequent threat (Petroski, 1991, Wantanakorn et al., 1999, Bijen, 2003, Lopez et al., 2010). The issues of design errors significantly contribute to the problems during construction process. Therefore, many problems derived from design errors are encountered in this phase.

From the previous studies, it is apparent that the study of design errors still remains significant because the problems resulting from design errors still occur during construction process and those problems have not been properly solved yet. In addition, the critical cases of each design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/ Electrical/Plumbing) are not yet determined. When these critical cases of design errors remains unknown, the practitioners cannot judge what design errors are critical and should be prioritized in finding the solutions on time.

Moreover, the past researches only focused on the general factors of designers leading to design errors, which could not be learned in details. Because of designers' limited experience, the examples of the problems due to each design errors are required to be identified in terms of experts' experience and knowledge. To learn from the examples of the problems due to design errors, the knowledge-based models are needed so as to store the knowledge of the past cases. By identifying the cases and attributes of each problem, the knowledge-based models are very necessary for designers and contractors to better understand the cases and situations of the problems caused by design errors. Otherwise, they may repeat the same mistakes if they never notice their past experience. Regardless of the same mistakes, new problems caused by design errors may also occur in the next projects. If the cases of new problem are similar to the previous ones of the past problem, designers or contractors can use the knowledge-based models as a guideline to check for the possible occurrence of design errors.

In conclusion, this research aims to identify the critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing) so that the problems due to those significant design errors can be learned and further developed into the knowledge-based models which can help improving the designers' and contractors' knowledge by checking design errors prior to construction.

1.3 Research Objective

The objective of this research is to establish the knowledge-based models for checking design errors in order to reduce the problems in building construction projects. To achieve this main purpose, several sub-objectives are illustrated as below:

- Identify the critical cases of design errors between structure and other building components such as structure, architecture, and MEP (Mechanical/ Electrical/Plumbing) which can lead to the problems in construction practices
- Develop the knowledge-based models for checking design errors in building construction projects.

1.4 Scope of Research

This research covers the high-rise building construction projects in Cambodia. The study will focus on the real problems due to design errors which frequently arise in construction practices. Contractors such as project managers, site managers, and site engineers who have many years of experience in building construction projects will be the relevant and potential respondents. In view of time constraint and limited budget, the details on the scope of research are specified as follows:

- Target location: Cambodia
- Projects: Reinforced concrete and high-rise building construction projects such as hotels, condominiums, shopping malls, apartments, office buildings, or others. High-rise building is defined in the International Building Code as a building with more than 75 feet (22,860 mm) (Geren et al., 2013).
- Respondents: Contractors (site engineers, site managers, and project managers, …)
- Scope of design errors:
  - Only design errors resulting from designers are focused, the errors from other parties are rejected in this study.
  - Design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/ Electrical/ Plumbing) are covered.
- Scope of problems due to design errors:
  - Problems found before the structure is built
  - Problems found after the structure is already built
  - Problems which arise during construction practices
  - Problems caused by other errors are not considered since these errors are not design errors; they are rather called construction errors which are not counted in this study.

1.5 Research Methodology

To accomplish the research objectives, the research methodology is designed as follows:

1. Review the relevant literature articles of design errors to identify the design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/ Plumbing)

2. Identify the critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/ Plumbing) by:
    2.1 List the cases of design errors between structure and other building components such as structure, architecture, and MEP systems under each group of design errors
    2.2 Develop questionnaire to find the critical cases of design errors which can lead to problems in construction
    2.3 Eliminate the uncritical design errors
3. Develop the knowledge-based models for checking design errors in building construction projects: case studies in Cambodia
    3.1 Choose the critical cases of design errors
    3.2 Classify the examples of problems due to design errors into different categories in terms of the structural elements of the buildings. For example: design errors between beam and other building components, design errors between column and other building components, design errors between slab and other building components, and so on.
    3.3 Questionnaires for interview are then created to ask the respondents to describe the examples of problems due to each case of design errors that they have faced in their real-life of works at construction sites
    3.4 Learn about the examples of each case to identify its attributes and conditions
    3.5 Code all examples of problems into the system by applying Microsoft Visual Basic Programing Language
4. Research conclusion
    4.1 Critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing)
    4.2 Decision trees of knowledge-based models of the problems due to design errors for checking design errors prior to construction.

1.6 Research Outline

This research is organized into seven chapters:

Chapter one describes about the importance of the research and the reasons why design errors should be focused. First of all, the influences of design errors in construction process are stated by providing some examples. Second, general definitions of design errors are also included along with their causes and impact in building construction projects. Then several related researches are briefly reviewed to tell about what had been done previously in order to reduce design errors. This part tends to show that the previous proposed models for mitigating design errors are really concerned in this study. Moreover, this chapter consists of five main points such as problem statement, research objectives, scope of study, research methodology and expected benefits.

Chapter two presents the literature reviews relevant to design errors. Definitions, factors, impact, and causes of design errors in construction projects are illustrated in details depending on the previous studies and other related documents. The methodology for reducing design errors are also clearly added in this chapter. From many previous researches, development of a model based on design error causation and prevention is preferred. Differently, the knowledge-based models according to the examples of the problems due to design errors will be focused in this study. Finally, the last parts are the research gaps and research framework of this research.

Chapter three focuses on the details of research methodology which respond to the research objectives. Research approach and design are explained by providing the detailed framework of the study. The desired outcome for each stage of the research is preliminarily envisaged. Especially, any methods, data analysis techniques and what will be done for further stages in this research are also discussed.

Chapter four explains about the data collection of part 1. The process of identifying the critical cases of design errors between structure and other building components is discussed. The details of data collection and analysis are also clearly described. The research findings of this part 1 are the critical cases of design errors which are prioritized from the combination of their percentage occurrence and impact score.

Chapter five discusses about the data collection of part 2. The development of the decision trees of knowledge-based models for checking design errors are explained in this chapter. The procedure to develop the decision trees for all selected and critical cases found from data collection of part 1 is also mentioned. The cross-case analysis to identify the attributes of each case of design errors is conducted with the examples obtained from qualitative interview. The findings of this part 2 are the attributes, conditions, and the decision trees for each critical case of design errors.

Chapter six is to propose a design error checking system by storing all decision trees of the critical cases into the Visual Basic for Applications (VBA). The inputs of the system are presented in this chapter. How to develop this system by using VBA programming is also described in details. Moreover, the key VBA codes are provided as a guideline in coding the decision trees with their attributes and conditions.

Chapter seven is the last chapter of this research which concludes everything from the data collection and data analysis. The research findings, research contribution, research limitation, and suggestion for further studies are mentioned.

1.7 Expected Benefits

After this research is successfully and completely accomplished, designers and contractors are able to obtain an effective tool to check the possibility of occurrence of design errors. Moreover, the knowledge-based models could help them to learn the previous problems due to design errors in order to avoid them for their future projects. In short, the future expected benefits from this study can be summarized:

- Contractors or designers are able to realize what important design errors are related to structure, architecture, and MEP systems (Mechanical/ Electrical/ Plumbing). Thus, designers maybe more careful on those important design errors during design process, whereas contractors also pay much attention on those errors prior to construction in their future projects.
- The problems due to design errors can be checked and reduced.

- The proposed knowledge-based models should be practical for both designers and contractors to check design errors which possibly arise during construction practices.
- By checking the possible occurrence of design errors with the proposed model, the schedule delays and cost overruns of the projects sometimes can be minimized according to less design errors.
- The knowledge-based models can be a supportive tool of Building Information Modeling (BIM) for identifying the conditions, situations, and attributes of each case of problems due to design errors.

CHAPTER II
LITERATURE REVIEW

2.1 Terms and Definitions of Design Errors

Design errors are differently defined according to the problematic issues occurring in a specific situation. In construction projects, these prevalent errors can be viewed in different directions based on the purposes of each study. In reality, the designs of a construction project are not simply favorable because design errors are always internally derived from any individuals or a group of relevant parties (Reason and Hobbs, 2003). Since there are many broad issues associated with design errors, the definition of design errors has to be specified. By learning from the previous researches, design errors are defined from the concept of design inputs, processes, and outputs or design products.

Focusing on the inputs of design, design information is regarded. Related to the information input of design, Reichart (1988) defined that design errors are unavoidable failures occurring when the information is incorrectly applied or not used in the design phase and the pertinent information is not accessible. In this case, the information deficiencies are an important root cause of design errors.

During design processes, human behavior is an important factor which can lead to any errors. In response to this rationale, Hagan and Mays (1981) explained that, “design error is a failure of the human to do a designed task within specified limits of exactness, sequence or time”. This interpretation can be inferred that design errors are caused by the common human errors due to the level of accuracy and time constraints. In other aspects, Bea (1994) stated that design error is an ignorance of a person from following the desired practice of design, which actually leads to intolerable or unfavorable quality. The author seemed to consider design errors as an individual’s characteristics in doing their works which involve a lack of action and an inappropriate action, rather than the individual’s surrounding influences. Moreover, Reason and Hobbs (2003) interpreted that the failure of planned actions to achieve the desired goal in the design process is called design errors. In some situations, those design errors occur unexpectedly and they are required to be solved (Busby, 2001).

Regarding the design outputs, several researchers also identified the term of design errors in accordance with the quality of design products. For example, Kaminetzky and Carper (1992) pointed out that design errors are the deviation from the actual value, insufficient precision, and differences in measurement. These errors result from inadequacy of human and mechanical perfection. This definition implies that human errors influence the quality of design products. Besides, Suther (1998) also shortly illustrated that, “design error is a deviation from the plans and specifications”. He additionally stated that the definitions of design errors can be defined differently by owners, designers, or contractors according to their responsibilities. Thus, the definitions of design errors from owners’, designers’, and contractors’ responses are found as listed in Table 2.1.

Table 2.1 Definition of design errors according to the perceptions of owners, designers, and contractors (Suther, 1998)

Owners	Designers	Contractors
1. An error or omission in the plans and specifications	1. Incorrect items in documents	1. Mistakes and omissions to the contract document.
2. Neglecting of designer from his duties	2. Flaws in project design	2. Design errors that delay or add cost to the project.
3. Errors, omissions and ambiguities in construction documents	3. Misinterpretations of owners’ desires versus the program developed by the designer	3. Mistakes and omissions in plans and technical specifications.
4. Foreseeable errors during design	4. Inconsistent plans or specifications	
5. Incomplete design data or conflicting design information	5. Inconsistent items in contract documents	
6. Mistakes in drawing details.	6. Failures by designer to perform his duties.	

In compliance with the objectives of this research, design errors definition is appropriately combined from the above reviews. In this research, design errors are the unavoidable failures of designers to fulfill the desired plans because of time limits, insufficiency of precision and perfection, information deficiencies, changes, omissions, ambiguities, lapses of attention, and individual’s ignorance. These errors normally arise both during design and construction phase. However, errors from construction operation are not considered as design errors; they are rather called construction mistakes which will not be considered in the scope of this study.

2.2 Design Errors between Structure and Other Building Components

In this research, design errors are the inevitable failures of designers to fulfill the desired plans. Due to the definitions reviewed from the previous articles, the design errors caused by designers can be design omissions, design conflicts, and design mistakes (Suther, 1998, Idoro and Aluko, 2012).

- ***Design omissions:*** The omission in specifications, technical specifications, plans, construction documents or contract documents (Suther, 1998). According to the Cambridge advanced learner’s dictionary (2008), omission arises “when something has not been included that should have been”. This implies that these errors occur when designer totally forgets to put something or any items in the drawings, specifications, or contract documents (the details in drawings, specifications, or contract documents are forgotten).

- ***Design mistakes:*** Mistakes in drawing details, contract documents, plans or technical specifications (Suther, 1998). The relevant information is valid and correct, yet the designer applies it incorrectly during design. These mistakes are made because of wrong calculation and inadequacy of designers’ experience. These are the human errors (designers’ errors), which are naturally found and cannot be avoided. Those mistakes can be lapses (memory failures) or slip (slip means the failure arises when the knowledge is correct) (Lopez et al., 2010). An example of slip is that when the quantity surveyor (QS) prepares a bill of quantities (BoQs), he/she has some questions to ask the architect. Since the contacts of architect and structural engineer might be located next to each other, the quantity surveyor accidentally sends those questions to the structural engineer instead of the architect (Lopez et al., 2010). Based on Zhang et al. (2004), this is a kind of slip in performing any actions.

- ***Design conflicts:*** Design errors of overlapping items in the design. Regardless of constructability, the design itself is correct. However, the items are not able to be constructed because of overlaps. In this case, the details in drawings or specifications are found conflicting. Design conflicts can be physical conflicts or functional conflicts.

This research covers the problems of design errors that the experts have experienced so far after the design/construction documents are approved until the construction stage. The design errors which are found in the bidding process until the approval of the design/construction documents are not counted in this study.

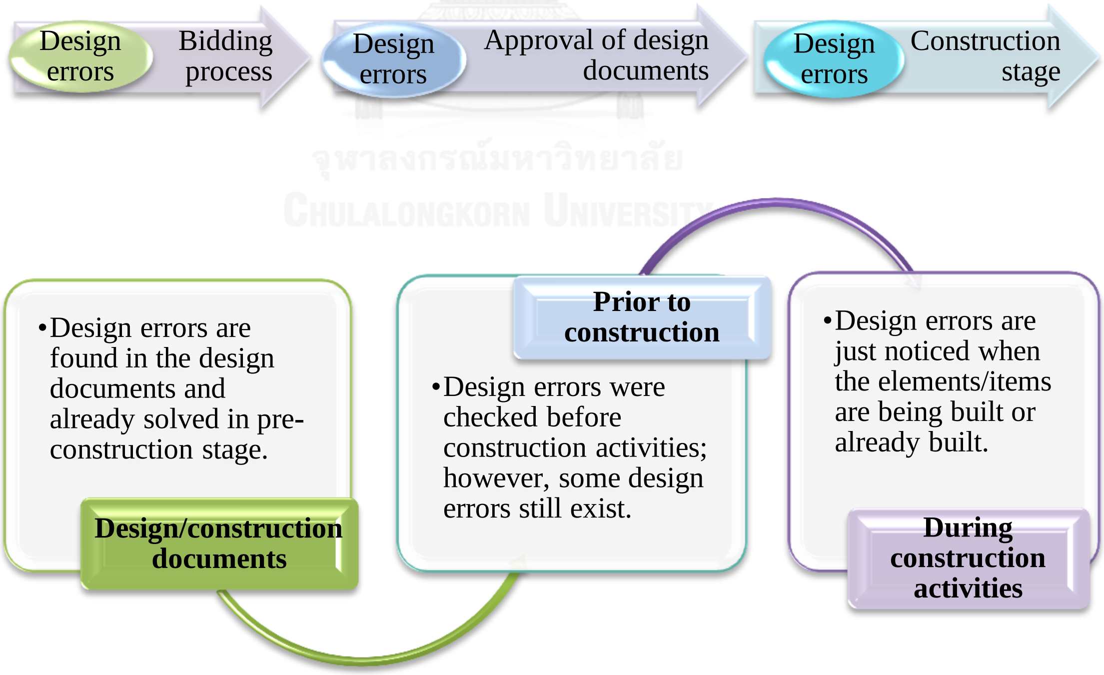

Figure 2.1 Stage of design errors

In this study, design errors arise during the detailed building design process when designers are careless and have limited experience on the real-life works at construction sites. According to Austin et al. (1999), the detailed building design process are divided into five disciplines which are architectural design, civil design, structural design, mechanical design, and electrical design.

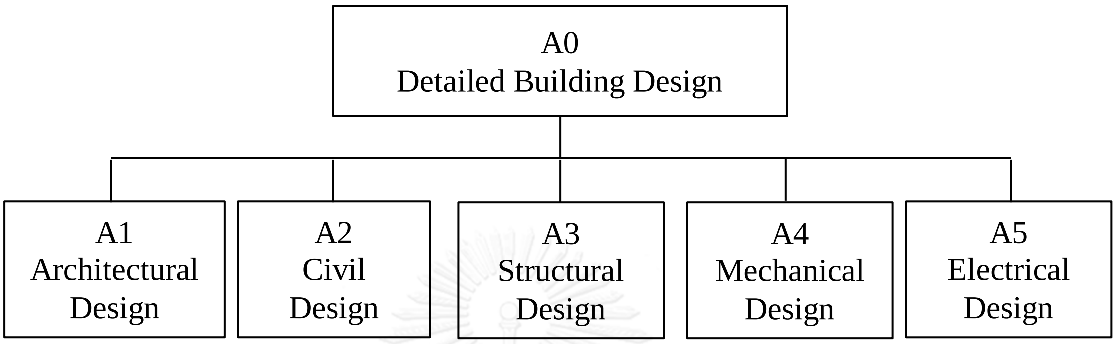

Figure 2.2 Detailed building design process by discipline (Austin et al., 1999, Tatum and Thomas, 1999)

Since this research focuses mainly on the buildings itself, civil works of civil design is irrelevant. Besides, Tatum and Thomas (1999) stated that the problems in current practices of MEP systems have to be improved because the limited space of buildings for this system can make the design and construction much more difficult. Due to this reason, the design errors between structure and plumbing system are also included in this study. In brief, design errors between structure and other building components consist of five different groups such as:

1) Group A: design errors between structure and architecture
2) Group B: design errors between structure and structure
3) Group C: design errors between structure and mechanical works
4) Group D: design errors between structure and electrical works
5) Group E: design errors between structure and plumbing works

The following figure presents the design errors between structure and other building components such as structure, architecture, and MEP systems to be studied.

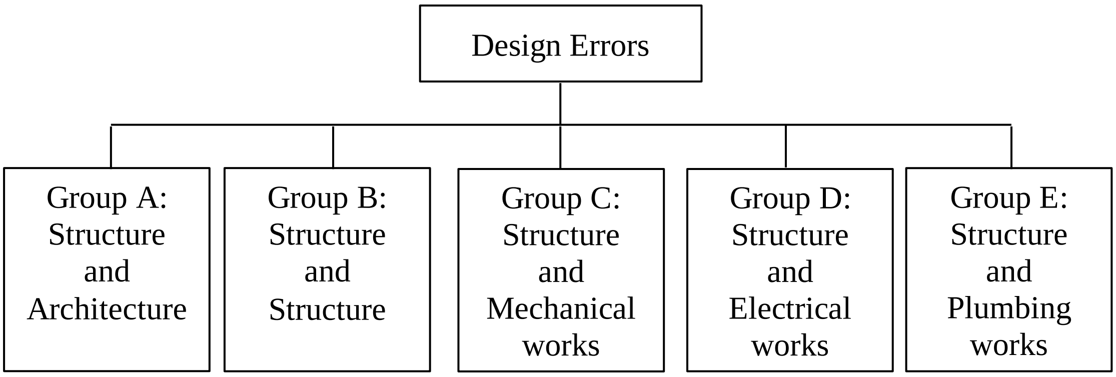

Figure 2.3 Design errors between structure and other building components (Austin et al., 1999)

Derived from the bill of quantities of building construction projects and other articles, this study focuses on the items of each discipline such as:

1) **Structure**: Retaining wall, footing, beam, column, slab, stair, reinforced concrete wall (shear wall, core wall…)
2) **Architecture**: Wall finishes, floor finishes, ceiling works, staircase finishes (stair handrail…), door/window, sanitary ware (materials in bathroom or kitchen)
3) **Mechanical works**: HVAC systems (Heating, ventilating, and air conditioning) and lift systems
    - ***HVAC systems*** consist of the following basic components: (a) Heat-generating system, (b) Cooling system, (c) Air-handling system, and (d) Control system for hand adjusting and/or automatic monitoring of the system operation. HVAC systems include the removing of dust and odors, freshening with outdoor air, adjustment of the temperature, and adjustment of the relative humidity.
    - ***Lift systems*** include the major lift components such as prime mover (electric machine or hydraulic pump), lift car (car frame), counterweight, guide rails, entrances/doors, safety gear and overspeed governor, buffers (energy accumulation, energy dissipation), roping systems (compensating ropes, traction systems), car and landing fixtures (buttons, indicators and switches) (Hui, 2010).

4) **Electrical works**: Electrical system, telephone/datacom system (Tatum and Thomas, 1999)
    - ***Electrical system*** is categorized into supply, distribution, and lighting.
    - ***Telephone/datacom system*** uses fiber optic lines.
5) **Plumbing works**: According to Flea (2010), there are six fundamental components of plumbing system such as:
    - ***Water supply and distribution system*** includes cold and hot water distribution system.
        - *a) Cold water distribution system* consists of upfeed water distribution, downfeed or gravity system, and hydropneumatic system (air pressure system).
        - *b)* The types of *Hot water distribution system* are upfeed and gravity return system, downfeed and gravity return system, and pump circuit system.
    - ***Sanitary drainage and disposal system*** includes waste collection system and ventilation system.
        - *a) Waste collection system:* waste pipe is used for conveying the wastewater or liquid waste.
        - *b) Ventilation system:* vent pipe is used to ensure that the air is circulated in a plumbing system.
    - ***Storm drainage system*** consists of three major systems of collecting rain water such as the independent system, the combined system, and the natural system.
        - *a) The independent system* takes the collected water directly to the water reservoirs.
        - *b) The combined system* refers to the pipe system that combines storm water (rainwater) with sanitary wastes.
        - *c) The natural system* is used to collect the rain water in cisterns without using any roof gutters or downspouts.
    - ***Plumbing fixtures*** are excluded from this plumbing system because the plumbing fixtures such as sinks, tubs, toilets, and so on are already included in sanitary ware of architectural works.

- ***Fire protection system*** is to make the building resistant by fire and to facilitate the evacuation process when there is fire.
- ***Fuel and gas piping system*** refers to the gas supply for laboratories, hospitals, manufacturing facilities and other buildings. The toxic gas can be released through this piping system.

2.3 Causes of Design Errors

In general, any design errors has their own contributing factors which result from different root causes. Up to this moment, design error causation has been specifically studied in a number of previous researches. The previous researches show that the causes of design errors have been explored from the broad aspects to the specific ones. Then a concept of breakdown structure for design error causation can be illustrated in Figure 2.4.

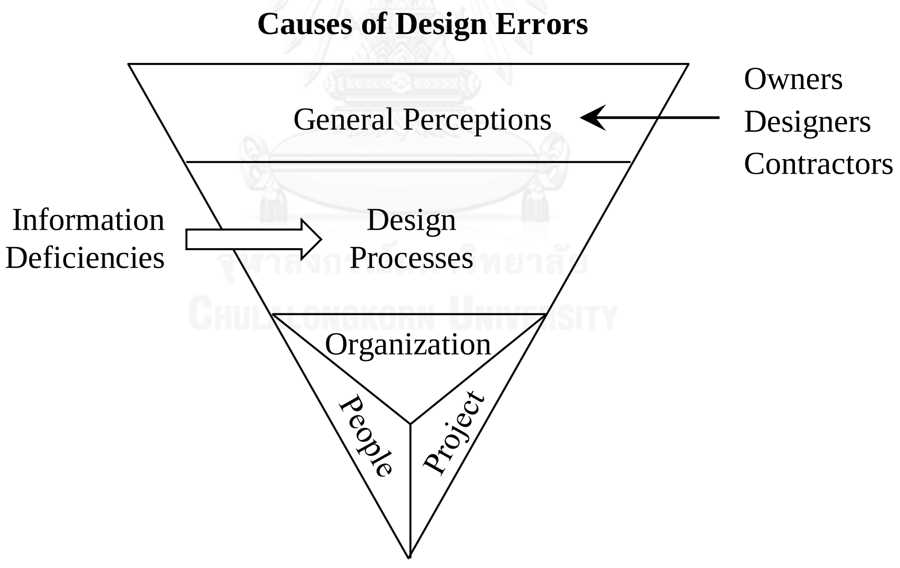

Figure 2.4 Breakdown structure of design error causation

In this figure, the causes of design errors are divided into three main viewpoints relatively. The first viewpoint is the general perceptions of the causes of design errors from owners, designers, and contractors (Suther, 1998). In second viewpoint, another study intended to concentrate on the causes of design errors due to the information of design (design inputs) (Reichart, 1988), whereas Love et al. (2000b) mainly studied about the causes of design errors during design processes. In the last point of view, the design error causation in design processes has been further separated into three different levels including the causes of design errors due to people, organization, and project (POP) (Lopez et al., 2010, Love et al., 2012, Love et al., 2013a, Love et al., 2014b). Each viewpoint on the causes of design errors will be clearly specified in the following sections of this chapter.

2.3.1 Design Error Causation based on Project Participants

As shown in Figure 2.4, the first wide viewpoint is the general perceptions from the project participants on the causes of design errors. Regarding a survey conducted by Suther (1998), the overwhelming theme of major contributing factors to design errors is lack of coordination between different disciplines. The coordination between owner and designer is the critical factor to establish a design product with quality.

Table 2.2 Perceptions on the contributing factors to design errors (Suther, 1998)

Owners	Designers	Contractors
- Poor qualification of the Architect and Engineer (A &E) - Lack of proper field investigation and document quality control - Lack of coordination between disciplines - Government spends too much time reviewing the A & E’s work - Lack of means to implement long range acquisition planning - Poor coordination and communication within the A & E’s design team - Inexperience of design	- Coordination with consultants and architect - Misunderstanding the scope or time - Lack of communication and coordination - Low budgets for design - Inexperience of drafting staff - Mis-coordination between lead designer and consultants; confusion by owner; lack of time - Insufficient oversight and design changes late in the process	- Client does not coordinate as what is required. - Designer rushes out drawings before proper review - Lack of construction experience by the designer - Budget and time pressure on the designer

Concerning the survey's responses, 62% of respondents claimed that sufficient and appropriate time could produce accurate and adequate coordination. In other words, time management is the main root cause that influences the coordination between relevant parties. This means that design errors can be reduced when there is enough time to produce accurate coordination between the project participants. However, not only dealing with coordination issues can effectively reduce design errors, but the other factors are also necessary. The overall contributing factors which are obtained from this survey are provided in Table 2.2.

2.3.2 Design Error Causation based on Information

Before approaching the causes of design errors during design processes, the information is also found as an important input which can create the errors in design. Based on the proposed definition, Reichart (1988) explained that the causes of design and construction errors (DCEs) were information deficiencies. It means that errors result from the lack, nonuse or misuse of information. These information deficiencies are the critical issues of design inputs leading to design errors (Figure 2.5). Based on the concept of information deficiencies, a design or construction error can occur when a design or construction requirement is:

- Objectively unavailable during the design phase or construction phase. It means that the required information is not known or lack of information.
- Objectively available but not used, which focuses on the nonuse of information due to oversight, forgetting, ignoring, stereotyped behavior and decision error.
- Objectively available but wrongly applied, which refers to the misuse of information caused by misjudgment, miscalculation or misinterpretation of the requirement.

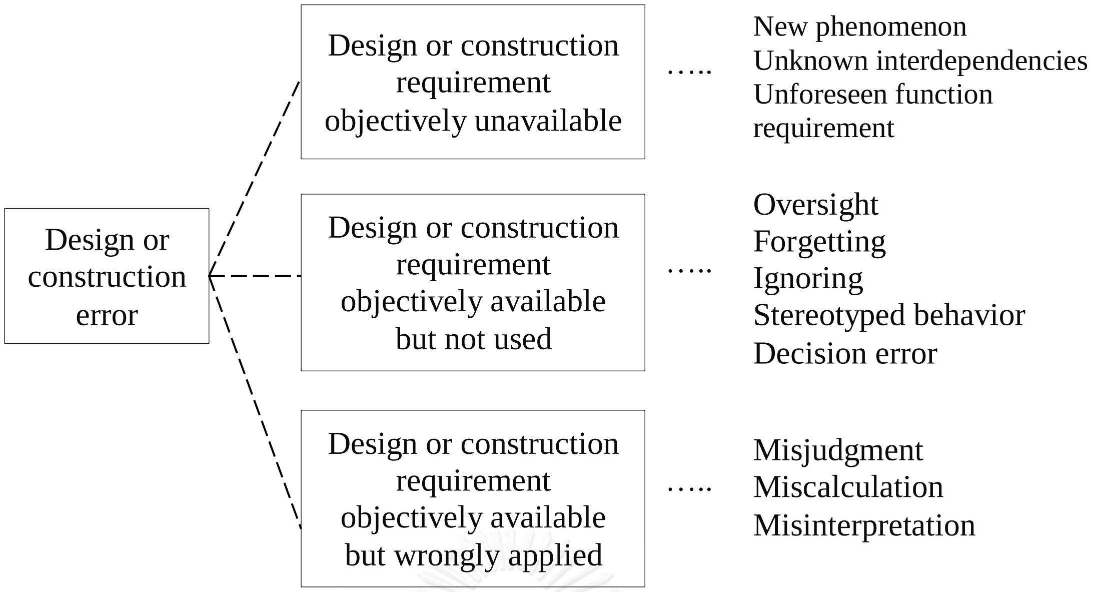

Figure 2.5 Causes of design or construction errors due to information deficiencies (Reichart, 1988)

2.3.3 Design Error Causation during Design Processes

During design processes, the causes of design errors are divided into four different processes such as (1) process of inducting/recruiting design personnel, (2) process of designing tasks, (3) error proneness during design, and (4) re-designing design tasks (Love et al., 2000b). In each process, the contributing factors that are attributed to design errors are required in order to develop a model for reducing design errors and rework in construction.

The process of inducting/recruiting design staff involves the shortfall of designers in a design firm. When the number of designers required for a project is less than those available in the design firm, new designers will be recruited or inducted. So, the total number of designers in a construction project consists of experienced designers, new designers, and inducted designers (an inducted designer refers to an experienced designer working on other projects but is sent to work on a new project in the same company). The newly recruited and inducted designers may need time to become experienced designers. If the office manager does not pay much attention on this recruitment process, the selected designers may not have enough ability to design the tasks. So, this process will affect the next process of design.

During the process of designing tasks, designers may design correctly or erroneously according to their experience. When all designers perform their works, they cannot avoid from making design errors because some of them are not yet familiar with the project requirements, characteristics, and history. Thus, the tasks should be assigned to each type of designers based on their individual ability to reduce design errors.

The third process is the error proneness during design. The affected factors are the work environment. Those factors are normal human error, schedule pressure, design fee pressure and parallelism.

The last process is re-designing the tasks. While the already designed tasks are found suspected or incorrect, designers need to re-design it. However, this process makes the design tasks more complicated.

2.3.4 Design Error Causation due to People, Organization, and Project

In another view, the common causes of design errors in design processes can be divided into three factors including people, organization and project, which are briefly named as POP (Lopez et al., 2010, Love et al., 2012, Love et al., 2013a, Love et al., 2014b). Researches revealed that the causes of design errors are dependent on each other (Love et al., 2008, Love et al., 2009). Therefore, the causes of design errors from people, organization and project issues should be reviewed.

Similarly, the nature of design errors are classified in order to identify the issues that need to be considered for preventing the occurrence of design errors (Lopez et al., 2010). In the article of Lopez et al. (2010), the conceptual taxonomy of errors or the situational cognitive failures such as thought and planned actions that contribute to errors can be classified into:

- ***Skill- or performance-based errors*** are lapses and slips from carelessness and neglect. *Lapses* are regarded as memory failures which occur at any of information processing stages (input, storage, and output failures) (Reason and Hobbs, 2003). *Slips* are the errors when the information is misinterpreted by an individual during executing process of a task.

- ***Rule- or knowledge-based errors*** are regarded as mistakes. A mistake is defined by Zhang et al. (2004) as the behavior that "leads to a failure because of incorrect or incomplete knowledge". These errors occur when the plan does not adequately achieve the desired and intended outcomes (e.g., the actions are performed as planned, but the plan will not achieve the outcome intended).
- ***Intentional violations or noncompliances*** are defined by van Dyck et al. (2005) as "intentional deviations from standards, norms, practices, or recommendations" (e.g., the failure to ensure the conformity with the client's specification).

Under the above-mentioned concept of error taxonomy and its characteristics, the causes of design errors due to people, organization, and project can be generalized in Table 2.3.

Table 2.3 Causes of design errors due to personal, organizational, and project level (Lopez et al., 2010)

Level	Causes of design errors	Error taxonomy
Personal	Loss of biorhythm	Skill-/performance-based error
	Adverse behavior	Violation/noncompliance
Organizational	Inadequate training/inexperience	Skill-/performance-based error
	Ineffective utilization of automation	Rule-/knowledge-based error
	Inadequate quality assurance	Rule-/knowledge-based error
	Competitive professional fees	Skill-/performance-based error
Project	Client/end user issues (unreasonable client and end user expectations)	Violation/noncompliance
	Time constraints	Skill-/performance-based error
	Ineffective coordination and integration of the design team	Rule-/knowledge-based error
	Inadequate consideration toward constructability	Rule-/knowledge-based error

In a nutshell, design error causation is prevalent among building construction projects. In the breakdown structure, there are three main level of design error causation (Figure 2.4). The basic causes are derived from the perceptions of owners, designers, and contractors. However, the causes of design errors during design processes are also studied. Since the information input contributes to the design errors in design processes, the causes of design errors due to information deficiencies are clearly described. In this case, lack, nonuse, and misuse of information are the main causes leading to design errors. Critically, the causes of design errors during design processes are then specifically divided into three different levels (people, organization, and project). Accordingly, each cause of design errors is also classified into various types of error taxonomy by applying the concept of human cognitive failures.

2.4 Impact of Design Errors

Design errors are found as one of troublesome issues in building and engineering projects (Love et al., 2013a). These errors are an endemic feature which produces failures with negative impact on the project management efficiency and effectiveness (Love et al., 2011b). Due to the previous findings, design errors still remain the compelling contributors to reworks, cost overruns, schedule delays, and unsafe environment, which have influences on project performance (Love et al., 2011b, Love et al., 2012). Love et al. (2014b) also claimed that the occurrence of design errors in construction projects could negatively affect the cost, schedule, and safety performance.

In construction projects, design errors are the sources of rework which primarily contributes to cost overruns and schedule delays (Love, 2002b, Palaneeswaran, 2006, Han et al., 2013, Love et al., 2014a). Additionally, omissions and errors are the major causes of rework and thus they can reduce the productivity, decrease the profit and attribute to disputes, incur more costs, and delay the project schedules (Love, 2002a, Palaneeswaran, 2006, Love et al., 2013c). For instance, the analysis of 107 ‘As-Built’ electrical drawings for an Iron Stacker Conveyor identified 449 errors and omissions, which required an estimated 859 extra man-hours at a cost of AU$128,850 (Love and

Zhou, 2012, Love et al., 2013c). Similarly, Burati et al. (1992) found that design changes, errors, and omissions were attributable to 79% of rework costs arising in industrial engineering projects.

Concerning about the impact of design errors on the project's cost, the analysis in another research revealed that the mean value of design error costs are 14.2% of original contract value of the studied projects (Lopez and Love, 2012, Love et al., 2014c, Love et al., 2014d). Moreover, the costs of rectifying the errors that arise within the process of design and documentation can potentially contribute to 5% increase in the project's cost (Cusack, 1992, Gardiner, 1994).

For schedule delays, Han et al. (2013) confirms in a university building project that design errors are one of the major causes, which lead to schedule delays although the construction manager make the efforts to complete the project on time.

In some particular cases, design errors create the unsafe environments which can lead to catastrophic fatalities. Furthermore, design errors are the significant causes of accidents. For example, it is found that design errors can lead to 80% to 90% of the failures prevailing upon building, infrastructure and other civil engineering projects (Lopez et al., 2010).

Based on the above-mentioned discussion, it is remarked that design errors have a high impact on project management and project performance in construction. It is undoubtedly clear that the mitigation of design errors is still in high demand for the benefits of all construction projects. Thus, the impact of design errors still endures continuously whenever the prevalence of design errors remains high and unable to be reduced.

2.5 Previous Methods for Reducing Design Errors

At meantime, being noticed from the previous researches, design error reduction has been studied by using different approaches and methods. The main themes of relevant previous researches on design error reduction can be separated into several areas according to the needs of those studies. Derived from those previous research articles, five important approaches for reducing design errors are already mainly discussed. Those include the general recommendations from owners, designers, and contractors, methods for mitigating design and construction errors based on information deficiencies, strategic management approach, assessment approach, and prevention approach.

For better understanding about these mentioned methods and approaches of design error reduction, the following sub-parts will provide more details of each approach from the previous literatures.

2.5.1 General Recommendations

The methods taken to mitigate design errors in construction projects were interested by Suther (1998). The research explored the recommendations for reducing design errors from three involving parties such as owners, designers, and contractors.

Table 2.4 Recommendations to reduce design errors from the perceptions of owners, designers, and contractors (Suther, 1998)

Owners	Designers	Contractors
▪ More review phase of documents and better guideline for design professionals ▪ Require the A&E to submit their Design Quality Assurance plan for each project ▪ Pursue A&E liability ▪ Emphasize the A&E firm's internal Quality Control Program ▪ Emphasize the submittal of A&E's Design Quality Control plan ▪ Going to design/build contracts.	▪ Regular coordination meetings. ▪ Design review sessions in-house and with contractor out-of-house ▪ Implement QA/QC procedures early and check all products before they go ▪ Design and quality control review ▪ Clarify program elements to consultants; receive sign off on program elements from owner ▪ Principle review, employee education, awareness of liability issues in contracts.	▪ Continuous value engineering by Project Managers ▪ Review during design process for checking errors and omissions ▪ Give designers more time and professional fee.

Each party provided similar perceptions based on their own aspects. Owners intend to concern about the designer's ability of quality control plan for each project. With the same purpose, designers focus on the communication level between engineers and contractors. Contractors otherwise have to take more responsibility to review and check the drawings in order to identify the design errors which can interrupt the project. The summary of their recommendations taken to diminish design errors are indicated in Table 2.4.

2.5.2 Methods for Reducing Design and Construction Errors Based on Information

A research conducted by Reichart (1988) found that the information situation during design attempted to reduce the impact of design errors. Two main aspects such as quality of information and management of information were needed to be improved. The information deficiencies induced design and construction errors (DCEs) were identified and the methods against these DCEs were propagated. Table 2.5 presents the methods against DCEs based on the lack, nonuse, and misuse of information.

Table 2.5 Methods against design and construction errors based on information (Reichart, 1988)

Error causes	Lack of information	Nonuse of information	Misuse of information
Methods against DCEs	▪ Little chance for improvement ▪ Most effective: excessive testing as realistic as possible	▪ Information structuring ▪ Information management ▪ Independent checks ▪ Coordination	▪ Information structuring ▪ Independent checks ▪ Diverse working groups ▪ Different methods, if available

2.5.3 Strategic Management Approach

In order to manage the errors, Helmreich (1998) explained that strategic management of errors aims to understand the causes of errors and to take appropriate actions such as changing policy, alternating procedures, and implementing special training to minimize and reduce the consequences and incidence of derrors. The basic concept of error management strategies consists of two components (1) error reduction which is to measure and limit the failures' occurrence, and (2) error containment which refers to the measures for boosting the detection and advancing the errors' recovery (Helmreich, 1998).

2.5.3.1 Error Reduction Approach

Applying the first error management strategy, error reduction approach, Lopez et al. (2010) used the causes of design errors due to POP as being described above to generalize the design error management strategies based on the reason that the identified causes are interdependent. The propensity of people's situated cognition, learning, and knowing is effective to prevent errors in relation to people, organization, and project environment.

In Figure 2.6, people management strategies have the greatest propensity to reduce design errors within the process of situated cognition, learning, and knowing. In this instance, people's ability to perform the tasks is influenced by the organization's working surroundings and processes of the project.

Noteworthy, the appropriate design error management strategies are not single. There is actually a multitude of strategies for reducing design errors in construction and engineering projects (Lopez et al., 2010). However, the design error management strategies being proposed in Figure 2.6 are the general guideline of strategic management approach for further research studies.

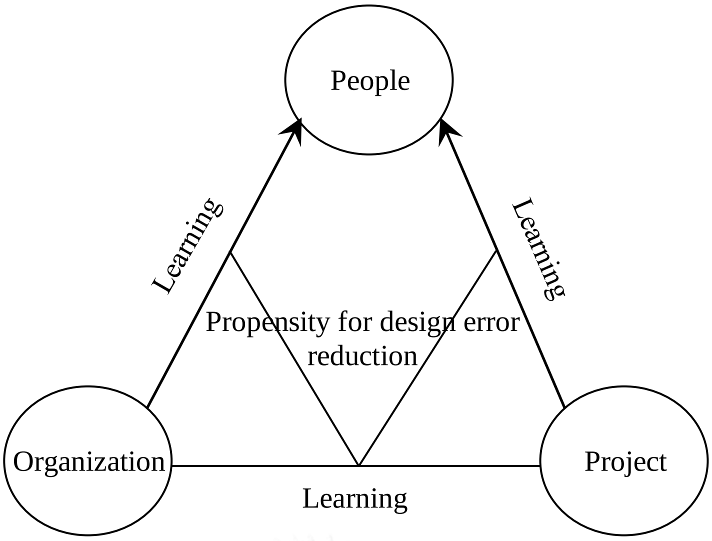

Figure 2.6 Strategies of propensity for design error reduction through people, organization, and project (Lopez et al., 2010)

2.5.3.2 Error Containment Approach

Later on, Love et al. (2014b) further studied about the management of design errors which attempted to detect design errors in construction projects. The author used the second error management strategy, error containment approach, for managing the errors by identifying the key enablers for reducing design errors and developing a framework from a POP perspective (People, Organization, and Project) (Love et al., 2014b).

In terms of people-related management issues, there are four independent themes of design errors such as cognition, behavior, motivation, and learning (Love et al., 2014b). First, cognitive errors encountered during design process are the attributors leading to biases in decision making (Busby, 2001). In addition, Busby (2001) and Love et al. (2008) clarified that a great amount of design errors that arise in construction and engineering projects were a result of cognitive failure. Second, behavior depends on an individual’s attitude, thinking, and actions. Homsma et al. (2007) found four external factors leading to design errors made by individuals’ behavior such as time pressure, task difficulty, bad luck, and noisy conditions. The third theme is motivation which is the effort and determination of a person to perform the works. Demotivation and inactive contribution in the activities during design process influence a person’s decision making and these are the root causes of design errors (Homsma et al., 2007, Love et al., 2014b). Finally, learning processes are needed in order to improve the knowledge of design errors. It is controversial that insufficient learning about design error causation can lead to design errors. Thus, learning about causation of design errors deems to be an effective approach for reducing design errors (Sense, 2007).

In relation with organization perspective, three management strategies for reducing design errors are importantly proposed in the model (Love et al., 2014b). Those consist of quality (benchmarking is included), culture, and training. For the first strategy, the quality management should be implemented and the quality of the design documentation produced by design organizations is needed to be improved. If this can be done effectively, design errors which are encountered both directly and indirectly in the project would be drastically reduced (Love et al., 2000a). Second strategy is to organize the culture by fostering an error reporting culture. This system should offer enough scope to analyse the occurrence of errors that have been committed (Love et al., 2014b). The last strategy from organization perspective is training that can reduce the incidence of knowledge-based errors effectively. Training also provides the knowledge for learning from design errors and thus developing more suitable strategies (Nordstrom et al., 1998).

From a project perspective, three areas for controlling design errors have been discussed. Those are integrated procurement methods, building information modeling (BIM), and 4D computer-aided design (CAD). Building on alliance procurement, integrated project delivery (IPD) can optimize the efficiency and reduce waste through all phases of design, fabrication, and construction. Using IPD together with BIM and 4D CAD can help mitigating design errors by communication, collaboration, and information management in construction projects (Sacks et al., 2010, Love et al., 2011a). All in all, the proposed management framework of design errors according to people, organization and project as being mentioned earlier is presented in Figure 2.7.

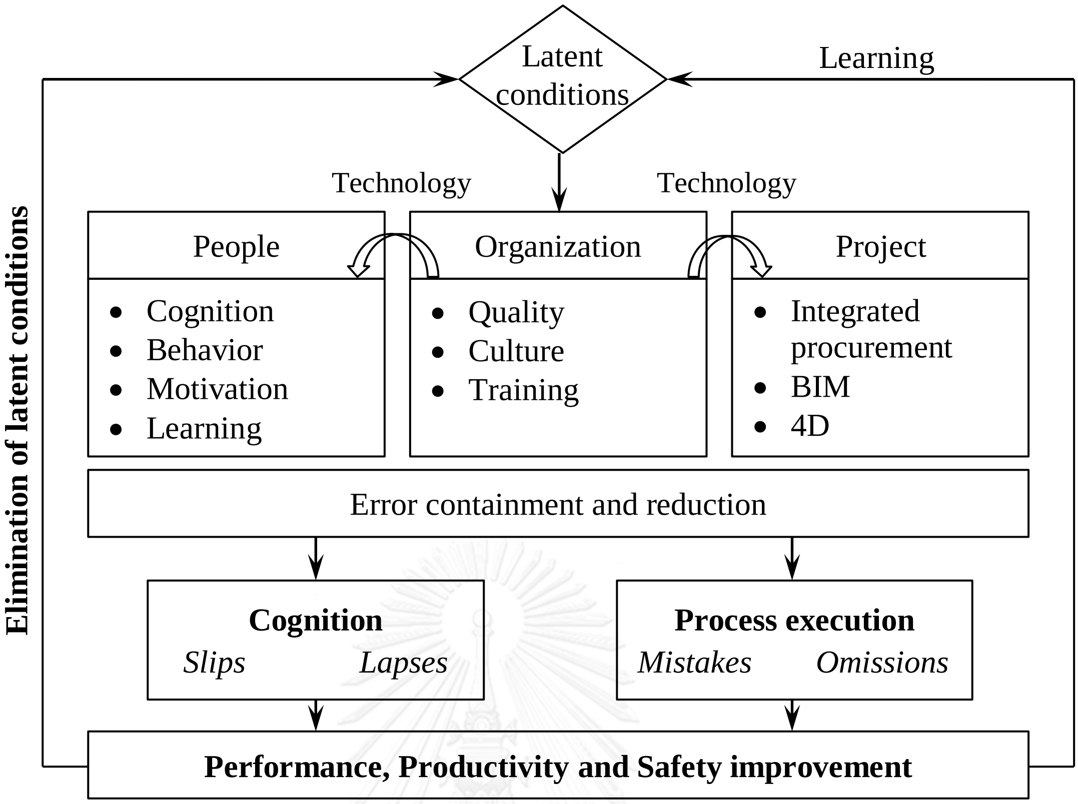

Figure 2.7 Framework for error management (Love et al., 2014b)

2.5.4 Assessment Approach

Despite the applications of the previous methods as mentioned above, assessing the impact of design errors is a meaningful step and very beneficial for reducing design errors (Han et al., 2013). Because the mechanism of design errors should be understood, Han et al. (2013) introduced a model which can help project managers to better understand the dynamics of design errors and to analyse the way in which those design errors can undermine project performance. Furthermore, Han et al. (2013) focused on the schedule delays as the vital impact of design errors and developed a model which consisted of seven sub-modules such as (1) generic work execution, (2) effort, (3) precedence relationship, (4) productivity, (5) resource, (6) progress measurement, and (7) managerial control. The generic work execution module is the most important component in the whole model structure. The dynamics of the generic work execution within an activity have six possible states of any work items, which are WTD (Work To Do), WAI (Work Awaiting Inspection), WD (Work Done), WARFIR (Work Awaiting Request For Information Reply), WPUC (Work Pending until Upstream Correction), and WADCA (Work Awaiting Design Changes Approval) (Cooper, 1993).

Applying the mathematical formulas formulated from the generic work execution module, the quantity of work items in a given status at any points in a time can be measured (Han et al., 2013). Moreover, the work rate, the productivity loss, and the total amount of wasted efforts due to design errors are also calculated. So, the impact of design error on schedule delays can be assessed and this assessment can effectively recover the delayed schedules by comparing actual work rate and nominal work rate. The following figure illustrates how the process of work execution flows in the project.

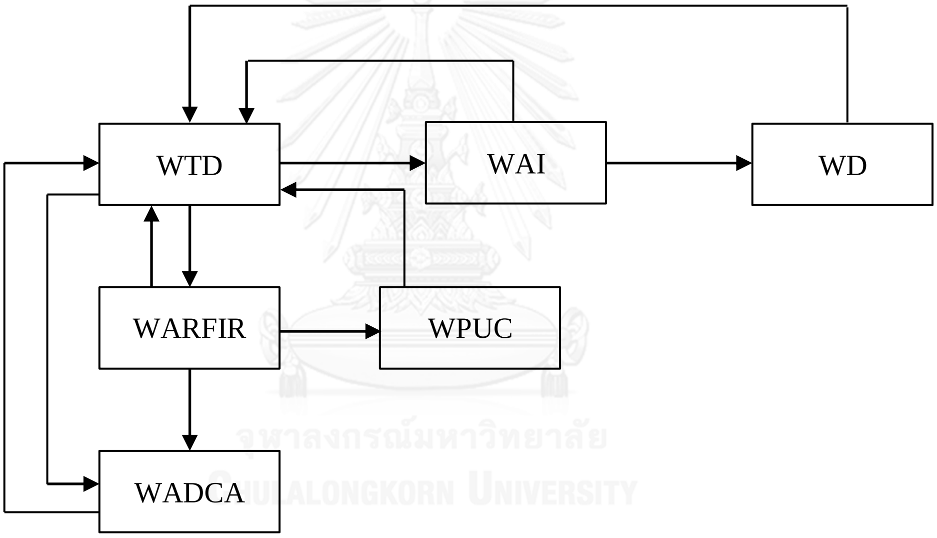

Figure 2.8 The process of generic work execution in the construction project (Han et al., 2013)

2.5.5 Prevention Approach

In prevention approach, Love et al. (2013b) initiated a learning framework for design error prevention. The casual influences contributed to design errors and failures were examined in order to enable the propagation of a learning framework for mitigating design errors, failures, and accidents. The prevention strategies express that learning about error causation is an effective way for their prevention (Sense, 2003).

Thus, design error causal variables are identified in relation with a project, organizational, and people level and those are also presented in the proposed framework (Figure 2.9). This learning framework is not only strategy, but rather a multitude of strategies that need to be pursued for preventing the prevalence of design errors in construction projects.

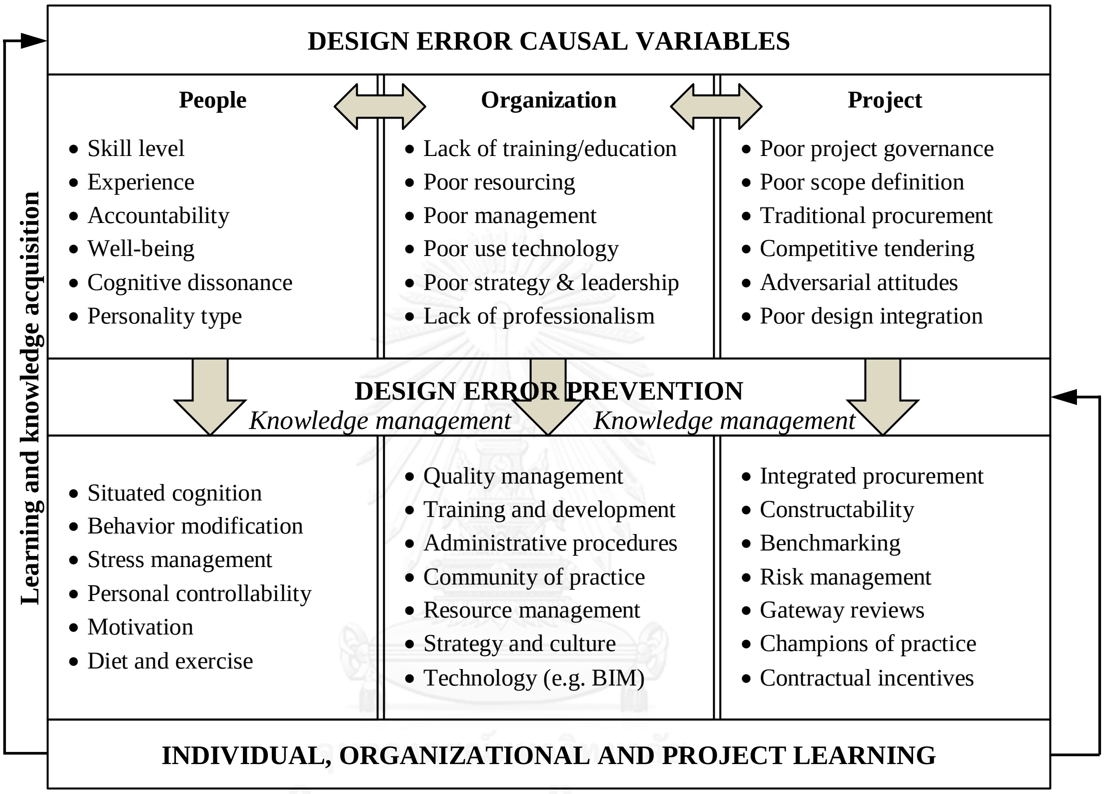

Figure 2.9 Learning framework for design error prevention (Love et al., 2013b)

In short, the previous applied approaches for mitigating and preventing the prevalence of design errors are in relationship with their causes and impact. Learning from design error causation, owners, designers, and contractors recommended their own perceptions on how to reduce design errors (Table 2.4). Regardless of other factors leading to design errors, information deficiencies were studied so that the methods for reducing design errors were propagated (Table 2.5). Despite information deficiencies, the causes of design errors due to people, organization, and project are found necessary for developing a strategic management of design errors (Figure 2.6 and 2.7). Although design error causation is used in many researches as a guideline for reducing design errors, their impact on project performance still threatens the whole project schedule. Assessing the impact of design errors is absolutely beneficial in this case. In addition, the way to prevent the occurrence of design errors is also already explained in a learning framework for design error prevention (Figure 2.9).

2.6 Research Gaps

According to the previous researches, causes and impact of design errors were already used to develop a model for better understanding design errors in the purpose of retaining and preventing the prevalence of design errors in construction projects. After detailed literature review, several attractive research gaps have been found. Those are described in the following paragraphs.

The main themes of previous studies of design errors are divided into three different levels such as people, organization, and project. In organization and project level, the culture, training, quality improvement, integrated procurement methods, and other computer technologies such as Building Information Modeling, 4D programs and so on are proposed for reducing design errors (Love et al., 2013b, Love et al., 2014b). Whereas the ways to manage the causes of design errors in people level are not yet studied in details because the previous researchers only found that cognition, behavior, motivation, experience, time, and learning are the people’s factors leading to design errors (Love et al., 2013b, Love et al., 2014b). They have not yet clearly explored any methods for improving those human’s factors.

Although many research studies attempted to reduce, prevent, strategically manage, or assess the impact of design errors, it is still not sufficient for the practitioners to understand clearly how to avoid design errors because a large number of strategies still needs to be adopted to improve human’s knowledge and experience in order to reduce and prevent design errors from occurring (Lopez et al., 2010, Love et al., 2012, Love et al., 2013b).

In other words, Love et al. (2013a) proved that understanding the relationships between the causes of design errors is necessary in reducing design errors. Nevertheless, the causes and effects of committing errors are not normal and their relationships are very complex (Tsang and Zahra, 2008). Improving the knowledge and experience is more effective for checking the occurrence of design errors rather than studying only their causes and impact. The only ideal approach for checking and reducing design errors is to see errors as symptoms of underlying problems (Busby, 1999, Busby, 2001, Homsma et al., 2007).

Moreover, the formal and procedural knowledge is usually insufficient for dealing with problems; the solvers have to lean on their experiential or previous knowledge (Li and Love, 1998). This means that experiential knowledge plays an important role in solving the problems. Owing to this reason, it is apparent that the problems due to design errors can be better checked and reduced when the experiential or previous knowledge are learned and well-understood.

Thus, checking the occurrence of design errors is prevalent and necessary for helping the practitioners to improve their experience to reduce the problems which are caused by those design errors. Because the critical cases of each design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing) are not yet specified based on their consequences on project performance, this research aims to identify the critical cases of those design errors so that the practitioners can know the critical and important design errors which should be prior to be solved urgently in current practices of building construction projects.

In compliance with the critical cases of design errors, the ideal problems due to design errors should be considered. Since these problems are very practical in the real world system of construction, they are the important knowledge which is required to be studied in order to use as references for checking the possible occurrence of design errors and to avoid repeated problems due to design errors in future projects.

Because these actual problems have not been taken into account yet, this research mainly focuses on them and studies about the cases for each problem in order to find the knowledge on how and why the problems arise in building construction projects by relying on the previous knowledge and experience of experts. From the research of Love et al. (2011a), BIM is proposed as a key strategy to reduce design error costs, which enable the role of BIM for design error reduction. Yet, it is dangerous if BIM becomes the sole driver for design error containment and reduction because BIM capacity is also limited and not empirical. It cannot detect all problems and failures. It can detect only design conflicts based on formal knowledge such as theories and codes. Other design errors (between structure and other building components such as structure, architecture, and MEP systems) of which the problems can arise in the actual construction practices cannot be checked. Thus, those latent failures will not be solved easily that can affect the productivity of construction and project performance. Therefore, BIM is suggested to be used as an enabler with other key strategic and new methods so that it will be considered as the panacea for solving the problems.

In this case, expert system tool is appropriate to be applied in formulating the knowledge-based models for checking design errors in the actual practices that the computer technology cannot do in terms of real-life experience. According to Chakraborty (2010), the main applications of expert systems in the area of knowledge works are:

- Diagnosis and troubleshooting of devices and systems
- Planning and scheduling
- Configuration of manufactured objects from sub-assembles
- Financial decision making
- Knowledge publishing
- Process monitoring and control
- Design and manufacturing

For example, in construction projects, expert system approach actually has been used in a number of previous studies. Previously, knowledge-based systems have been adopted to deal with problems in various construction domains such as construction project monitoring and control (McGartland and Hendrickson, 1985), construction design (Cole, 1991), construction site level facilities layout (Chau and Anson, 2002), and decision support for construction planning (Oluwoye, 2012). However, none of these adoptions appeared to be associated with the real-life problems caused by design errors and knowledge-based expert system is not yet considered to be applied for checking design errors between a specific structural element and other building components. Because diagnosis, troubleshooting, and knowledge publishing are the applications of expert systems, the problems due to design errors can be effectively sorted out. Therefore, knowledge-based expert system approach is the best effective and efficient methodology for checking the possible problems caused by design errors in construction projects.

2.7 Research Framework

To fulfill the above mentioned research gaps, the research framework of knowledge-based model development of problems due to design errors is designed and arranged as illustrated in Figure 2.10. In this framework, the problems due to design errors can be elicited from the experts' experience and knowledge of what they have met during construction phase (before, during, and after construction activities). Then the cases and attributes of problems of the most concerned and critical design errors between structural elements and other building components such as structure, architecture, and MEP systems (Mechanical / Electrical / Plumbing) will be further asked from them. Next, this knowledge will be coded explicitly into the knowledge-based models by applying expert system approach. To assure that the developed model is applicable, the experts are requested to involve in another step for model validation. This validation actually is to confirm the experts about the cases of problems they have provided in the previous step.

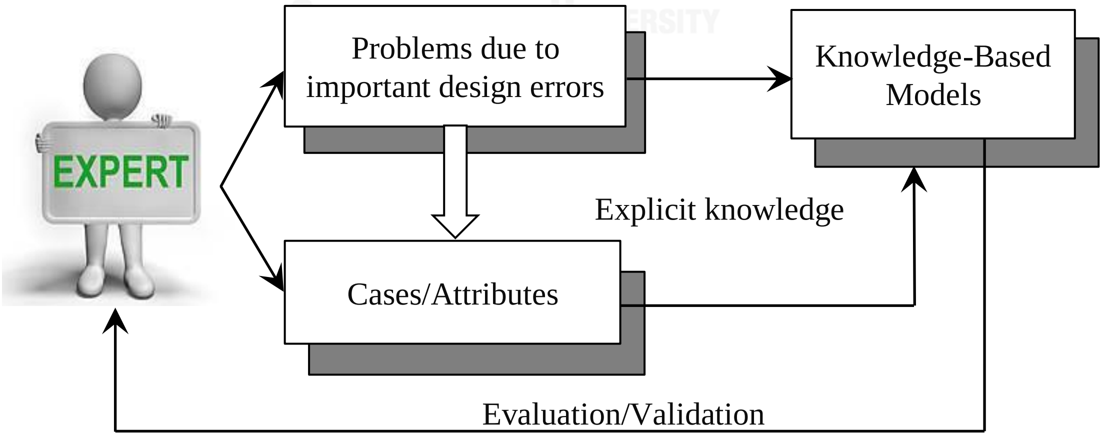

Figure 2.10 Research framework of knowledge-based model development

2.8 Summary

In conclusion, design errors in building construction projects have been discussed by many researchers because they are one of the main concerns leading to fatalities, accidents, schedule delays, cost overruns and so on. Previous researches on design error reduction in construction projects mainly consider on involvers' perceptions, methods due to information deficiencies, design error management, impact assessment, and prevention approach. These five approaches were applied in the previous studies depending on only two main themes: the causes and impact of design errors. However, the reduction of design errors still remains a frequent threat and there are still research gaps for further studies on how to check design errors between structure and other building components in building construction projects. Because the only ideal method for checking and reducing design errors is to view errors as symptoms of the problems based on the experiential knowledge for problem solving, the study of problems due to design errors is more effective to check whether the problems can arise from design errors in construction practices.

CHAPTER III
RESEARCH METHODOLOGY

The objective of this chapter is to propose a research methodology to develop the knowledge-based models for checking the possibility of occurrence of problems due to design errors in construction practices. First of all, the research type and approach is described. Then the design of this research is explained by proposing the overall steps of research methodology with detailed explanation of each research process. Next, the chapter describes about the development of the model using the knowledge-based expert system. Most importantly, the techniques for data collection and data analysis in the last part of this chapter are also provided.

3.1 Research Type and Approach

Many research types and approaches have been conducted to develop the model for preventing and detecting the problems. Since this study focuses on the experience and knowledge of the experts, it is concerned with qualitative phenomenon (Kothari, 2004). There are many techniques of such qualitative research. Expert System (ES) is one of those techniques, which is currently found interesting and applied by many researchers.

Knowledge-based system approach is a type of artificial intelligence to learn what happened in the past activities and to find the rules to solve or detect the real-world problems. Expert systems is a knowledge base which contains the knowledge of human experts, not the knowledge from textbooks or non-experts (Feigenbaum et al., 1993). The term expert systems (ES) and knowledge-based systems (KBS) are used synonymously. Professor Edward Feigenbaum of Standford University, an early pioneer of expert systems, has defined that, “An expert system is a computer system that emulates, or acts in all respects, with the decision-making capabilities of a human expert” (Giarratano and Riley, 2004). For the same instance, KBS is an application to transfer a specific knowledge from humans to a computer for decision making and problem solving (Liao, 2005). In this research, knowledge-based system is applied for the purpose of:

- Eliciting and storing the previous knowledge of problems due to design errors in construction practices from the experts;
- Coding the cases and problems caused by design errors into the knowledge-based models.

For this study, the previous experience on the problems caused by design errors will be explored. The main purpose of using this knowledge-based expert system is to generalize the previous knowledge of problems resulting from design errors into a model so that the attributes and conditions of each problem can be learned. Nevertheless, it requires many data collections in order to construct this expert system model. Collecting data in this research is concerned with the subjective assessment of attitudes, opinions, and behavior of the respondents. This is the qualitative approach of which the data collection can be obtained by observations, depth interviews, focus group interviews, books, other documents or other techniques. In such qualitative approach, the results are either non-quantitative or not analyzed quantitatively. In short, this study uses this qualitative approach to identify all cases of the problems due to design errors in building construction projects.

3.2 Research Design

Research is normally conducted by investigating to get any information. It is an important tool to find a new conclusion on a specific issue. It aims to develop a guideline or model for the benefits of the users in a particular aspect. Regarding the problem statement, research methodology for this study is designed at the initial stage. Thus, the research process can be clearly explained in response to the research objectives. This process is defined in the followings:

1. Review the relevant literature articles of design errors to identify the design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/ Plumbing)
2. Identify the critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing) under each group of design errors by:

   2.1 List the cases of design errors between structure and other building components such as structure, architecture, and MEP systems based on the structural elements of buildings
   2.2 Develop questionnaire to find the critical cases of design errors which can lead to problems in construction
   2.3 Eliminate the uncritical design errors
3. Develop the knowledge-based models for checking design errors in building construction projects: case studies in Cambodia
   3.1 Choose the critical cases of design errors
   3.2 Classify the examples of problems due to design errors into different categories in terms of the structural elements of the buildings. For example: design errors between beam and other building components, design errors between column and other building components, design errors between slab and other building components, and so on.
   3.3 Create the questionnaires for interview to ask the respondents to describe the examples of problems due to each case of design errors that they have faced in their real-life of works at construction sites
   3.4 Learn about the examples of each case to identify its attributes and conditions
   3.5 Code all examples of problems into the system by applying Microsoft Visual Basic Programing Language
4. Research conclusion
   4.1. Critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing)
   4.2. Decision trees of knowledge-based models of the problems due to design errors for checking design errors prior to construction.

To achieve the research objectives, the process of research methodology is shown in the figure below:

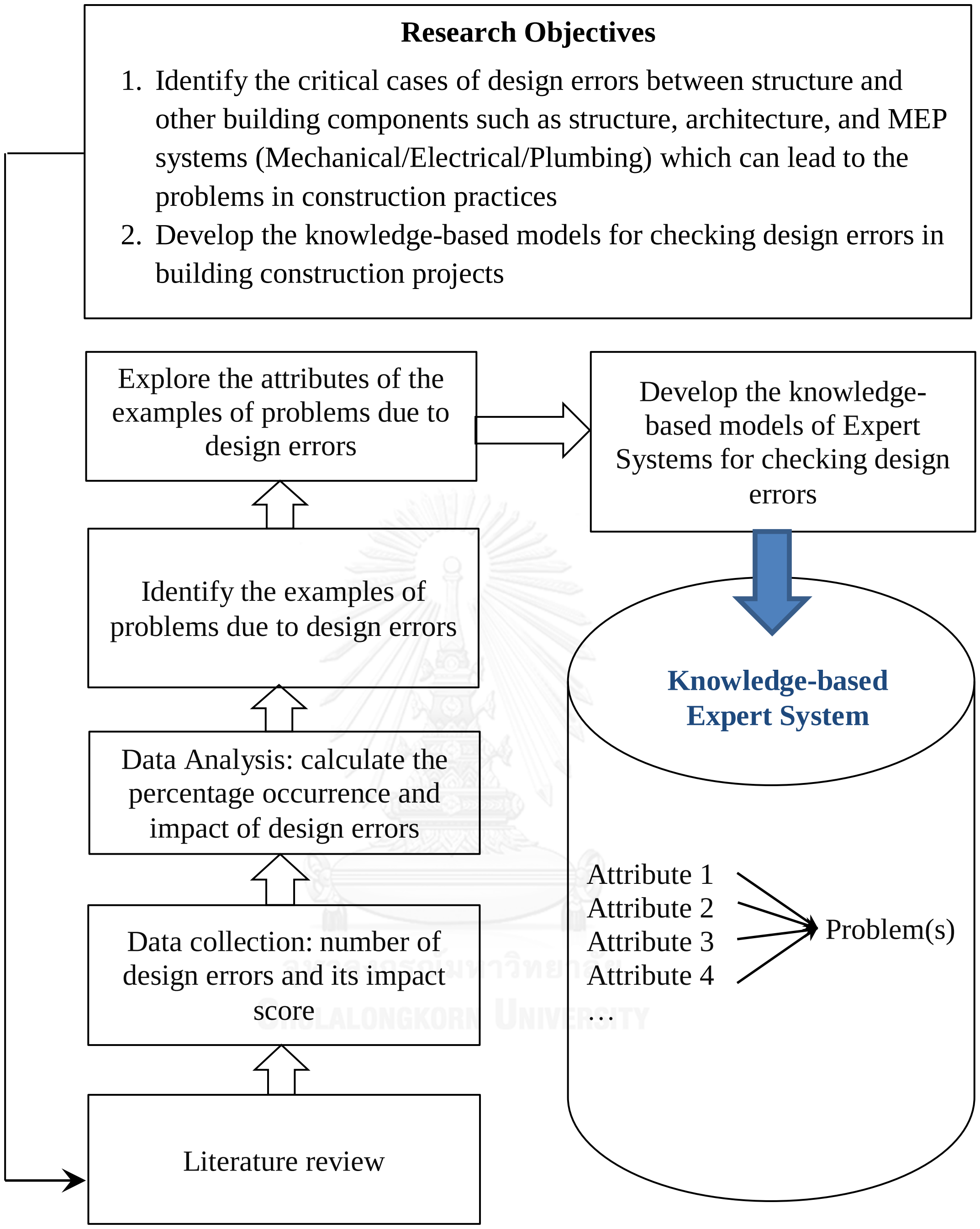

Figure 3.1 Research methodology

3.3 Knowledge-Based Model Development

Regarding knowledge-based systems, the components of KBS consists of knowledge base, inference engine, knowledge engineering tools, and user interface (Zhou et al., 2004, Liao, 2005, Turban et al., 2005). Based on these components, the development of expert systems involves two stages which are (1) knowledge engineering stage and (2) software development stage (Starfield and Bleloch, 1983).

Knowledge engineering stage is performed to address the problem areas. This stage involves the knowledge acquisition and knowledge representation (Hanum et al., 2010).

- *Knowledge acquisition:* All relevant and required knowledge are identified and elicited from the experts or other sources of information.
- *Knowledge representation:* Knowledge is presented in various ways. In this study, the knowledge of all cases and attributes which are relevant to the problems due to design errors are examined and represented by the decision trees.

In the last stage, software development is very important to choose an appropriate knowledge management tool to develop a system in accordance to the attributes and conditions of the problems of each case of design errors.

From the process of research methodology, there are two main parts in this study. The first part represents the knowledge acquisition of knowledge engineering stage. This part aims to identify the critical cases of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical / Electrical / Plumbing), while the second step is to represent the knowledge of problems due to design errors by determining all their related attributes and conditions. After the knowledge representation, the software development stage attempts to develop a system of knowledge-based models for checking the possible occurrence of problems due to design errors in building construction projects. These two main parts are explained in more details in the following figure.

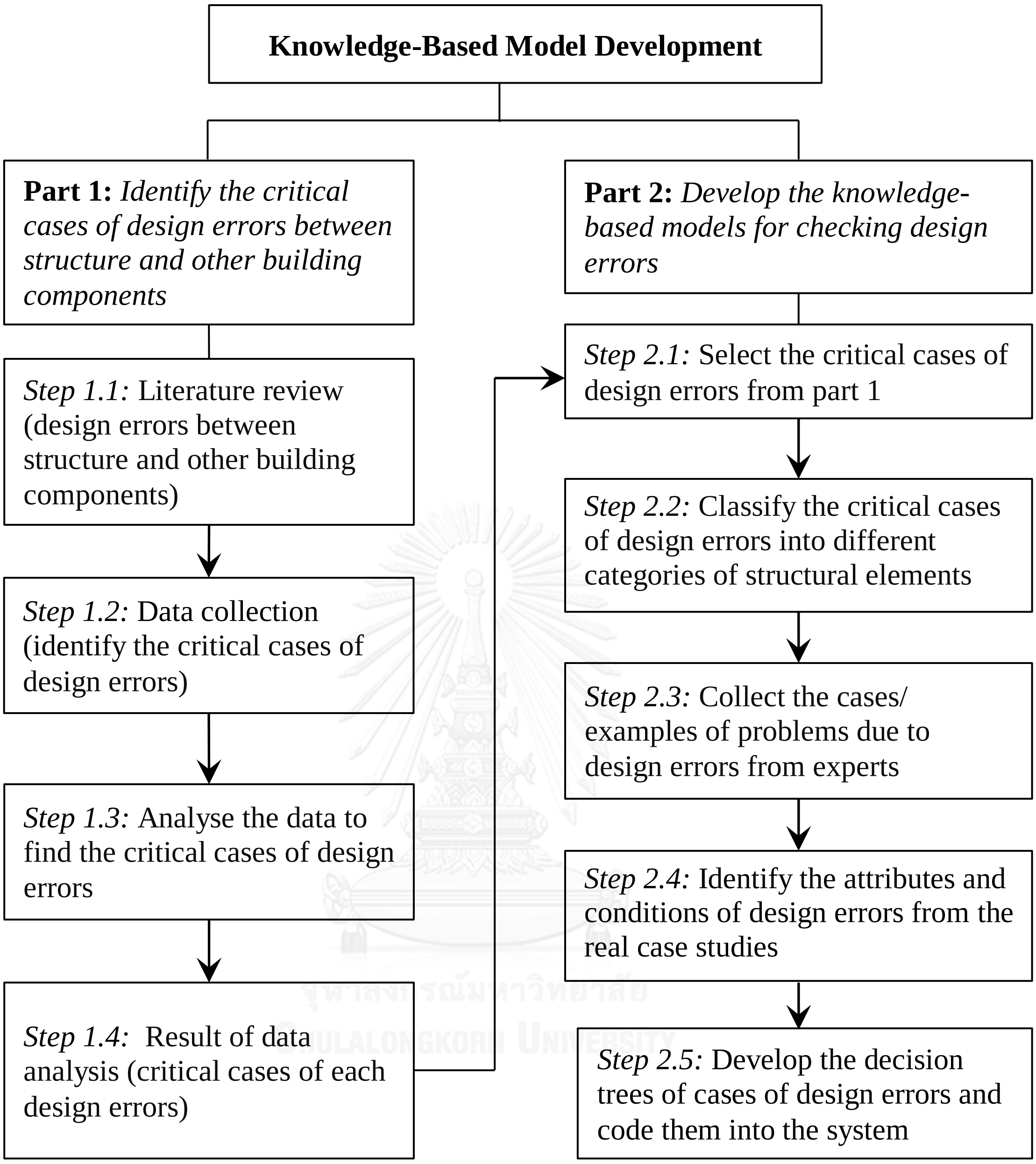

Figure 3.2 Knowledge-based model development

3.4 Data Collection

Data collection is very important for research study; it can influence the reliability and validity of the research results. In this study, the objective of data collection is to gather the information pertinent to the previous experience and knowledge of the experts including site engineers, site managers, and project managers regarding the problems caused by design errors at construction sites.

Therefore, the survey questionnaire and interview technique are appropriate to be applied.

Because this research is separated into two parts, the data will be collected differently so as to accomplish the objectives of the research. Thus, data collection process consists of two parts as well. However, the results of the first data collection will be used to fulfill the objective of the second part.

3.4.1 Data Collection of Part 1

In this first part, the purpose of this study is to identify the critical cases of design errors which can lead to the problems in building construction projects. As mentioned earlier, the survey questionnaire is used. In order to design the questionnaire, the design errors between structure and structure, architecture, or MEP systems (Mechanical / Electrical / Plumbing) which are listed from literature review are used as a guideline. Based on Figure 3.2, this is the step 1.1 in part 1.

As being reviewed in the previous chapter, five groups of design errors are illustrated. Table 3.1, 3.2, 3.3, 3.4, and 3.5 present the design errors between structure and architectural works, structure and structure, structure and mechanical works, structure and electrical works, and structure and plumbing works, respectively. These matrix tables are used as the framework for formulating the survey questionnaires of data collection in part 1.

Table 3.1 Matrix table A – Design errors between structure and architecture

A		**Architecture**					
		Wall finish	Floor finish	Ceiling works	Staircase finish	Door/ Window	Sanitary ware
Structure	Retaining wall						
	Footing						
	Beam						
	Column						
	Slab						
	Stair						
	RC wall						

Table 3.2 Matrix table B – Design errors between structure and structure

B		Structure						
		Retaining wall	Footing	Beam	Column	Slab	Stair	RC wall
Structure	Retaining wall							
	Footing							
	Beam							
	Column							
	Slab							
	Stair							
	RC wall							

Table 3.3 Matrix table C – Design errors between structure and mechanical works

C		Mechanical works	
		HVAC systems	Lift systems
Structure	Retaining wall		
	Footing		
	Beam		
	Column		
	Slab		
	Stair		
	RC wall		

Table 3.4 Matrix table D – Design errors between structure and electrical works

D		Electrical works	
		Electrical system	Telephone/ datacom system
Structure	Retaining wall		
	Footing		
	Beam		
	Column		
	Slab		
	Stair		
	RC wall		

Table 3.5 Matrix table E – Design errors between structure and plumbing works

E		**Plumbing works**				
		Water supply and distribution system	Sanitary drainage and disposal system	Storm drainage system	Fire protection system	Fuel and gas piping system
Structure	Retaining wall					
	Footing					
	Beam					
	Column					
	Slab					
	Stair					
	RC wall					

The next step (step 1.2) is to identify the critical cases of design errors. With the likert scale-questions, the respondents will be asked to answer in the level of agreement and disagreement measurement. Normally, Likert questions are created with five or seven levels of either negative or positive response in agree or dis-agree scale. Hole (2011) stated that Likert scale is widely used to rate the scale in survey research and it also provides more accuracy without bias and inequality in the result.

Five-point Likert scale is selected for developing the questionnaire in this research because of its two aspects. First, there is no any measurement theory or scale to assign the value to a Likert item. Moreover, it is arbitrary. So, the researchers can assign any value of the Likert item which can respond to their research objectives. Second aspect is that the distance of each Likert item is equal. For instance, the distance between item 1 and 2 is the same as the one between item 3 and 4. This equal distance is very essential to prevent the bias in data analysis. Nevertheless, five-point Likert scale is suitable to be applied in this study to find the critical cases of design errors between structure and other building components.

According to ProjectMangementInstitute (2013), the combination of probability of occurrence and impact is assessed in order to prioritize the risks for further analysis. In this study, the rating score of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical / Electrical / Plumbing) based on their impact on project performance is ranked by using five-point Likert scale as shown in Table 3.6.

Table 3.6 Five-point Likert scale for ranking the impact of design errors on project performance

Description	Scenario				Score
	This error requires the design revision	This error needs time for solving	This error can incur more cost	Construction cannot be continued	
Disastrous	Yes	Yes	Yes	Yes	5
Severe	Yes	Yes	Yes	No	4
Substantial	Yes	Yes	No	No	3
Marginal	Yes	No	No	No	2
Negligible	No	No	No	No	1

To prioritize the most critical and important design errors, the percentage occurrence of each design error is also evaluated. By realizing the number of problems per case of design errors, this percentage occurrence can be determined. The percentage formula is applied. Therefore, the number of examples (problems) per case of design errors between structure and other building components such as structure, architecture, and MEP systems is asked from the experts based on their experience in the current projects they are involved in.

In step 1.3, the data of ranking of design errors is analyzed by applying the risk analysis which is explained in details in the next part of data analysis. Finally, the uncritical design errors between structure and other building components such as structure, architecture, and MEP systems are eliminated (step 1.4) and the critical cases of design errors are prioritized and chosen for data collection of part 2.

3.4.2 Data Collection of Part 2

After the data collection and data analysis of part 1 are already finished, the subsequent part is to develop the knowledge-based models for checking design errors in the form of decision trees. Based on the data analysis in part 1, the important design errors are selected (***step 2.1***).

In order to arrange the cases of design errors for facilitating the model development, step 2.2 is to classify those critical cases into different categories based on the structural elements of buildings (for example, design errors between beam and other building components, design errors between column and other building components, design errors between slab and other building components, design errors between stair and other building components, etc.).

In step 2.3, it is necessary to elicit and capture the relevant examples of the previous problems due to each important design errors from the experts. According to Jonassen and Hernandez-Serrano (2002), four activities in the interview are adapted to collect those relevant examples, which are:

1) Identify the skilled practitioners. They are those who have some or many years of experience in facing the problems caused by design errors during construction processes. In this research, those are contractors such as project managers, site managers, or site engineers.
2) Show the experts the concerned problems that are being sought for. Using the critical cases of design errors between structure and other building components as a guideline, present one example of a problem to them. This is to remind the experts of their past experience on similar problems.
3) Ask the respondents to describe the examples of problems due to each case of design errors (***step 2.3***). In this activity, audiotape is very effective to record the stories of the examples they are describing because it can help to facilitate the next activity.

4) Decide what the examples of problems teach (***step 2.4***). Thus, the attributes, conditions, and situations of problems due to each case of design errors can be retrieved from those examples.

As a result, the expected data of this interview will provide a number of various problems due to design errors in different categories with their attributes and conditions. These different categories can facilitate in formulating the decision trees of knowledge-based expert systems for checking the possible occurrence of problems due to design errors. Within these problems' categories, the last step (***step 2.5***) is to develop the decision trees of each critical case of design errors and code them into the system of the model. How to code this knowledge will be described in data analysis of part 2.

3.5 Data Analysis

After the collection processes, data has to be analyzed for the purpose of studying and revealing the relationships, patterns, and trends that can be found within it (CommunityToolBox, 2013). The analysis is to ensure that the data are relevant and important. The following sub-sections describe about how to analyze the data from data collection of part 1 and 2.

3.5.1 Data Analysis of Part 1

In this step, the cases of design errors are ranked and scored by every respondent. Following the ***Risk Analysis*** (percentage occurrence multiplied by impact), the cases of design errors are prioritized for further action. This analysis technique is beneficial because it can reduce the level of uncertainty and focus on high-priority cases of design errors between structure and other building components such as structure, architecture, and MEP systems (ProjectMangementInstitute, 2013).

To analyse the data of part 1, it is required to assess the percentage occurrence and impact in order to investigate the likelihood that each case of design errors will occur and to examine the consequence or impact of each case of design errors on project performance. The cases of design errors can be prioritized based on the rating score from the target respondents. The identification of the critical cases of design errors and their priority are conducted by calculating the score of every case of design errors, which is the combination of percentage occurrence and impact (R value of each case equals to the percentage occurrence multiplied by impact).

$$\boldsymbol{R = P \times I}$$

Where R is risk rating value;

P is percentage occurrence of each case of design errors;

$P = \ Number\ of\ cases\ in\ x/Total\ number\ of\ cases\ in\ a\ project$

(x is each group of design errors between structure and other building components);

I is the score of impact of each design error's case on project performance.

In this research, the rating rule for prioritizing and selecting the most important design errors are in accordance with the score of each design errors (R value) between structure and other building components such as structure, architecture, and MEP systems. The cases of design errors under each group, which have greatest score, are considered as important and to be selected for further step of this study. Thus, the score of this rule for the percentage occurrence and impact is due to the score of each case of design errors. The cases in the most priority zones of percentage occurrence and impact score are the most critical cases of design errors in this study.

3.5.2 Data Analysis of Part 2

Cross-Case Analysis

In this study, cross-case analysis is proposed as a mechanism for investigating all cases of each problem due to design errors. The knowledge from the critical cases can be used as a guideline to create the decision trees for developing the knowledge-based system.

Cross-case analysis is chosen as an analysis technique in this study because it is an empirical research method of case study approach which is applied to investigate the phenomenon in real-life contextualization (Roley, 2002, Yin, 2003). Additionally, this qualitative case study focuses on the issues or problems illustrated by the cases (Creswell, 1998). Importantly, this analysis is performed by looking into the commonalities and any relevant differences in all cases (McWhorter et al., 2013) and this analysis technique divides the data by type across all cases gathered (Soy, 1997).

To analyze the gathered data of all critical cases in part 2, cross-case analysis is applied to categorize the similarities and differences of the cases. Since the structural elements of the buildings are the main attribute of the model to be developed, multiple cases are classified and chosen according to the examples of problems due to each case of design errors and their context that are relevant to each structural element of the building.

Knowledge-Based Systems

Knowledge-based system (KBS) is a computer-based tool which is used to incorporate the heuristic knowledge into the models (Chau and Albermani, 2003). Chau and Albermani (2003) also claimed that KBS can emulate the knowledge of experts in a specific problem. In this study, learning about the examples of problems due to design errors urges to determine all attributes and conditions, which are the basis for knowledge-based model development. Thus, the knowledge-based models are constructed to check the possibility of occurrence of problems due to each case of design errors by using Microsoft Visual Basic as the programming language for coding.

Visual Basic is selected in this study because it is a programming language on the Windows operating system of which the code is performed in response to the knowledge or events (Sellappan, 2006). Visual Basic can proceed rapidly in creating an application; it provides many influential features such as information forms, user interfaces, error handling, and other programming structures (Hassan et al., 2006). Comparing with other programs, Visual Basic is easier to test and can be modified. Moreover, it takes less time for coding and creating a powerful application. In other words, Visual Basic is a complete package to create user interfaces that are easy to manage and learn.

In this research, Visual Basic programming language is applied to code the previous knowledge of problems due to each case of design errors by using case studies. The main attribute of each case of design errors is the structural elements of the building such as retaining wall, footing, beam, slab, column, stair, and reinforced concrete wall. The respective attributes are the contributing factors which can lead to the problems of design errors. Those factors are relevant to structure, architecture, and MEP systems. A conceptual framework to look into how this program can be written is developed as shown in the following figure.

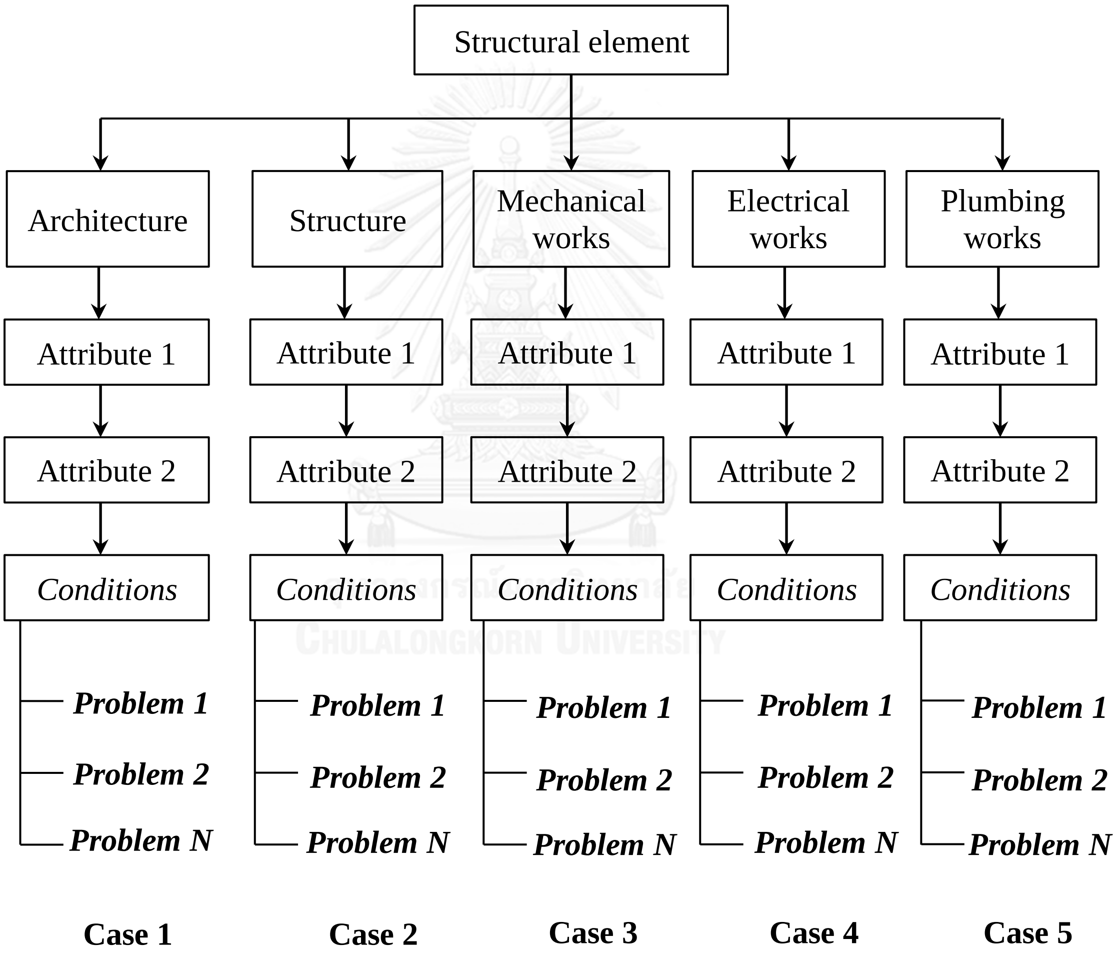

Figure 3.3 Conceptual framework for knowledge-based model development

3.6 Summary

The methodology of this research is explained clearly in this chapter. In order to achieve the research objectives, the research process consists of two main parts. First, the identification of the critical cases of design errors is performed by asking the respondents to give the score to each case of design errors with Likert items and the number of cases of problems due to each design error’s case. Second, the examples of problems due to important design errors are retrieved from the historical experience and knowledge of the target respondents so that the knowledge-based models can be developed with the Visual Basic application. The process of data collection and data analysis are described in detail in the following chapters.

CHAPTER IV

IDENTIFICATION OF CRITICAL CASES OF DESIGN ERRORS BETWEEN STRUCTURE AND OTHER BUILDING COMPONENTS

In this chapter, the process of identifying the critical cases of design errors between structure and other building components is explained. How to collect the data is also illustrated together with the description of respondents' information and project characteristics. Then all possible cases of design errors are introduced, and the process of data analysis and results are discussed. As a result, the most important cases of design errors are prioritized and selected as the framework to examine the attributes and conditions of design errors and to develop the knowledge-based models.

4.1 Description of Data Collection

4.1.1 Survey Questionnaire

The data collection was conducted by using interview technique with a survey questionnaire. The survey questionnaire was divided into two sections. In the first section, the respondents were asked to give their own information such as their current position and years of experience on site. The second section required them to provide the number of design errors and evaluate their impact score in five different matrix tables of design errors between structure and other building components such as architecture, structure, and MEP systems (Mechanical / Electrical / Plumbing). In this second section, each respondent was asked to focus on only an already complete building construction project which they had worked for during construction practices. So, this is a project-based questionnaire which requires the respondents to remind their memory back about the number of design errors' cases and its impact score. For the number of cases of design errors in each sampling project, the respondents had to remind their memory about the design errors' cases they had met in their mentioned project by:

- Examining the notes and highlights on the hard copy of shop drawings (layout plans of each floor of the building…);

- Reviewing the shop drawings and As-Built drawings to find the cases which had occurred;
- Checking the daily reports, monthly reports, and other relevant documents.

For the impact score of each case of design errors, the respondents had to evaluate it based on the Five-point Likert scale as shown in Table 3.6. The sample of survey questionnaire is attached in Appendix A.

The data collection was conducted from October until November, 2014 with experienced civil engineers of the contractors of reinforced concrete building construction projects in Phnom Penh city, capital city of Cambodia. Since Phnom Penh is the center of commerce, the headquarters and construction sites of most construction companies are located in this capital city. Thus, it was convenient to distribute the questionnaire to the respondents via direct personal contacts.

As a result of data collection, eleven valid answers of the survey questionnaire were gathered for analysis. The length of time (that each respondent spent for the questionnaire) was varied from two hours to three hours according to their memory on design errors in the building construction project they had mentioned. However, some respondents were appointed for interview several times because they required much time to remind and review about the cases of structure with other building components in their mentioned project.

4.1.2 Background of Respondents

To select the capable respondents, the position and experience are the key criteria. In this survey, the target respondents have to be civil engineers of contractors and have to involve in the whole construction works of building projects. All target respondents are civil engineers who have current position as site engineers, site managers, project managers, and managing directors of the contractors. In this research, the people with these positions are knowledgeable and have enough ability to provide rich information of design errors. Moreover, all of them had also involved in the project since the start-up of construction works until the completion of construction. In Table 4.1, 27% of respondents are managing directors, another 27%

of them are project managers, and other 27% are site engineers, whereas other 18% are site managers. Based on this result, those respondents are qualified to answer the questionnaire via interview.

Table 4.1 Position of respondents

Position of contractors	Number of respondents	Percentage	Cumulative percentage
Site manager	2	18%	18%
Site engineer	3	27%	45%
Project manager	3	27%	73%
Managing director	3	27%	100%
Total	11	100%	

Apart from the position, experience is another main criterion for selecting a qualified respondent. It was quite difficult to interview the respondents about their past experience and memory. Usually, years of experience can influence the respondents' perceptions and responses. All civil engineers of contractors can provide the information of design errors based on their past performance in the actual construction activities and practices. All of the respondents have at least two years' experience working in building construction projects. They hold at least Bachelor's Degree of Civil Engineering. According to Table 4.2, about half of them have working experience between 5 and 10 years and the average years of experience of all respondents are at 7 years. The experience of respondents is summarized in Table 4.2.

Table 4.2 Experience of respondents

Experience	Number of respondents	Percentage	Cumulative percentage
Less than 5 years	3	27%	27%
5 - 10 years	6	55%	82%
More than 10 years	2	18%	100%
Total	11	100%	

4.1.3 Project Characteristics

For all sampling projects, every stakeholder has to collaborate on the whole process of construction in order to complete a project. The relevant parties have to develop the design of their project according to the following steps. First, the architect designs the architectural plans based on the requirements of the principal and owner's satisfaction. After the approval of those architectural designs, structural engineer starts to create a structural system in compliance with the architectural plans. Last, the installation of mechanical, electrical, and plumbing systems (MEP systems) are developed and integrated into the structural and architectural designs. Many coordination problems arise when these three systems are designed separately with individual focus (Plume and Mitchell, 2007). Traditionally, engineers have to ensure a good coordination between all systems of the project before construction stage (Gijezen et al., 2009). Therefore, engineers have to check the design drawings of all systems in order to examine design errors between those systems. However, this traditional method of checking design errors is not an effective process since the comparison of designs on different drawings can be easily failed due to the unclear overview of the designs and their coordination with each other. Hence, most design errors are still prevalent issues among construction projects. In order to find an effective mechanism to reduce design errors, it is necessary to understand which design errors are critical with high occurrence and high impact in those sampling building construction projects. Thus, the data collection of part 1 in this research is very necessary.

After this data collection, eleven valid answers of the questionnaire were gathered. The information of eleven building construction projects was obtained. Among those building projects, four are hotels, one is condominium, two are apartments, three are commercial buildings, and the other one is shopping center (Table 4.3; Figure 4.1). During data collection, the construction of these projects was already complete regarding structure, architecture, and MEP systems. However, the structural design of these buildings is varied due to the competency of designers and complexity of the buildings. Furthermore, the number of design errors which occur in any projects is also varied because it is in accordance with the designers' performance during design process and their experience on building construction projects.

Table 4.3 Project characteristics

Projects	Number of projects	Percentage	Cumulative percentage
Hotel	4	36%	36%
Condominium	1	9%	45%
Apartment	2	18%	64%
Commercial building	3	27%	91%
Shopping center	1	9%	100%
Total	11	100%	

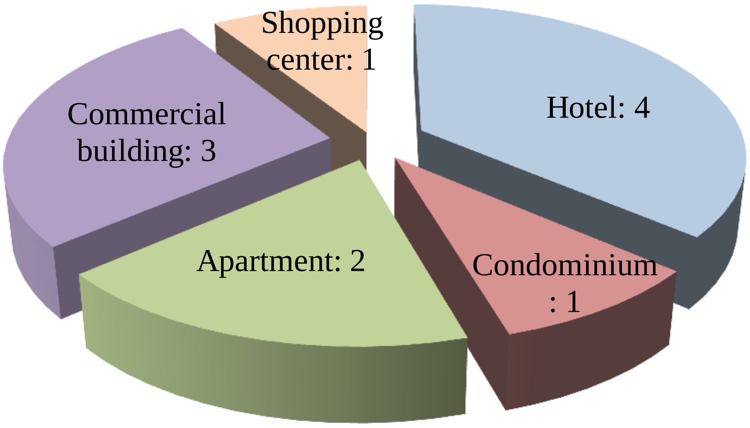

Figure 4.1 Project characteristics

In the first section of survey questionnaire, the information of building construction projects was also asked from the respondents. The number of floors, total area, total height, date of starting project, date of finishing project, and duration of construction completion of the concerned building projects were provided. All of the projects have at least 840 square meters of total area and at least 28 meters of total height. The maximum total height of all projects is 188 meters, whereas the maximum total area is approximately 125,000 square meters. Based on Geren et al. (2013), these sampling building construction projects are all considered as high-rise building with the height more than 75 feet (22,860mm). Table 4.4 shows the information of all building construction projects.

Table 4.4 Information of projects

No.	Reinforced Concrete Building Projects	Number of Floors	Total Building Area (m^2)	Total Height (m)	Date of starting project	Date of finishing project	Duration of construction completion
1	Hotel	9	7,200	41.50	Aug / 2012	Aug / 2014	2 years
2	Hotel	11	3,648	38.40	July / 2012	Sept / 2014	2 years and 2 months
3	Hotel (delayed one year)	18	114,024	76.58	Aug / 2009	Dec / 2014	5 years and 5 months
4	Hotel	23	15,000	99.00	Sept / 2012	Nov / 2014	2 years and 2 months
5	Condominium	13	7,150	52.00	Nov / 2010	Sept / 2012	1 year and 10 months
6	Apartment	7	840	28.00	Jan / 2014	Nov / 2014	10 months
7	Apartment	14	1,475	52.00	Jan / 2012	Aug / 2014	2 years and 7 months
8	Commercial building	12	6,000	64.00	May / 2011	Feb / 2013	1 year and 9 months
9	Commercial building	11	6,600	40.00	May / 2013	Nov / 2014	1 year and 6 month
10	Commercial building	39	11,800	188.00	2009	Topped out in 2012	3 years (completed in 2014)
11	Shopping center	5	125,000	34.00	Nov / 2012	June / 2014	1 years and 8 months

In addition, the main structural elements and other main building components being designed in each sampling project are also described and obtained from the respondents. Based on these structural elements and other building components, the cases of design errors between a specific structural element and other components can be identified and counted. For section two of the questionnaire, the results of data of those projects from all respondents are attached in Appendix B.

Table 4.5 Structural elements and other building components in each project

No.	Projects	Structural elements	Other building components
1	Hotel	- Piles / footing - Retaining wall - Septic tank - Ground beam / beam, slab - column - Lift core wall - Stairs	- Mechanical systems - Electrical systems (telephone wire, internet wire…) - Piping systems (hot/cold water systems, waste water systems, storm drainage system, fire protection system…) - Civil works (walkways)
2	Hotel	- Bored piles / footing - Ground beam / beam - Septic tank - Slab; Staircases - RC wall / pool's RC wall	- Architectural works - Mechanical systems (Lift systems…) - Electrical systems - Plumbing systems - All civil works
3	Hotel	- Pile caps (footing) - Retaining wall - Septic tank - Ground beam / beam, slab - Column - Lift pit / Lift wall - Staircases - Helipad, Skylight	- All architectural works: brick wall, plastering, tiling … - Electrical works - Plumbing works - Mechanical works: Lift systems / Elevator systems - Civil works
4	Hotel	- Bored piles / pile caps (footing) - Retaining wall - Septic tank - Ground beam / beam - Basement slab / slab - Staircases - Lift core wall (RC wall) - Stump column / column	- All architectural works - Piping systems: waste water, hot/cold water, fire protection piping … - Electrical works: electrical machines, datacom/telephone wires… - Mechanical works: mechanical machines lift systems, air conditioning, elevator systems…

Table 4.5 Main structural elements and other building components in each project (continued)

No.	Projects	Structural elements	Other building components
5	Condominium	- Pile caps (footing) - Retaining wall (swimming pool) - Septic tank - Ground beam / beam, slab - Column - Shear wall (Lift wall) - Staircases - Roof structure	- Underground drainage system (sanitary drainage and disposal system, piping systems…) - Mechanical systems: Lift systems - Electrical systems - All architectural works - Civil works
6	Apartment	- Foundation: bored piles and pile caps - Retaining wall - Septic tank - Super structure: Column, beam, slab, and stair of reinforced concrete	- Architecture: brick wall, plastering, painting, ceramic tiles for floor and wall finish, PVC glass of door/window, wooden door, gypsum board ceiling … - Electrical system: lighting, TV, Internet - Plumbing system: waste water, water supply (cold and hot), storm drain - Mechanical system: elevator system, Lift system
7	Apartment	- Piles / Pile caps - Retaining wall - Septic tank - Slab - Beam - Column - Staircase - Lift wall (reinforced concrete)	- Lift motor room - Genset room - ATS system - MV Switch gear room - Hose real pump - Wet riser pump - Cold/hot water pipes - Transfer pump - Fire protection pump - Fresh air fan - Kitchen exhaust fan - Air conditioning system - Electrical systems

Table 4.5 Main structural elements and other building components in each project (continued)

No.	Projects	Structural elements	Other building components
8	Commercial building	- Piles/pile caps (Footing) - Retaining wall - Septic tank - Ground beam / beam - Column - Slab - Lift core wall - Reinforced concrete wall (shear wall) - Stairs	- All architectural works - Civil works - Mechanical works - Electrical works - Piping systems for water supply, sanitary, fire hoses, …
9	Commercial building	Reinforced concrete building with: - Bored piles / pile caps - Concrete slab/ beam, Column - Slab, staircases - Shear wall - Basement wall (retaining wall) - Septic tank	- All architectural works - MEP: mechanical, electrical, and all plumbing systems - Elevator and lift systems
10	Commercial building	- Bored piles / pile caps - Retaining wall - Septic tank - Ground beam/ beam - Column - Basement slab / slab - Stairs - Lift core RC wall	- MEP (Mechanical, Electrical, and Plumbing): Elevator and lift systems, piping systems, TV, Internet, Telephone systems …) - Fire fighting - MVAC / PVC pipes - All architectural works

Table 4.5 Main structural elements and other building components in each project (continued)

No.	Projects	Structural elements	Other building components
11	Shopping center	- Septic tank - Piling-bored piles - Structural works – RC (reinforced concrete structure) - Roof structure (Sinema and skirting areas) – steel structure and roof panel - Lift core wall – RC wall - Concrete road - Staircase – concrete stair and concrete wall	- Architecture – brick wall, gypsum ceiling, floor finish (tiling and skirting), door/window, sanitary ware… - Elevator and lift system (cone products) - Water supply and distribution system, Sanitary and drainage system – Plastic pipes - Rainwater – Concrete pipes

4.1.4 Possible Cases of Design Errors Between Structure and Other Building Components

After the data collection of part 1 and based on the responses from all target respondents, some impossible cases were explored. Obtaining from the answers in all 5 matrix tables for design errors of group A, B, C, D, and E (matrix tables as used in the survey questionnaire of part 1), only 122 cases of design errors occurred among all 154 cases in all eleven sampling building construction projects. Therefore, the 32 impossible cases are negligible in this study. Table 4.5 shows the possible and impossible cases among all sampling projects under five groups of design errors.

Table 4.6 Possible and impossible cases of design errors

No.	Groups of design errors between structure and other building components	Possible cases	Impossible cases	All listed cases
1	Group A: Design errors between structure and architecture	31	11	42
2	Group B: Design errors between structure and structure	43	6	49
3	Group C: Design errors between structure and mechanical works	12	2	14
4	Group D: Design errors between structure and electrical works	10	4	14
5	Group E: Design errors between structure and plumbing works	26	9	35
	Total	***122***	***32***	***154***

4.2 Analysis of Design Errors

The analysis of data was divided into five steps. First of all, the percentage occurrence of design errors was calculated. Second, the impact of design errors, evaluated by the respondents, was analyzed. Third, the combination of percentage occurrence and impact of design errors was discussed. The result of this combination was used to view the different priority zones of each group of design errors between structural elements and other building components. As described in chapter two, there are five groups of design errors such as group A of design errors between structure and architecture, group B of design errors between structure and structure, group C of design errors between structure and mechanical works, group D of design errors between structure and electrical works, and group E of design errors between structure and plumbing works. Similarly, the same method of combination between percentage occurrence and impact score was also applied in order to classify the different priority zones of each possible case of design errors. Finally, the low, medium, and high important cases of design errors were identified based on this combination. All steps of this analysis are subsequently explained in the following parts.

4.2.1 Percentage Occurrence of Groups of Design Errors

The percentage occurrence of groups of design errors was converted from the number of design errors between each structural element and other building components in a building construction project. The following percentage formula was applied.

$$P_{ij} = 100 \frac{N_{ij}}{\sum N_j} \ (\%) \qquad (1)$$

Where:

i represents each group of design errors (i = A, B, C, D, E);

j refers to each building project (j = 1, 2, 3, …, 11);

P_{ij} is the percentage occurrence of group i of design errors in project j;

N_{ij} is the number of cases of design errors under group i in project j;

$\sum N_j$ is the total number of all cases of design errors occurring in project j.

The calculation of percentage occurrence of design errors in project 1 was shown as an example by applying equation (1). According to the collected data (Appendix B), project 1 consists of design errors between structure and architecture N_{A1} = 71 cases, design errors between structure and structure N_{B1} = 95 cases, design errors between structure and mechanical works N_{C1} = 26 cases, design errors between structure and electrical works N_{D1} = 14 cases, and design errors between structure and plumbing works N_{E1} = 36 cases (Table 4.5). In total, all number of design errors in project 1 is $\sum N_1$ = 242 cases. The percentage occurrence of design errors in project 1 was calculated as below:

$$P_{A1} = 100 \times \frac{71}{242} \ (\%) = 29.34\%$$

$$P_{B1} = 100 \times \frac{95}{242} \ (\%) = 39.26\%$$

$$P_{C1} = 100 \times \frac{26}{242} \ (\%) = 10.74\%$$

$$P_{D1} = 100 \times \frac{14}{242} \ (\%) = 5.79\%$$

$$P_{E1} = 100 \times \frac{36}{242} \ (\%) = 14.88\%$$

In comparison with the percentage occurrence of design errors in project 1 among all five groups of design errors, the result shows that design errors between structure and structure mostly occurred since P_{B1} = 39.26% is the highest value of percentage occurrence. The second ranking is design errors between structure and architecture (P_{A1} = 29.34%), the third is design errors between structure and plumbing works (P_{E1} = 14.88%), the fourth is design errors between structure and mechanical works (P_{C1} = 10.74%), and the rarely occurred group is design errors between structure and electrical works (P_{D1} = 5.79%). Applying the same method, the percentage occurrences of all groups of design errors in other ten projects of this study are summarized in Table 4.7. The calculation sheets are also shown in Appendix B.

Table 4.7 Percentage occurrence of groups of design errors in each project

Groups of Design Errors (*i*) Projects (*j*)	Design errors of group A	Design errors of group B	Design errors of group C	Design errors of group D	Design errors of group E	Total
Project 1 (Hotel)						
No. of cases	71	95	26	14	36	242
$P_{i\,1}$	29.34%	**39.26%**	10.74%	5.79%	14.88%	100%
Ranking	2	**1**	4	5	3	
Project 2 (Hotel)						
No. of cases	46	40	3	4	24	117
$P_{i\,2}$	**39.32%**	34.19%	2.56%	3.42%	20.51%	100%
Ranking	**1**	2	5	4	3	
Project 3 (Hotel)						
No. of cases	144	64	46	0	42	296
$P_{i\,3}$	**48.65%**	21.62%	15.54%	0.00%	14.19%	100%
Ranking	**1**	2	3	5	4	
Project 4 (Hotel)						
No. of cases	47	40	14	0	24	125
$P_{i\,4}$	**37.60%**	32.00%	11.20%	0.00%	19.20%	100%
Ranking	**1**	2	4	5	3	
Project 5 (Condominium)						
No. of cases	57	120	4	1	42	224
$P_{i\,5}$	25.45%	**53.57%**	1.79%	0.45%	18.75%	100%
Ranking	2	**1**	4	5	3	

Table 4.7 Percentage occurrence of groups of design errors in each project (continued)

Groups of Design Errors (*i*) / Projects (*j*)	Design errors of group A	Design errors of group B	Design errors of group C	Design errors of group D	Design errors of group E	Total
Project 6 (Apartment)						
No. of cases	49	24	11	4	20	108
$P_{i\,6}$	**45.37%**	22.22%	10.19%	3.70%	18.52%	100%
Ranking	**1**	2	4	5	3	
Project 7 (Apartment)						
No. of cases	40	74	11	10	25	160
$P_{i\,7}$	25.00%	**46.25%**	6.88%	6.25%	15.63%	100%
Ranking	2	**1**	4	5	3	
Project 8 (Commercial Building)						
No. of cases	70	64	0	0	20	154
$P_{i\,8}$	**45.45%**	41.56%	0.00%	0.00%	12.99%	100%
Ranking	**1**	2	4	4	3	
Project 9 (Commercial Building)						
No. of cases	49	21	19	12	20	121
$P_{i\,9}$	**40.50%**	17.36%	15.70%	9.92%	16.53%	100%
Ranking	**1**	2	4	5	3	
Project 10 (Commercial Building)						
No. of cases	99	98	26	18	51	292
$P_{i\,10}$	**33.90%**	33.56%	8.90%	6.16%	17.47%	100%
Ranking	**1**	2	4	5	3	
Project 11 (Shopping Center)						
No. of cases	59	84	20	24	22	209
$P_{i\,11}$	28.23%	**40.19%**	9.57%	11.48%	10.53%	100%
Ranking	2	**1**	5	3	4	
$P_i=1/11\Sigma P_{ij}$	***36.25%***	***34.71%***	***8.46%***	***4.29%***	***16.29%***	***100%***
Ranking	***1***	***2***	***4***	***5***	***3***	

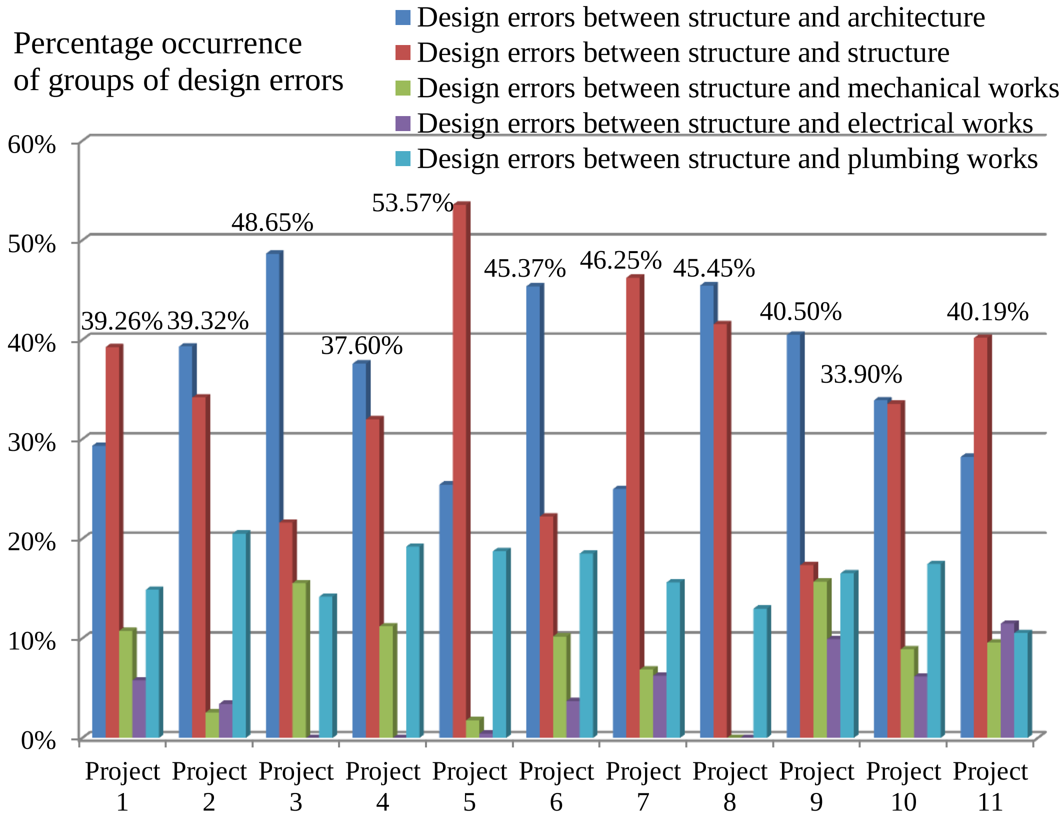

Figure 4.2 Percentage occurrence of groups of design errors in each project

According to the percentage occurrence in Table 4.7, Figure 4.2 presents the bar charts of these results. It is found that hotel projects often have problems with design errors between structure and architecture (A) which is higher than the other groups of design errors, whereas condominium and apartment projects mostly have experienced both design errors between structure and architecture (A) and design errors between structure and structure (B). For commercial buildings, design errors between structure and architecture (A) are the most frequent occurrence among all groups of design errors. The result of shopping center project also clearly shows that design errors between structure and structure (B) are the highest occurred problems which always arise during construction practices (P_{B11} = 40.19%).

To sum up, the percentage occurrence of design errors in group A, B, E, C, and D are ranked as the first, second, third, fourth, and fifth, respectively. These results indicates that design errors between structure and architecture (A) have P_A = 36.25% in average which are seen as the most critical occurrence and which frequently occur in current building projects in Cambodia. However, design errors between structure and structure (B) also highly occur (P_B = 34.71%). Besides, design errors between structure and plumbing works (E) are frequently found (P_E = 16.29%), while design errors between structure and mechanical works (C) are occasionally met (P_C = 8.46%). For design errors between structure and electrical works (D), they rarely arise in those studied projects (P_D = 4.29%). In spite of this ranking, the percentage occurrence of design errors is varied due to the competency of various structural engineers, nature, and complexity of each building construction project.

4.2.2 Impact of Groups of Design Errors

The impact score of cases of design errors was evaluated by the respondents from 1 to 5 which mean negligible, marginal, substantial, severe, and disastrous, accordingly. Converting from the impact of each case of design errors under each group, the impact of each group of design errors (group A, B, C, D, and E) can be determined. It is the mean value of the impact score of all cases of design errors under each group. The following formula is then used to calculate this impact score for each sampling project.

$$I_{ij} = \frac{1}{N}\sum_{x=1}^{N} I_x \qquad (2)$$

Where:

i represents each group of design errors (i = A, B, C, D, E);

j refers to each building project (j = 1, 2, 3, …, 11);

I_{ij} is the impact score of group i of design errors in project j;

N is the total number of occurred cases under group i in project j;

I_x is the value of impact score of each occurred case under group i in project j.

The calculation of impact score of group A in project 1 (I_{A1}) was explained as an example by applying equation (2). According to the data collection of part 1 (Appendix B), I_x of group A in project 1 are [2, 4, 4, 3, 3.50, 3, 2, 4, 4, 3, 4, 2, 2.50, 3, 4]. So the value of N is equal to 15 based on the number of I_x. The impact score of design errors between structure and architecture (group A) in project 1 was determined as below:

$$I_{A1} = \frac{1}{15}(2+4+4+3+3.5+3+2+4+4+3+4+2+2.5+3+4) = 3.20$$

Applying the same formula, the impact scores of all groups of design errors in other ten sampling projects are found. Appendix B shows the calculation of these impact scores and the results are also briefly described in Table 4.8.

Table 4.8 Impact score of groups of design errors in each project

Groups of Design Errors (i) Projects (j)	Impact scores of groups of design errors in each project				
	Design errors of Group A	Design errors of group B	Design errors of group C	Design errors of group D	Design errors of group E
Project 1	3.20	2.73	3.46	**3.80***	2.96
Project 2	3.00	2.64	**4.00***	2.00	2.75
Project 3	1.90	2.53	**4.00***	***N/A***	**4.00***
Project 4	2.09	2.00	**2.80***	***N/A***	2.50
Project 5	2.11	1.17	**4.00***	3.00	1.67
Project 6	2.08	2.14	**3.00***	2.00	**3.00***
Project 7	1.81	**2.16***	1.83	1.67	2.00
Project 8	3.11	3.00	***N/A***	***N/A***	**3.75***
Project 9	2.77	1.55	3.00	3.00	**3.25***
Project 10	**2.71***	2.55	2.20	2.67	2.16
Project 11	3.31	**3.57***	3.25	3.50	3.10

* Maximum impact score of groups of design errors in each project;

N/A means that design errors could not be found in the projects.

Due to the impact of each group of design errors shown in Table 4.8, design errors between structure and mechanical works (C) had the maximum impact score among all five groups of design errors in five different projects. Besides, design errors between structure and plumbing works (E) were found to have the highest impact score in four of all eleven projects. In two projects, design errors between structure and structure (B) had the maximum impact score, whereas design errors between structure and architecture (A) and design errors between structure and electrical works (D) consisted of only one project with the highest impact score.

The summary of impact of groups of design errors in all eleven projects is illustrated as bar charts in Figure 4.3 and the maximum impact score of groups of design errors in each project is also presented.

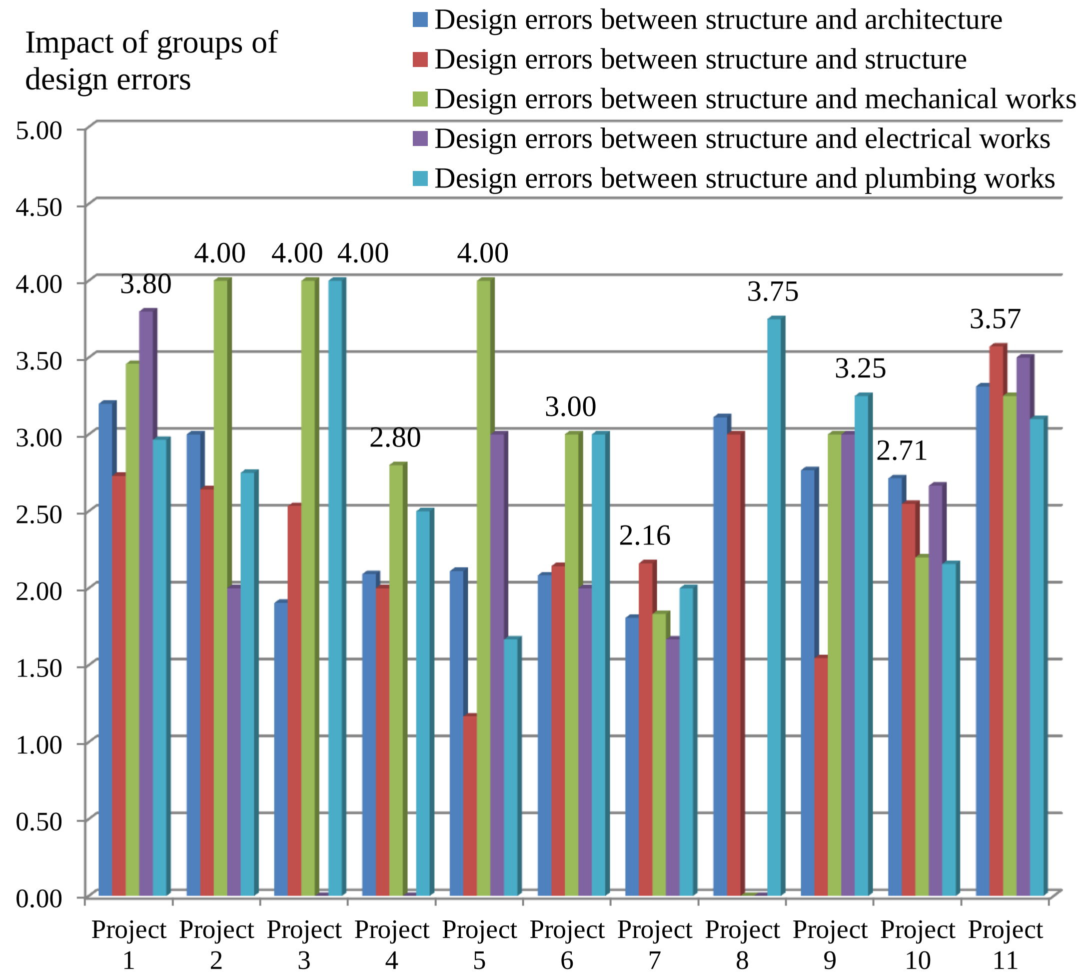

Figure 4.3 Impact score of groups of design errors in each project

However, the values of maximum impact score of all five groups of design errors in each project are varied and not equal. The meaning of those values is different due to the scale of impact score as explained in Table 4.9. So, the highlighted notes in Table 4.8 exactly show the impact scale of design errors. The interval value of ***Disastrous*** impact is from 4.21 to 5.00, ***Severe*** is from 3.41 to 4.20, ***Substantial*** is from 2.61 to 3.40, ***Marginal*** is from 1.81 to 2.60, and ***Negligible*** is from 1.00 to 1.81. These intervals were calculated by the subtraction between maximum and minimum score of impact and then it was divided by five different scales.

$$Cumulative\ impact\ value = \frac{Maximum\ impact - Minimum\ impact}{5}$$

$$Cumulative\ impact\ value = \frac{5-1}{5} = 0.80$$

Thus, the cumulative impact value equals to 0.80 and this was used to classify the five different scales of impact as shown in Table 4.9 (Disastrous, Severe, Substantial, Marginal, and Negligible). In addition, the highlighted notes are also included so as to easily view the scale of impact score in Table 4.8. Table 4.9 shows that violet color represents Disastrous scale, green is Severe, orange is Substantial, blue is Marginal, and white color refers to Negligible. For the yellow highlights with italic and bold underlined ***N/A*** refer to the absence of the design error's occurrence in the mentioned building construction project; thus, respondents cannot know its impact scale. This is the reason why its impact score equals ***N/A***.

Table 4.9 Classification of impact score

Impact Scale	Interval Value	Highlighted Note
Disastrous	4.21 – 5.00	Violet
Severe	3.41 - 4.20	Green
Substantial	2.61 - 3.40	Orange
Marginal	1.81 - 2.60	Blue
Negligible	1.00- 1.80	White
N/A	*N/A*	*N/A*

As being described above on the results of impact of groups of design errors in each project (Table 4.8), it was found that 55% (six projects with orange highlights) of all collected projects experienced the **substantial impact** and the other 45% (five projects with blue highlights) got **marginal influence** from design errors between structure and architecture (A). Design errors between structure and structure (B) also **marginally affected** to approximately 45% of total gathered projects, and to the other

55% of those projects with **substantial**, **severe**, and **negligible causes**. Noticeably, design errors between structure and mechanical works (C) sometimes could cause **severe impact** (four projects with green highlights) and sometimes could lead to **substantial influence** (four projects with orange highlights) on project performance. Not many problems of this group of design errors resulted in **marginal impact** (two projects with blue highlights). Another group of design errors between structure and electrical works (D) actually could contribute to some difficulties and problems during construction practices and the result was explored that these design errors could influence **substantially** to the performance of some projects. However, they did not occur in several sampling projects (three projects with yellow highlights). Last but not least, the impact score of design errors between structure and plumbing works (E) shows that 45% of eleven projects (five projects with orange highlights) experienced the **substantial impact** from these design errors, other three, two, and one projects were suffered **marginally**, **severely**, and **negligibly**, respectively.

Figure 4.4 illustrates the explanation of impact score of design errors based on the number of projects that used to experience the problems of the five groups of design errors between structure and other building components.

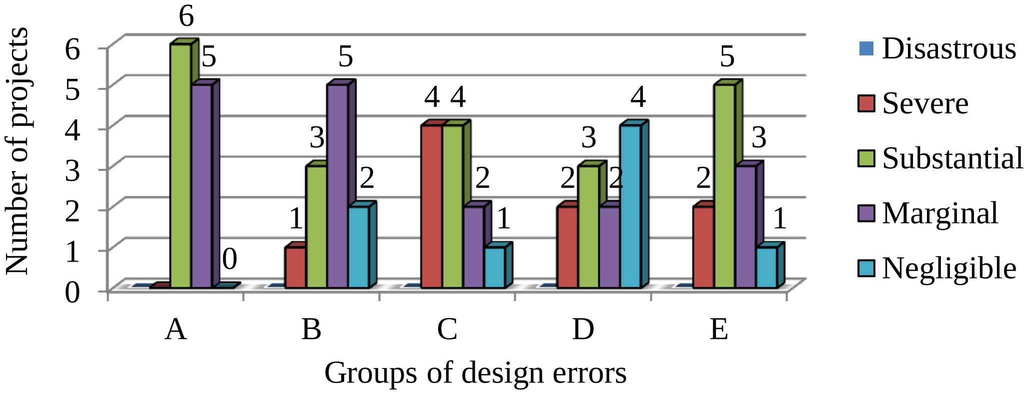

Figure 4.4 Explanation of impact of design errors

In conclusion, the results in Table 4.8 imply that design errors between structure and other building components mostly affect the construction practices substantially. Most building construction projects used to have problems resulting from design errors which influenced the project performance in substantial level. Furthermore, design errors between structure and mechanical works (C) are the first priority to be considered because they can lead to severe and substantial impact on construction practices. Next, design errors between structure and plumbing works (E) are also important because the severe and substantial impacts are resulted from these design errors. The third priority is design errors between structure and architecture (A). These errors can cause most substantial and some marginal influences. Anyhow, design errors between structure and structure (B) should be also considered even though they can only incur most marginal impacts. Finally, design errors between structure and electrical works (D) are the last priority which can be negligible. Nevertheless, these errors can lead to severe or substantial causes from time to time depending on the design quality and design processes of the projects.

4.2.3 Combination of Percentage Occurrence and Impact of Groups of Design Errors in Each Project

Discussing about only the percentage occurrence of groups of design errors or only its impact score actually is not really consistent for identifying the most critical groups of design errors. The combination between the percentage occurrence and impact score is necessary to determine the cut-off scores for prioritization. Then the critical groups of design errors in any projects are identified in order to see which groups of design errors should be ranked as the first priority and subsequently. In conformance with risk analysis technique, the priority zones can be divided based on the plotted scatters with two dimensional coordinates (***x***, ***y***) where x represents the percentage occurrence and y refers to the impact score. In order to classify the priority zones, the cut-off points for both axes have to be determined. In this research, nine zones are identified according to the actual data. For each axe, two cut-off points are required and two different boundary lines are needed for assigning nine different zones. In this case, three intervals for each coordinate are calculated.

By using the method of curving grades mathematically, the cut-off points for the percentage occurrence of groups of design errors (axe *x*) are determined. This curving mathematical method is called “bell curve”. Bell curve is resulted from the range of grades consisting of a few high values, most mid-range scores and a few low scores (WikiHow). In this particular case, it is unfair to grade the scores based on its range.

By using a bell curve grading method, the mean value of score is set as a middle range, which means the highest scores should be the first priority and the lowest scores should be unimportant. According to Richeson (2008), the mean plus a standard deviation would give higher range and both tails would give the highest and lowest ranges. For all five groups of design errors, the maximum percentage occurrence among all projects is P_{B5} = 53.57% and the minimum value is 0.00%. The maximum impact score among all samplings is I_{ij} = 4.00 and the minimum score is I_{B5} = 1.17, whereas *N/A* means that design errors do not occur in the projects.

Table 4.10 Combination of percentage occurrence and impact of groups of design errors in each project

Groups of Design Errors (i) / Projects (j)	structure & architecture (Group A)		structure & structure (Group B)		structure & mechanical works (Group C)		structure & electrical works (Group D)		structure & plumbing works (Group E)	
	P_{ij} (%)	I_{ij}	P_{ij} (%)	I_{ij}	P_{ij} (%)	I_{ij}	P_{ij} (%)	I_{ij}	P_{ij} (%)	I_{ij}
Project 1	29.34	3.20	39.26	2.73	10.74	3.46	5.79	3.80	14.88	2.96
Project 2	39.32	3.00	34.19	2.64	2.56	4.00	3.42	2.00	20.51	2.75
Project 3	48.65	1.90	21.62	2.53	15.54	4.00	***0.00***	***N/A***	14.19	4.00
Project 4	37.60	2.09	32.00	2.00	11.20	2.80	***0.00***	***N/A***	19.20	2.50
Project 5	25.45	2.11	***53.57***	1.17	1.79	4.00	0.45	3.00	18.75	1.67
Project 6	45.37	2.08	22.22	2.14	10.19	3.00	3.70	2.00	18.52	3.00
Project 7	25.00	1.81	46.25	2.16	6.88	1.83	6.25	1.67	15.63	2.00
Project 8	45.45	3.11	41.56	3.00	***0.00***	***N/A***	***0.00***	***N/A***	12.99	3.75
Project 9	40.50	2.77	17.36	1.55	15.70	3.00	9.92	3.00	16.53	3.25
Project 10	33.90	2.71	33.56	2.55	8.90	2.20	6.16	2.67	17.47	2.16
Project 11	28.23	3.31	40.19	3.57	9.57	3.25	11.48	3.50	10.53	3.10

P_{ij} refers to percentage occurrence of each group of design errors;
I_{ij} refers to impact score of each group of design errors.

Computing via Microsoft excel, the mean value of percentage occurrence for all five groups of design errors is 20.00%, where its standard deviation is 14.96%. In accordance with the bell curve grading method, the first cut-off point of axe *x* is

20.00% and the second cut-off point of axe x is the mean plus a standard deviation which equals 34.96% (Table 4.11).

For axe y, the cut-off points for the impact of each group of design errors can be obtained from the evaluation scores in data collection. Those scores were given from the minimum score of 1 to the maximum score of 5, which mean negligible till disastrous impact. Since three intervals are required, the cumulative cut-off point is equal to the maximum score divided by three as shown below:

$$Cumulative\ cutoff\ point\ of\ axe\ y = \frac{5}{3} = 1.67$$

As mentioned earlier, two boundary lines and two cut-off points are needed. Based on the cumulative cut-off point of axe y, the first cut-off point of axe y is 1.67, where the second cut-off point of axe y equals 3.33.

After all cut-off points for both coordinates (x, y) are calculated, the boundary lines of nine priority zones is drawn; and the combination result is computed (Figure 4.5). All cut-off points for both coordinates (x, y) are shown in Table 4.11.

Table 4.11 Cut-off points for coordinates (x, y) of groups of design errors

Cut-off point	Percentage occurrence	Impact
First cut-off point	20.00%	1.67
Second cut-off point	34.96%	3.33

By observing the groups of design errors in each project in the nine zones shown in Figure 4.5, design errors between structure and architecture (group A) are located in zone II, IV, and V. And most design errors between structure and architecture (group A) are found in zone IV and V. Remarkably, design errors between structure and mechanical works (group C), design errors between structure and electrical works (group D), and design errors between structure and plumbing works (group E) are in zone III and VI.

Therefore, this result expresses that design errors between structure and architecture (group A) and design errors between structure and structure (group B) have both medium and high impact with medium and high occurrence. On the other hand, design errors of group C, D, and E mostly have medium impact and low occurrence. However, design errors of these three groups in some projects also have high impact, but their occurrence is still low. In order to see more details, next part of the chapter explains the analysis of combination between percentage occurrence and impact of each case of design errors under each group.

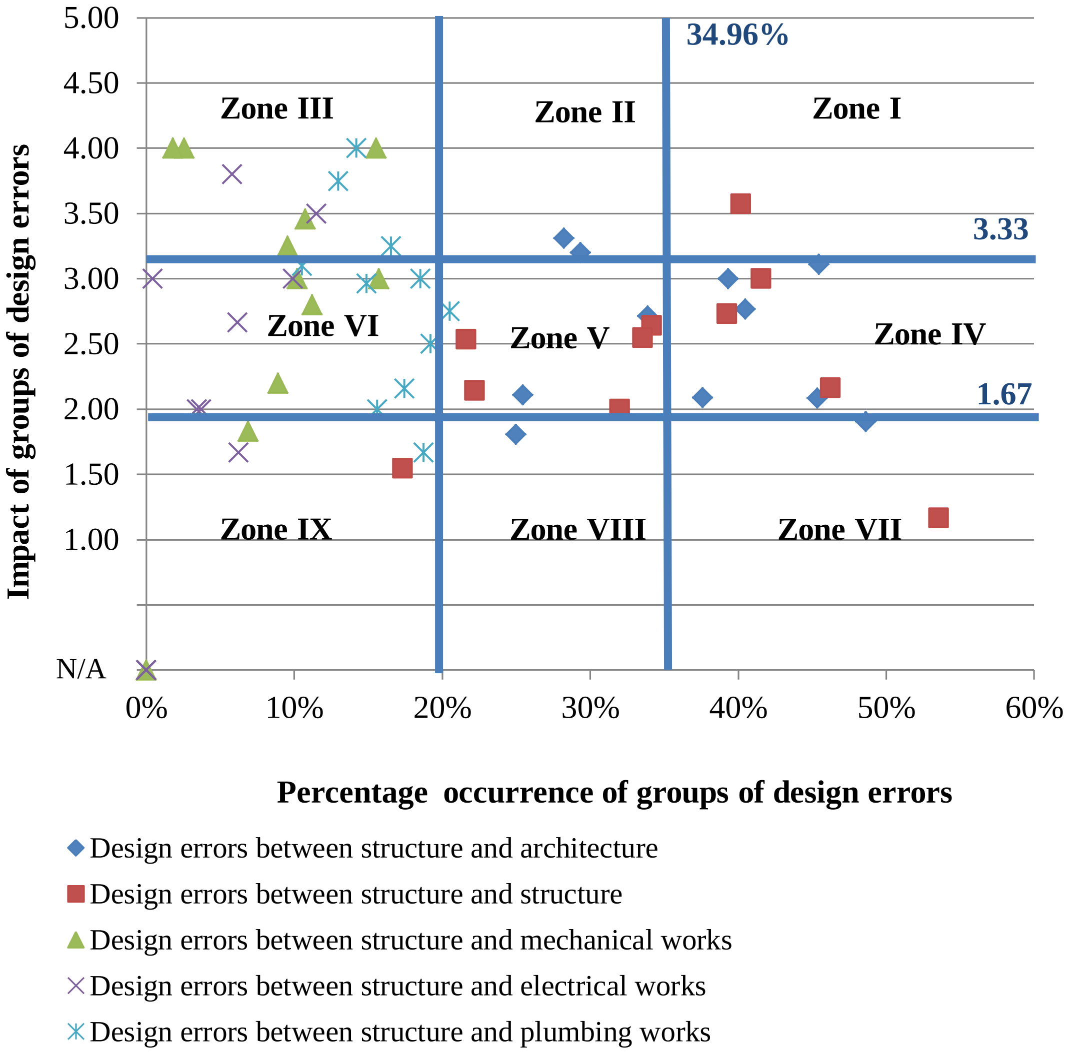

Figure 4.5 Priority zones of groups of design errors in each project

4.2.4 Combination of Percentage Occurrence and Impact of Cases of Design Errors for All Sampling Projects

Even though the combination of percentage occurrence and impact of groups of design errors in each project is already done, the combination between percentage occurrence and impact of each case under those groups is still required to find the important cases of design errors by studying on the prioritized zones. In order to rank all cases of design errors, the average percentage occurrence and the average impact score of each case of design errors are calculated.

This average value of percentage occurrence of each case of design errors is equal to the summation of the percentage occurrence of each case of design errors for all studied projects divided by the number of studied projects, and then multiplied with 100%. This equation is as below:

$$P = 100 \, \frac{\sum \left(C_j / \sum N_j \right)}{n} \ (\%) \qquad (3)$$

Where:

P	is the average percentage occurrence of each case of design errors;
j	refers to each building project (j = 1, 2, 3, …, 11);
C_j	is the number of each case of design errors occurring in project j;
$\sum N_j$	is the total number of all cases of design errors occurring in project j;
n = 11	is the number of all building construction projects of which the information was collected.

For the average impact score of each case of design errors, it equals the mean value of the impact score of only the occurred cases among all samplings. The equation below is applied:

$$I = \frac{1}{NI} \sum_{y=1}^{NI} I_y \qquad (4)$$

Where:

I	is the average impact score of each case of design errors;
NI	is the total number of the projects in which each case of design errors occur (maximum NI is 11);
I_y	is the value of impact score of each occurred case in project j.

Applying the equation (3) and (4), the average percentage occurrence and the average impact score of each case of design errors among all sampling projects are determined. These results are shown in Appendix B. To combine the average percentage occurrence with the impact score of each case, it needs to identify the different intervals and boundary lines so as to see the different priority zones of this combination. Thus, the bell curve grading method is used to explore the cut-off points for the average percentage occurrence of each case of design errors (axe *x*). However, the negligible cases are not included in data analysis of this study. Actually, some cases of design errors are negligible since they are impossible to occur. Those are design errors between retaining wall and ceiling works, design errors between retaining wall and sanitary ware, design errors between footing and ceiling works, design errors between stair and footing, design errors between stair and retaining wall, and so on. Regardless of 32 invalid cases, it remains only 122 possible cases of design errors that are possible to occur (Table 4.6). With the valid 122 cases, the mean value and its standard deviation are computed.

Mean value of percentage occurrence of 122 possible cases = 0.82%
Standard deviation of percentage occurrence of 122 possible cases = 0.86%

Therefore, the first cut-off point of axe *x* equals the mean value 0.82%, whereas its second cut-off point is the mean value plus its standard deviation which equals 1.68%.

Besides, the cut-off points of axe *y* remains the same because the impact scores are still ranked from 1 to 5 correspondingly. Table 4.12 tells all cut-off points for both coordinates (*x*, *y*) of cases of design errors.

Table 4.12 Cut-off points for coordinates (*x*, *y*) of possible cases of design errors

Cut-off point	Percentage occurrence	Impact
First cut-off point	0.82%	1.67
Second cut-off point	1.68%	3.33

With the cut-off points for coordinates (*x*, *y*), the priority zones are classified into three levels which are low, medium, and high. Thus, the values of cut-off points differentiate these three levels. Table 4.13 and Figure 4.6 present all nine priority zones that are separated by three levels and the cut-off points of both average percentage occurrence (axe *x*) and average impact score (axe *y*).

Table 4.13 Priority zones of possible cases of design errors

Zones	Percentage Occurrence (*x*)	Impact (*y*)
Zone I	P >= 1.68% (high)	I >= 3.33 (high)
Zone II	0.82% <= P < 1.68% (medium)	I >= 3.33 (high)
Zone III	P <= 0.82% (low)	I >= 3.33 (high)
Zone IV	P >= 1.68% (high)	1.67 <= I < 3.33 (medium)
Zone V	0.82% <= P < 1.68% (medium)	1.67 <= I < 3.33 (medium)
Zone VI	P <= 0.82% (low)	1.67 <= I < 3.33 (medium)
Zone VII	P >= 1.68% (high)	I < 1.67 (low)
Zone VIII	0.82% <= P < 1.68% (medium)	I < 1.67 (low)
Zone IX	P <= 0.82% (low)	I < 1.67 (low)

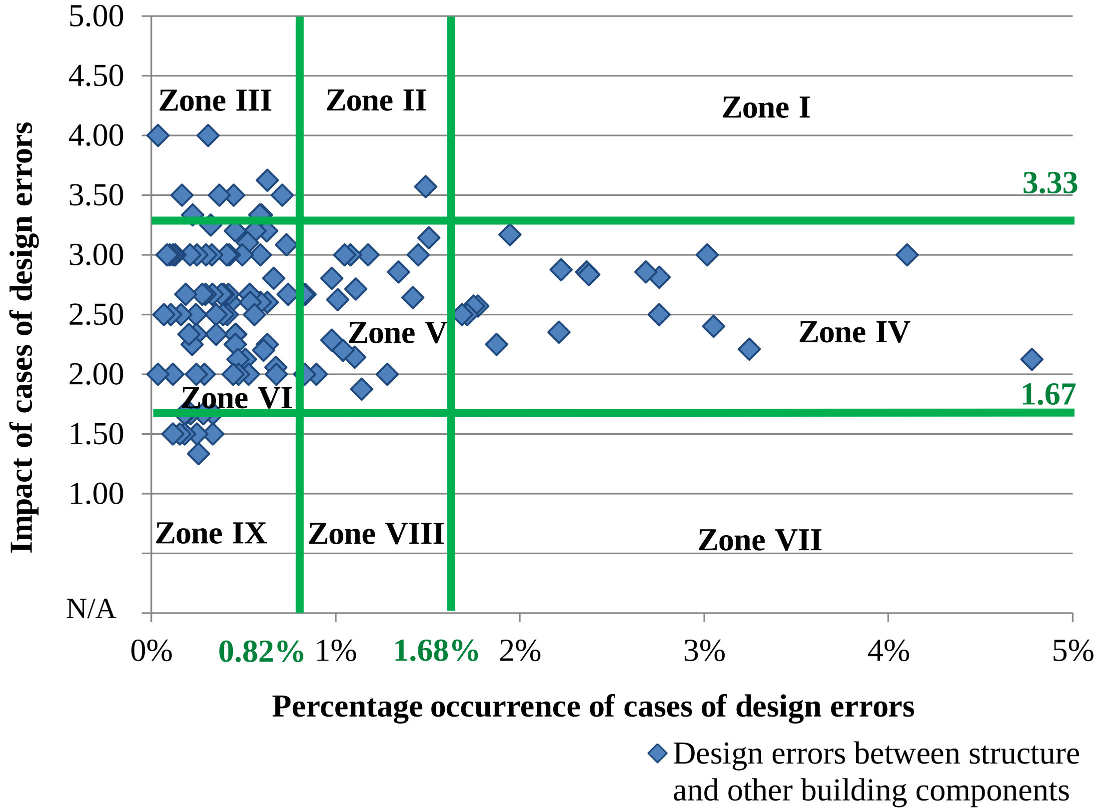

Figure 4.6 Priority zones of possible cases of design errors

4.3 Low Important Cases of Design Errors

Based on Figure 4.6, zone IX is the low priority zone because this zone has both low percentage occurrence and low impact score. There are only six cases under this zone. Among these low important cases, two cases are in group A such as RC wall and sanitary ware (A42) and retaining wall and staircase finish (A4). Another three cases are in group E such as column and sanitary drainage and disposal system (E17), column and water supply and distribution system (E16), and beam and fuel and gas piping system (E15). One more case is footing and RC wall (B14) which is in group B. These six cases rarely occur in all sampling projects and their impact score is less than 1.80 which is very low comparing to the impact score of other possible cases. Due to the classification of impact score in Table 4.9, it shows that the six cases under this zone IX are negligible and its occurrence does not require design revision, time, or cost for solving. Although they are less important and negligible, these cases should be also considered during design. It will be great if designers or structural engineers can avoid the occurrence of these design errors as much as possible.

4.4 Medium Important Cases of Design Errors

Considering about the medium important cases of design errors, all cases in zone VI and zone VIII with low/medium percentage occurrence or low/medium impact (Figure 4.6) are focused. Zone VIII actually does not consist of any cases of design errors. Thus there are totally 68 medium important cases of design errors under zone VI. However, these 68 cases are not prioritized and selected for the next step of this study because only the high important cases are of much concern.

Within all of these medium important cases, the specific cases under each group of design errors are also listed in Table 4.14. It is noticed that 11 cases are in group A which is about 35.48% (11/31 possible cases) among all 31 possible cases under this group. 27 cases are in group B which is around 62.79% (27/43 possible cases) among all 43 possible cases under this group B. 7 cases are in group C which is approximately 58.33% (7/12 possible cases) among all 12 possible cases under this group C. another 9 cases are in group D which is about 90% (9/10 possible cases) among all 10 possible cases under this group D. Last, 14 cases are in group E which is around 53.84% (14/26 possible cases) among all 26 possible cases under this group E. Due to these results, it is remarked that the medium priority zones consist of more cases than the high priority zones. This expresses that engineers should also check and pay attention on the 68 medium important cases of design errors even though these cases are not prioritized as the most critical cases in this study.

Table 4.14 68 medium important cases in each group of design errors

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group A - Design errors between structure and architecture						
1	A23	Column and door/window	0.57%	3.20	0.0181	1
2	A2	Retaining wall and floor finish	0.54%	2.67	0.0143	2
3	A32	Stair and floor finish	0.68%	2.00	0.0136	3
4	A22	Column and staircase finish	0.46%	2.33	0.0108	4
5	A18	Beam and sanitary ware	0.53%	2.00	0.0106	5
6	A40	RC wall and staircase finish	0.38%	2.67	0.0102	6
7	A16	Beam and staircase finish	0.47%	2.13	0.0100	7
8	A39	RC wall and ceiling works	0.24%	2.50	0.0061	8
9	A35	Stair and door/window	0.24%	2.00	0.0049	9
10	A5	Retaining wall and door/window	0.13%	3.00	0.0039	10
11	A8	Footing and floor finish	0.12%	3.00	0.0035	11
Group B - Design errors between structure and structure						
12	B39	Stair and column	0.63%	3.20	0.0201	1
13	B26	Column and slab	0.67%	2.80	0.0186	2
14	B31	Slab and beam	0.59%	3.00	0.0178	3
15	B19	Beam and slab	0.63%	2.60	0.0164	4
16	B49	RC wall and RC wall	0.59%	2.60	0.0154	5
17	B34	Slab and stair	0.46%	3.20	0.0146	6
18	B21	Beam and RC wall	0.56%	2.50	0.0140	7
19	B32	Slab and column	0.54%	2.60	0.0140	8
20	B15	Beam and retaining wall	0.68%	2.06	0.0139	9
21	B8	Footing and retaining wall	0.61%	2.20	0.0135	10

Table 4.14 68 medium important cases in each group of design errors (continued)

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group B - Design errors between structure and structure						
22	B20	Beam and stair	0.41%	3.00	0.0124	11
23	B41	Stair and stair	0.39%	2.67	0.0105	12
24	B46	RC wall and column	0.41%	2.50	0.0103	13
25	B28	Column and RC wall	0.46%	2.25	0.0103	14
26	B4	Retaining wall and column	0.46%	2.25	0.0103	15
27	B7	Retaining wall and RC wall	0.39%	2.50	0.0098	16
28	B22	Column and retaining wall	0.47%	2.00	0.0095	17
29	B47	RC wall and slab	0.44%	2.00	0.0089	18
30	B45	RC wall and beam	0.33%	2.67	0.0089	19
31	B29	Slab and retaining wall	0.35%	2.50	0.0088	20
32	B42	Stair and RC wall	0.29%	2.00	0.0058	21
33	B12	Footing and slab	0.34%	1.67	0.0056	22
34	B35	Slab and RC wall	0.22%	2.25	0.0050	23
35	B5	Retaining wall and slab	0.21%	2.33	0.0048	24
36	B27	Column and stair	0.28%	1.67	0.0047	25
37	B44	RC wall and footing	0.21%	1.67	0.0036	26
38	B30	Slab and footing	0.11%	2.50	0.0027	27
Group C - Design errors between structure and mechanical works						
39	C8	Column and lift systems	0.41%	3.00	0.0123	1
40	C1	Retaining wall and HVAC systems	0.43%	2.60	0.0112	2
41	C13	RC wall and HVAC systems	0.42%	2.67	0.0112	3
42	C10	Slab and lift systems	0.35%	2.33	0.0082	4
43	C7	Column and HVAC systems	0.19%	2.67	0.0050	5
44	C3	Footing and HVAC systems	0.09%	3.00	0.0026	6
45	C2	Retaining wall and lift systems	0.07%	2.50	0.0017	7

Table 4.14 68 medium important cases in each group of design errors (continued)

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group D - Design errors between structure and electrical works						
46	D9	Slab and electrical system	0.73%	3.08	0.0226	1
47	D5	Beam and electrical system	0.51%	2.13	0.0109	2
48	D13	RC wall and electrical system	0.32%	3.25	0.0106	3
49	D7	Column and electrical system	0.33%	3.00	0.0099	4
50	D14	RC wall and telephone/datacom system	0.25%	3.00	0.0075	5
51	D1	Retaining wall and electrical system	0.28%	2.67	0.0074	6
52	D11	Stair and electrical system	0.16%	2.50	0.0040	7
53	D12	Stair and telephone/datacom system	0.13%	3.00	0.0039	8
54	D8	Column and telephone/datacom system	0.12%	2.00	0.0024	9
Group E - Design errors between structure and plumbing works						
55	E8	Footing and storm drainage system	0.74%	2.67	0.0198	1
56	E2	Retaining wall and sanitary drainage and disposal system	0.52%	3.10	0.0163	2
57	E14	Beam and fire protection system	0.49%	3.00	0.0148	3
58	E24	Slab and fire protection system	0.63%	2.25	0.0142	4
59	E32	RC wall and sanitary drainage and disposal system	0.42%	3.00	0.0127	5
60	E13	Beam and storm drainage system	0.46%	2.33	0.0106	6
61	E5	Retaining wall and fuel and gas piping system	0.30%	3.00	0.0089	7
62	E35	RC wall and fuel and gas piping system	0.29%	2.67	0.0078	8
63	E34	RC wall and fire protection system	0.21%	3.00	0.0063	9
64	E11	Beam and water supply and distribution system	0.24%	2.33	0.0057	10

Table 4.14 68 medium important cases in each group of design errors (continued)

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group E - Design errors between structure and plumbing works						
65	E27	Stair and sanitary drainage and disposal system	0.19%	1.67	0.0031	11
66	E3	Retaining wall and storm drainage system	0.10%	3.00	0.0031	12
67	E18	Column and storm drainage system	0.18%	1.67	0.0030	13
68	E4	Retaining wall and fire protection system	0.04%	2.00	0.0008	14

4.5 High Important Cases of Design Errors

According to the results of nine priority zones as illustrated in Figure 4.6, the zones with high/medium percentage occurrence or high/medium impact are prioritized and selected for further step of this study. Based on this prioritized method, zone I, II, III, IV, V, and VII are the critical zones and all cases under these zones are considered as the high important cases of design errors. Zone I and zone VII does not consist of any cases of design errors. So, it is found that there are totally 48 critical cases of design errors under zone II, III, IV, and V. All critical cases of design errors under each zone are listed in Appendix C. Relying on the results in this Appendix C, zone II consists of only one case which is design errors between RC wall and lift systems. This case is important even though its occurrence is only 1.49% lower than the occurrence of the other cases because its impact is already high (3.57). In zone III, 10 cases of design errors are explored. Another 18 cases are in zone IV. All cases in zone III and IV are design errors between structure and architecture, structure and structure, structure and mechanical works, and structure and plumbing works. Remarkably, only one case of design errors between structure and electrical works is found in zone V. This case is design errors between slab and telephone/datacom system.

Among all 48 high important cases of design errors, the specific cases under each group of design errors are noticeably found. Based on Table 4.15, 18 cases are prioritized under group A of design errors between structure and architecture. The top five cases in this group are design errors between slab and floor finish, column and wall finish, RC wall and wall finish, beam and ceiling works, and beam and wall finish. For the case of slab and floor finish, the structural slab level at the bathroom should be dropped off lower than the structural slab level at normal areas. When designers do not pay much attention on the dropped level and slope requirement, this slab level is not dropped. In this case, the water cannot flow easily to the drain. For normal areas, designer should also consider about the floor finish thickness to make sure that there is reserved thickness for the tiling finish without affecting the slab level in architecture. Related to the case of column and wall finish, the structural column is found in the middle of masonry wall and the corners of this column are projected outside the wall. The architect does not prefer this design since it can affect the decoration of the wall. Moreover, the starter bars to connect the column with the masonry wall should be put in order to avoid from the fissures at the joint. The case of RC wall and wall finish also influences the architectural design of the RC wall finishing. The structural RC wall thickness should be less than what is required in architecture because the thickness presented in architectural plan already includes the finishing works. Regarding the case of beam and ceiling works, designers do not consider about the ceiling height and the space for installing MEP systems under the soffit of beam. It is found that the soffit of beam is lower than the ceiling level and the MEP systems could not be installed. The architect then has to re-design the ceiling finish. For the fifth ranking case in this group A of design errors between structure and architecture, beam and wall finish is concerned. At current floor, the position of structural beam at the top of the masonry wall is very important in the design. The problem is that the alignment of structural beam is found incorrect and located in different central alignment with the masonry wall from the lower floor to current floor when it should be the same based on architecture. This different alignment changes the height of the masonry wall from 3m to 3.40m (because the depth of beam is 400mm). Architect does not satisfy with this change since it affects the ceiling design. In summary, it is noticed that the occurrence of the problems caused by design errors of group A (structure and architecture) are mostly associated with the wall finish (masonry wall, tiling works, plastering works,…). Floor finish and ceiling works should be also checked with the other structural elements in order to avoid from the problems during construction activities.

For group B, 15 cases of design errors are important. Design errors between column and beam are the first important case in this group, followed by design errors between beam and beam, beam and column, column and column, and footing and beam. In this research, design errors between column and beam have different meaning from design errors between beam and column due to the problem of particular structural element. Design errors between column and beam refer to the problems of column which are affected by the conditions of beam. Contrastingly, design errors between beam and column are the problems of beam which are associated with the conditions of column. For this study, it is found that the case of column and beam is mostly associated with the problem of the column from lower floor to current floor with the beam at current floor. The size of the column is small which cannot support the beam with bigger size at upper floor. So the column is then cracked and repaired since its strength is not sufficient. For the case of beam and beam, the face bars (middle bars) are very necessary for strengthening the stirrups and to prevent from torsion. If designers forget to put this bars in the middle of beam when it is required, the beam can be cracked due to the torsion force. Therefore, designer must carefully check the requirement of this face bars to assure that the stirrups can resist with this force. In addition, the beam reinforcement at the joint of two beams can obstruct the flow of the concrete and aggregates if this reinforcement is very complicated. The concrete cover might be lost as well. This means that designers not only have to design a strong structure, but they also have to consider about the buildability of their design. Another case of beam and column is related to the problem of the complicated reinforcement at the joint of the beam at current floor with the column from current floor to upper floor (column above the beam). Critically, it is another problem of cantilever beam which has longer span than the allowable span. So, the design of the column under this beam cannot resist with the loads imposed on it. This beam is then deflected. Besides, the case of column and column can be the problems of starter bars to connect one column to another column.

If the starter bars are not sufficiently designed, the strength of column at current floor cannot carry the loads imposed on it by the column to upper floor. In this case, the size of column at current floor should be carefully checked to assure that it is bigger than the size of column to upper floor. Last, the fifth ranking case in this group is design errors between footing and beam. An example of this error is about the incorrect level of the footing and ground beam that designers put in the design drawing. The depth of ground beam has conflict with the footing section because designers do not pay much attention on the required top level of ground beam. For this problem, designers just note the bottom level of footing with -1.50m, whereas the top level of beam is not given. Actually, the required top level of ground beam is +0.05m. Between these two levels, only 1.55m left for installing footing of 1,100m, stump column of 500mm, and ground beam of 500mm. Consequently, this remaining space is not adequate. In short, the cases of design errors in group B are the problems of beam and column with the other building components. Importantly, the details of main reinforcement and starter bars are really concerned and shall be inspected to avoid from the problems caused by any design errors by designers.

In group C of design errors between structure and mechanical works, 5 cases are also prioritized. Those cases are design errors between beam and HVAC systems, RC wall and lift systems, slab and HVAC systems, beam and lift systems, and footing and lift systems. The problems between structural elements and HVAC systems or lift systems are often about the reserved openings for installing these systems. The problem of beam and HVAC systems is the route of sleeve and exhaust pipe. This route is found across the beam section along the span of beam, which is not allowed because beam can be deflected and cracked due to insufficient strength. Moreover, if this route is across the beam section in transversal direction, the effective cover of beam might be reduced when the diameter of the sleeve for HVAC systems is too big to penetrate into the beam. Next, the case of RC wall and lift systems is related to the reserved opening for the lift box and the reserved opening for the lift button (up and down button). These openings sometimes are not sufficient because designers design the structure without considering about the required size of the lift box or lift button. Similarly, for slab and HVAC systems, the reserved opening should be checked in order to avoid drilling the slab after the slab is constructed. Another case is the problems of beam and Lift systems. The position of beam has to be carefully considered because the incorrect position of beam can reduce the required size of the opening. The fifth ranking case is the problems of footing and lift systems. Lift pit under the lift box is found having conflict with the lift systems. The top level of lift pit is higher than the level of ground floor. When the lift box reaches the ground floor, the level for people to stand in the lift box is higher than the level of ground floor. Actually, these levels should be equal based on architecture requirement. To sum up, most design errors between structural elements and mechanical works are relevant to the levels and the reserved openings for installing the mechanical systems.

Uniquely, only one case of design errors between slab and telephone/datacom system under group D is prioritized as the critical case. The problem of this case is about the route of the wires of telephone/datacom system. Mostly designers do not provide any details of the sleeve penetration at the slab for running the tube wiring of this system. Consequently, it requires to drill a hole on the slab to run this wire from one floor to the other floor. After drilling, the fissures appear on the slab around the corners of the hole.

Lastly, design errors between structure and plumbing works (group E) consist of 9 important cases. The top five cases in this group are design errors between slab and sanitary drainage and disposal system, slab and water supply and distribution system, slab and storm drainage system, beam and sanitary drainage and disposal system, and footing and sanitary drainage and disposal system. For the top first, second, and third cases, the problems of design errors are about the reserved openings for running the pipes. Designer often reserves the opening at slab in the wrong position or sometimes with the wrong required size. Then the slab is drilled to enlarge the opening or sometimes is extended to fill the opening at the wrong position. Regarding the case of beam and sanitary drainage and disposal system, designer has to pay much attention with the design of ground beam where the sewage pipes mostly run. When designers do not carefully check the route of sewage pipes, the level of the route for these pipes is across the beam section along the span of beam (in longitudinal direction). This is not allowed because beam can be deflected and cracked. The fifth ranking case in this group is the problems of footing and sanitary drainage and disposal system. It is similar that the sewage pipes are rarely allowed to run under the footing. Thus, designer should be carefully checked during the design of footing. When the level of public sanitary sewer system is lower than the level of footing, the route of sewage pipes requires the slope for draining the waste water. Even though the route of sewage pipes is easily modified, it does not mean that this route can be flexible all the time. Because of the complicated structure of footing, stump column, ground beam, and especially the slope requirement, the route of sewage pipes can be changed. Consequently, the water might be leaked if the sewage pipe runs under the footing since the pipe can be damaged due to the loads imposed on it. In brief, all of these problems are some examples of design errors between structural elements and the piping system of plumbing works.

In conclusion, design errors between structure and architecture (group A) are the most concern since 18 cases are prioritized as the high important and critical cases. It is followed by design errors between structure and structure (group B) of which 15 cases are found important. The third concern is design errors between structure and plumbing works (group E) which consists of 9 prioritized cases. The fourth is design errors between structure and mechanical works (group C) with 5 important cases. The last is design error between structure and electrical works (group D) with only one important case.

Table 4.15 48 high important cases in each group of design errors

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group A – Design errors between structure and architecture						
1	A26	Slab and floor finish	4.10%	3.00	0.1231	1
2	A19	Column and wall finish	4.78%	2.13	0.1016	2
3	A37	RC wall and wall finish	2.68%	2.86	0.0767	3
4	A15	Beam and ceiling works	3.05%	2.40	0.0733	4
5	A13	Beam and wall finish	3.25%	2.21	0.0717	5
6	A30	Slab and sanitary ware	1.95%	3.17	0.0617	6
7	A17	Beam and door/window	1.75%	2.57	0.0450	7

Table 4.15 48 high important cases in each group of design errors (continued)

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group A – Design errors between structure and architecture						
8	A34	Stair and staircase finish	1.42%	2.64	0.0375	8
9	A41	RC wall and door/window	1.18%	3.00	0.0353	9
10	A31	Stair and wall finish	1.05%	3.00	0.0315	10
11	A1	Retaining wall and wall finish	1.01%	2.63	0.0265	11
12	A33	Stair and ceiling works	1.28%	2.00	0.0256	12
13	A14	Beam and floor finish	1.04%	2.20	0.0229	13
14	A25	Slab and wall finish	0.59%	3.33	0.0197	14
15	A27	Slab and ceiling works	0.90%	2.00	0.0179	15
16	A28	Slab and staircase finish	0.83%	2.00	0.0166	16
17	A24	Column and sanitary ware	0.31%	4.00	0.0124	17
18	A29	Slab and door/window	0.22%	3.33	0.0075	18
Group B – Design errors between structure and structure						
19	B24	Column and beam	2.76%	2.81	0.0775	1
20	B17	Beam and beam	2.76%	2.50	0.0689	2
21	B18	Beam and column	2.22%	2.88	0.0639	3
22	B25	Column and column	2.21%	2.35	0.0520	4
23	B10	Footing and beam	1.77%	2.57	0.0456	5
24	B11	Footing and column	1.72%	2.50	0.0429	6
25	B16	Beam and footing	1.69%	2.50	0.0422	7
26	B9	Footing and footing	1.08%	3.00	0.0325	8
27	B1	Retaining wall and retaining wall	1.11%	2.71	0.0302	9
28	B2	Retaining wall and footing	0.71%	3.50	0.0249	10
29	B3	Retaining wall and beam	1.10%	2.14	0.0237	11
30	B38	Stair and beam	0.63%	3.63	0.0229	12
31	B40	Stair and slab	0.98%	2.29	0.0224	13
32	B23	Column and footing	0.82%	2.67	0.0220	14
33	B33	Slab and slab	1.14%	1.88	0.0214	15

Table 4.15 48 high important cases in each group of design errors (continued)

No.	Code	Design errors between structure and other building components	Percentage occurrence	Impact	R=PxI	Ranking
Group C – Design errors between structure and mechanical works						
34	C5	Beam and HVAC systems	2.36%	2.86	0.0675	1
35	C14	RC wall and lift systems	1.49%	3.57	0.0532	2
36	C9	Slab and HVAC systems	1.51%	3.14	0.0474	3
37	C6	Beam and lift systems	0.98%	2.80	0.0274	4
38	C4	Footing and lift systems	0.17%	3.50	0.0059	5
Group D – Design errors between structure and electrical works						
39	D10	Slab and telephone/datacom system	1.45%	3.00	0.0435	1
Group E – Design errors between structure and plumbing works						
40	E22	Slab and sanitary drainage and disposal system	3.02%	3.00	0.0905	1
41	E21	Slab and water supply and distribution system	2.38%	2.83	0.0673	2
42	E23	Slab and storm drainage system	1.88%	2.25	0.0422	3
43	E12	Beam and sanitary drainage and disposal system	1.34%	2.86	0.0384	4
44	E7	Footing and sanitary drainage and disposal system	0.84%	2.67	0.0223	5
45	E33	RC wall and storm drainage system	0.60%	3.33	0.0200	6
46	E31	RC wall and water supply and distribution system	0.45%	3.50	0.0157	7
47	E9	Footing and fire protection system	0.37%	3.50	0.0130	8
48	E6	Footing and water supply and distribution system	0.04%	4.00	0.0015	9

4.6 Discussion

Based on the findings above, it is noticed that the value of percentage occurrence for each case of design errors is very low comparing to 100%. With this low percentage occurrence, the R value (percentage occurrence multiplied by impact score) is also low. Because the value of percentage occurrence is calculated from the number of each occurred case divided by the total number of all occurred cases in a sampling project, it is quite sure that the value obtained are not high when the total number is far greater than the number of each case. For example, case A1 has only 3 cases whereas the total cases in project 1 are 242 cases. Thus, it is consistent that the value of this proportion must be low.

In this event, engineers or designers cannot judge each case of design errors based on this low value. They can judge if each case is critical according to the priority zones as illustrated in Table 4.13 and Figure 4.6. Moreover, the cases under a group of design errors cannot compare with the cases under other groups of design errors. The R value is used only for the benefits of ranking the cases under a specific group. Therefore, the results show the various most concerned cases under group A, B, C, D, and E.

4.7 Conclusion

This chapter is to identify the critical cases of design errors from the experience of contractors in eleven different building construction projects which were already finished and complete. First, the percentage occurrence of design errors was determined from the number of design errors by using percentage formulas. Second, the impact score of those design errors were obtained via five-point Likert scale. Finally, the percentage occurrence and impact of design errors were combined so that the figures were plotted. After that, nine priority zones were explored and the cases of design errors were ranked by their R value in a specific group of design errors.

The results reveal that design errors between structure and architecture of group A are the most concerned problems among other five groups, which is followed by design errors between structure and structure of group B, structure and plumbing works of group E, structure and mechanical works of group C, and structure and electrical works of group D. The 48 important cases of design errors under all five groups were prioritized as the critical cases which were selected from the high priority zones: zone I, II, III, IV, V, and VII.

The overall findings of design errors' cases and their rankings within each group of design errors provide very beneficial information for both designers and contractors to improve their design and their construction practices. They can understand what cases of design errors should be more concerned in order to mitigate the problems caused by design errors in their building construction projects. The problem is that how those engineers reduce the occurrence of these prioritized cases and how they can know the possible problems which can occur by a specific case of design errors. That is why, it is necessary to develop a tool of knowledge-based by identifying the attributes and conditions of each critical case of design errors which can contribute to the possible problems. Therefore, the critical cases of design errors of this research are selected for further development of decision trees of knowledge-based models for checking design errors in building construction projects in Cambodia.

CHAPTER V

DEVELOPMENT OF KNOWLEDGE-BASED MODELS FOR CHECKING DESIGN ERRORS

This chapter explains the process to develop the knowledge-based models for checking design errors. The models are formulated based on the 48 important cases of design errors which were identified in chapter 4. The examples of these cases were obtained from the respondents via interview. Then the analysis of these collected examples was conducted by using cross-case analysis and by learning about their problems. All attributes and conditions of each case were then determined. The results and the development of the models in the form of decision trees were described in this chapter.

5.1 Description of Data Collection

This is the data collection of part 2 for this research. Since this part is qualitative, interview technique was performed with the 48 prioritized cases of design errors identified in chapter 4. Those cases are categorized into seven groups which are design errors between retaining wall and other components, footing and other components, beam and other components, column and other components, slab and other components, stair and other components, and reinforced concrete wall and other components. The sample of this questionnaire is also attached in Appendix D.

Due to the 48 important design errors, the target respondents were requested to tell the problems caused by each case of design errors they have experienced at construction sites of building construction projects in Cambodia. Those respondents are the engineers of contractors who have currently been working at building construction site in Cambodia. Some of them were selected among the respondents of the first survey in part 1 in order to ensure their understandings about this research and also to improve the consistency of their responses. Other new respondents needed much time for detailed explanation about the purpose of the interview and scope of study. However, all of them shared different examples of design error’s cases which are elaborated in the next sections of this chapter.

5.2 Framework of Knowledge-Based Models

In chapter 4, 48 cases under all five groups of design errors were prioritized as the significant cases of design errors. All these cases are used as the framework of knowledge-based models to ask the respondents for the problems they used to meet in the real-life construction works. All these cases are classified into seven various categories due to the studied structural elements such as retaining wall, footing, beam, column, slab, stair, and reinforced concrete wall (RC wall). The purpose of this categorization is to arrange all explored cases into a manner so that it can facilitate the respondents in quick understanding about the needs of the questionnaire. Importantly, these categories are for the benefits to develop the decision tree of the knowledge-based models. Table 5.1 summarizes all cases of design errors in each category.

Table 5.1 Important cases of design errors

Categories	**Cases of design errors**
Category 1	*Design errors between retaining wall and other components*
1.1	Retaining wall and beam
1.2	Retaining wall and footing
1.3	Retaining wall and retaining wall
1.4	Retaining wall and wall finish
Category 2	*Design errors between footing and other components*
2.1	Footing and beam
2.2	Footing and column
2.3	Footing and fire protection system
2.4	Footing and footing
2.5	Footing and water supply and distribution system
2.6	Footing and lift systems
2.7	Footing and sanitary drainage and disposal system
Category 3	*Design errors between beam and other components*
3.1	Beam and beam
3.2	Beam and ceiling works
3.3	Beam and column
3.4	Beam and door/window

Table 5.1 Important Cases of design errors (continued)

Categories	**Cases of design errors**
Category 3	*Design errors between beam and other components*
3.5	Beam and floor finish
3.6	Beam and footing
3.7	Beam and HVAC systems
3.8	Beam and lift systems
3.9	Beam and sanitary drainage and disposal system
3.10	Beam and wall finish
Category 4	*Design errors between column and other components*
4.1	Column and beam
4.2	Column and column
4.3	Column and footing
4.4	Column and sanitary ware
4.5	Column and wall finish
Category 5	*Design errors between slab and other components*
5.1	Slab and ceiling works
5.2	Slab and door/window
5.3	Slab and floor finish
5.4	Slab and HVAC systems
5.5	Slab and sanitary drainage and disposal system
5.6	Slab and sanitary ware
5.7	Slab and slab
5.8	Slab and staircase finish
5.9	Slab and storm drainage system
5.10	Slab and telephone/datacom system
5.11	Slab and wall finish
5.12	Slab and water supply and distribution system
Category 6	*Design errors between stair and other components*
6.1	Stair and beam
6.2	Stair and ceiling works
6.3	Stair and slab

Table 5.1 Important Cases of design errors (continued)

Categories	**Cases of design errors**
Category 6	*Design errors between stair and other components*
6.4	Stair and staircase finish
6.5	Stair and wall finish
Category 7	*Design errors between reinforced concrete wall and other components*
7.1	Reinforced concrete wall and door/window
7.2	Reinforced concrete wall and lift systems
7.3	Reinforced concrete wall and storm drainage system
7.4	Reinforced concrete wall and wall finish
7.5	Reinforced concrete wall and water supply and distribution system

5.3 Knowledge-Based Model Development

To develop the knowledge-based models, three main steps are required. The first process is to collect the examples of each case of design errors (data collection of part 2). In second step, the differences and similarities of each case are explored by applying the cross-case analysis method. Last but not least, the decision trees of knowledge-based models are established.

In the first step, the interview for data collection in part 2 is based on the framework of knowledge-based models as listed in Table 5.1. This interview has collected a list of the examples of all 48 critical cases of design errors. Appendix E summarizes those examples under different categories of design errors. In the table of this appendix, the abbreviation of Ex 1, Ex 2, or Ex 3 represent Example 1, Example 2, or Example 3 under a specific category of design errors. It is also noted as Ex 1 [2, 3] which means this is the first example which is described by second and third respondent.

For the second step, the differences and similarities of cases of design errors are then studied in order to identify the main attributes (contributing factors) of each case. In this study, cross-case analysis is performed by looking into the commonalities and any relevant differences in all examples of each case (McWhorter et al., 2013). In appendix E, the examples of each case of design errors are discussed to explore the main contributing factors and conditions that can cause the problems during construction activities. Those factors and conditions are also highlighted in bold letters as shown in Appendix E. Applying the cross-checked technique of cross-case analysis, the main attributes of each case of design errors are found.

Last, the decision trees of knowledge-based models are formulated according to the main highlighted attributes as found in Appendix E. These attributes or contributing factors are used as the inputs of the system.

These three steps are described in details by focusing on each case of design errors under each category in the following sections.

5.3.1 Category 1: Design Errors between Retaining Wall and Other Components

- **Examples of cases of design errors**

Category 1 consists of four cases of design errors such as design errors between retaining wall and beam, retaining wall and footing, retaining wall and retaining wall, and retaining wall and wall finish. In category 1 of Appendix E, the problems from the examples of retaining wall and beam were resulted from the required starter bars, location of retaining wall, and the applied loads during design process. These causations leaded to the cracking and fissures at the joint of retaining wall and beam. Other three examples talked about the problems of retaining wall and footing. It was found that the fissures appeared at the joint and the level of retaining wall affected the depth of footing. This problem was severe because it required deeper excavation. Design errors between retaining wall and retaining wall mostly were the lack of water stop details and rebar details (water stop at construction joint, starter bars, rebar specification…) that designer forgot to put in the design drawing. The problem of retaining wall and wall finish occurred when the water was leaked and the alignment of masonry wall did not match with the alignment of retaining wall. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

As mentioned earlier, the attributes of each case are cross-checked by studying on the problems explained by the respondents as shown in Appendix E. In Table below, example 1 (Ex1) in 1.1 is not the same as example 1 (Ex1) in 1.2 because those examples are under different cases of design errors. For instance, three attributes of retaining wall and beam are ticked "✓" which means that these attributes are the main contributing factors of this case. The width of beam, retaining wall thickness, and the required starter bars to connect beam with retaining wall are the key attributes that can cause the retaining wall become cracked (Appendix E – Category 1). Table 5.2 lists the attributes (contributing factors) of four cases under design errors between retaining wall and other components.

Table 5.2 Cross-case analysis – Category 1

Category 1: Design errors between retaining wall and other components					
Code	Cases of design errors	Cross-checked			
1.1	Retaining wall and beam [Attributes]	Ex1	Ex2	Ex3	Ex4
	Width of beam	✓			
	Retaining wall thickness	✓			
	Required starter bars to connect beam with retaining wall	✓			
	Location of retaining wall with architecture		✓		
	Beam strength			✓	✓
	Soil pressure on retaining wall			✓	
	Loads of retaining wall				✓
1.2	Retaining wall and footing [Attributes]	Ex1	Ex2	Ex3	
	Required starter bars to connect footing with retaining wall	✓			
	Soil pressure on retaining wall		✓		
	Footing strength		✓		
	Required retaining wall height (required underground floor height)			✓	
	Required upper floor level			✓	
	Bottom level of retaining wall (underground floor level)			✓	

Table 5.2 Cross-case analysis – Category 1 (continued)

Category 1: Design errors between retaining wall and other components				
Code	Cases of design errors	Cross-checked		
1.3	Retaining wall and retaining wall [Attributes]	Ex1	Ex2	
	Water stop details in specification	✓		
	Rebar details (rebar bending) in specification		✓	
1.4	Retaining wall and wall finish [Attributes]	Ex1	Ex2	Ex3
	Retaining wall thickness	✓	✓	✓
	Required thickness of the masonry wall at the upper level			✓
	Plastering thickness for each side of the masonry wall			✓
	Bottom level of retaining wall		✓	
	Ground water level		✓	
	Water pipes	✓		

- **Decision tree development**

According to the cross-checked table above and the conditions of each problem, the attributes of each case are then developed as the inputs of the decision trees of knowledge-based models. The outputs of the decision trees answer the question if the conditions of all inputs can lead to any problems of design errors.

For retaining wall and beam (case 1.1), its decision tree is shown in Appendix F on page 221. Based on that figure, the inputs are required starter bars to connect beam with retaining wall, beam's width, retaining wall thickness, beam strength to carry the loads of retaining wall and soil pressure, and the location of retaining wall with architectural plan. Due to Table 5.2 – case 1.1, six attributes are ticked. Beam strength, soil pressure, and loads of retaining wall are combined into only one input. This is because beam strength has to carry the loads of retaining wall as well as the soil pressure (Ex 3 and Ex 4 – Category 1 of Appendix E). The attribute of "required starter bars to connect beam with retaining wall" also consists of other four related inputs which are based on the study on Ex 1 of case 1.1. The conditions of the inputs are extracted from the understandings of each example. Thus, the problems can be checked based on those conditions.

The decision tree of retaining wall and footing (case 1.2) is illustrated in Appendix F on page 222. In that figure, five attributes are explored such as required retaining wall height, required upper floor level, bottom level of retaining wall, required starter bars to connect footing with retaining wall, and the strength of footing. Similarly, Table 5.2 – case 1.2 shows six attributes; though, footing strength and soil pressure are combined into only one input since the footing has to carry the loads that are imposed on it.

The decision tree of retaining wall and retaining wall (case 1.3) is figured in Appendix F on page 223. In this decision tree, two attributes such as water stop details and rebar details are used as the inputs of the model. For this case, two attributes are ticked due to Table 5.2 – case 1.3.

The last case under this category is retaining wall and wall finish (case 1.4) of which the decision tree is developed in Appendix F on page 224. That figure lists all six ticked attributes as the inputs of the model. Based on Ex 1 of case 1.4 in Appendix E, the existence of the pipes running through the retaining wall is the cause of problems. So, the choices of this input should be whether the pipes exist or not. For Ex 2, the level of ground water affects the level of retaining wall. Its condition thus is to compare its level. Last is the thickness of the retaining wall and masonry wall. To make sure they are in the same alignment, the condition of these inputs should be an inequation, for instance, Hm + 2Hp < > = H. Hm refers to retaining wall thickness, Hp is plastering thickness for each side of masonry wall, and H represents the required thickness of masonry wall at the upper level above the retaining wall.

5.3.2 Category 2: Design Errors between Footing and Other Components

- **Examples of cases of design errors**

Category 2 consists of seven cases of design errors such as design errors between footing and beam, footing and column, footing and fire protection system, footing and footing, footing and water supply and distribution system, footing and lift systems, and footing and sanitary drainage and disposal system. In category 2 of Appendix E, the case of footing and beam consisted of three examples which were related to the depth of footing, depth of beam, stump column, the level of structure, and also the existing building nearby. The problems were about the incorrect level, overlapped structure, and the influence of the structure to the neighboring environment. For footing and column, two examples were found. The first problem was the difficulty of installing the starter bars to connect the footing with the column. Second problem was the mistake of designer to put the position of footing too close to the boundary line of the existing building. Another case of footing and fire protection system also had some issues related to the route of the pipe of fire protection system and footing reinforcement. The pipe was not allowed to run across the footing section because it would have conflict with the footing reinforcement and reduce the strength of footing. If it ran under the footing, another problem arose since the pipe may be easily broken by the loads from footing. Regarding design errors between footing and footing, the distribution bars were the most critical factor which could lead to many problems. Too much reinforcement could reduce concrete cover and the strength of the concrete. Similarly to the case of footing and fire protection system, the case of footing and water supply and distribution system focused on the route of the pipe at the sub-structure of the building. For footing and lift systems, lift pit was concerned. The reactor of traction lift may not be able to work properly when its required height was not fulfilled. The level of lift pit, footing, or bottom floor contributed to this failure if they were not carefully checked. The last case of this category is design error between footing and sanitary drainage and disposal system. The pipe route of waste water sometimes is found under, above, or across the footing section before starting the construction. If it was above the footing, no problem arose; however, when it ran under or across the footing section, different problems occurred. It may have conflict with the footing reinforcement or it may be easily broken when it was under the footing. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

For design errors between footing and other components, the analysis of the differences and similarities of each case has found some remarkable attributes. Those attributes are the contributing factors which can lead to the problems between footing and other components. Table 5.3 lists the attributes (contributing factors) of seven cases under design errors between footing and other components.

Table 5.3 Cross-case analysis – Category 2

Category 2: Design errors between footing and other components				
Code	Cases of design errors	Cross-checked		
2.1	Footing and beam [Attributes]	Ex1	Ex2	Ex3
	Depth of footing	✓		
	Depth of beam	✓	✓	
	Height of stump column	✓		
	Required top level of footing/pile cap (=Required bottom level of footing/pile cap + Depth of footing)		✓	
	Required bottom level of footing/pile cap	✓		
	Required top level of beam	✓	✓	
	Total height from the top level of beam to the bottom level of footing	✓		
	Stump column	✓	✓	
	Space between top level of footing/pile cap and bottom level of beam		✓	
	Existing building			✓
	Location of footing/pile cap			✓
2.2	Footing and column [Attributes]	Ex1	Ex2	
	Size of footing	✓		
	Size of stump column	✓		
	Required safety space between stump column and footing	✓		
	Position of footing		✓	
	Existing building		✓	
2.3	Footing and fire protection system [Attributes]	Ex1	Ex2	
	Pipe of fire protection system	✓	✓	
	Pipe above the footing	✓	✓	
	Pipe under the footing	✓		
	Pipe across the footing section		✓	

Table 5.3 Cross-case analysis – Category 2 (continued)

Category 2: Design errors between footing and other components				
Code	Cases of design errors	Cross-checked		
2.4	Footing and footing [Attributes]	Ex1	Ex2	Ex3
	Position of footing	✓		
	Size of footing		✓	
	Required distribution bars for footing (longitudinal and transversal reinforcement)		✓	
	Spacing between distribution bars for footing		✓	
	Diameter of distribution bars for footing		✓	
	Number of distribution bars for footing		✓	
	Concrete cover for footing		✓	
	Space between two footings			✓
2.5	Footing and water supply and distribution system [Attributes]	Ex1	Ex2	
	Pipe of water supply and distribution system	✓	✓	
	Pipe above the footing	✓	✓	
	Pipe under the footing	✓		
	Pipe across the footing section		✓	
2.6	Footing and lift systems [Attributes]	Ex1	Ex2	Ex3
	Lift pit at the bottom floor (ground/underground floor)	✓	✓	✓
	Top level of footing/pile cap	✓		✓
	Depth of lift pit	✓	✓	
	Types of Lift	✓	✓	
	Level of lift pit			✓
	Required height of the reactor of lift systems	✓	✓	
	The level of bottom floor (ground/underground floor)		✓	
2.7	Footing and sanitary drainage and disposal system [Attributes]	Ex1	Ex2	Ex3
	Pipe/sleeve of sanitary drainage and disposal system	✓	✓	✓
	Position of pipe/sleeve nearby the footing	✓		
	Pipe/sleeve across the footing section	✓		✓
	Pipe/sleeve above the footing	✓	✓	✓
	Pipe/sleeve under the footing		✓	

Decision tree development

The first case of footing and beam (case 2.1) has its decision tree as shown in Appendix F on page 225-226. Based on the examples, two decision trees are found since the presence of stump column between footing and beam also affects the output. The depth and level of footing and beam are the main inputs for this case. With the incorrect level and depth, footing might have conflict with beam. The position of footing/pile cap is very important. If footing is located too close to the existing building, it might not be allowed.

The decision tree of footing and column (case 2.2) is figured in Appendix F on page 227. For this decision tree, five attributes are cross-checked and used as the inputs to check for the problem. Those are the size of footing and column (stump column), the safety space (cover) between footing and column, the position of footing, and the existing building. The conditions of this problem are to compare the size of footing with the size of column in order to make sure that there is safety space (cover) between footing and column. Moreover, the position of footing is needed to check if it can affect the nearby existing building.

The decision tree of footing and fire protection system (case 2.3) is illustrated in Appendix F on page 228. This figure includes three main inputs such as the pipe of fire protection system, footing reinforcement, and the position of pipe above the footing, across the footing, or under the footing. Actually, this case is very rare since the route of pipe is flexible and can be modified to avoid having conflict with the footing. However, the route of this pipe sometimes cannot be modified due to a specific requirement. To check the possibility of the problems caused by this design error, these three inputs can guide the practitioners based on the input conditions.

The fourth case is footing and footing (case 2.4) of which the decision tree is explained in Appendix F on page 229. According to that figure, the main inputs are the position of footing, size of footing, required distribution bars for footing (longitudinal and transversal reinforcement), concrete cover, spacing between footings, and diameter, spacing, and number of reinforcement. The conditions of this case are to check the space for installing all distribution bars in the footing and to compare the footing position in structure with the requirement in architecture.

The next case between footing and water supply and distribution system (case 2.5) is also similar to the case between footing and fire protection system. Its decision tree is in Appendix F on page 230. It is quite critical to put the position of pipe of water supply and distribution system nearby the footing. Different problems might occur if the pipe is placed above, across, or under the footing. Nevertheless, this case is very rare to occur in building construction projects.

The decision tree of footing and lift systems (case 2.6) is shown in Appendix F on page 231. The inputs of this decision tree consist of type of lift, level of footing, level of bottom floor and lift pit, and the required height of the reactor of traction lift systems. Since the electric lift does not have reactor system to push the lift box from the bottom floor to upper floor, there is no any problem occur. For traction lift, the depth of lift pit might have conflict with the reactor system if designer does not correctly design the level of footing and bottom floor.

Lastly, the decision tree of footing and sanitary drainage and disposal system (case 2.7) is figured in Appendix F on page 232. Similarly to case 2.3 and 2.5, the position of pipe above, across, or under the footing can lead to various problems. The width of beam, level of pipe route, level of footing, and the space from the pipe to the edge of footing (when the pipe across the footing section) have to be checked for the problem of this case.

5.3.3 Category 3: Design Errors between Beam and Other Components

- **Examples of cases of design errors**

Category 3 consists of ten cases of design errors such as design errors between beam and beam, beam and ceiling works, beam and column, beam and door/window, beam and floor finish, beam and footing, beam and HVAC systems, beam and lift systems, beam and sanitary drainage and disposal system, and beam and wall finish. In category 3 of Appendix E, four examples of the case between beam and beam were listed. In example 1, the face bars (middle bars) in beam was required to strengthen the stirrup to prevent from the torsion. Designers did not put the face bars; the beam was then cracked due to the torsion of beam. Example 2 focused on the complicated beam reinforcement in both beams. Another example explains about the wrong calculation of beams which had a long span and could not carry the loads. For the last example, designer forgot to give the information about how to install the main bars in the bottom layer of the first and second beam. Thus, it was found that the reinforcement of beam could not be placed properly and it had conflict with the depth of beam. For the case of beam and ceiling works (case 3.2), the depth of beam and ceiling level were the main contributors. The space from the soffit of beam to the ceiling level was not enough for MEP installation. Next case is design errors between beam and column (case 3.3). Since it is in group A of design errors between structure and structure, the problems were mostly relevant to the main reinforcement of beam. The complexity of beam reinforcement at the support was of much concern because it was impossible to install those rebar effectively. If beam was cantilever, the span of beam should be also considered to assure that this span was allowable by the design standard. The fourth case of this category is beam and door/window. The reserve opening for door/window was found not sufficient for installing the required size of door/window. This was because the depth of beam was too deep and projected into the reserved opening. Moreover, the cracks sometimes appeared at the top corners of the door/window because of the absence of lintel above the door/window. The fifth case is beam and floor finish (case 3.5). The floor finish level was not consistent with the floor finish as required in architecture. For this case, the thickness of floor finish was very important to be studied before designers decided the level of beam under the gutter. Other case between beam and footing (case 3.6) also had three examples. The problem in the first example was about the starter bars to connect beam with the footing which was forgotten to be placed in the footing before pouring the concrete. Second and third issues were about the cantilever ground beam. The unclear soil compaction due to the infiltration of underground water could make the cantilever beam subsided. The span of cantilever beam was also critical if it was not allowed by the design standard. For beam and HVAC systems (case 3.7), the route of pipe for HVAC systems sometimes had to run across the beam section. Since the depth of beam was not high enough and the diameter of pipe was too big, it was not allowed to run this pipe because the effective cover of beam (1.5 of pipe diameter) might be not sufficient. Then the strength of beam was not strong enough to carry the loads imposed on it and the beam might be cracked. Another case of beam and lift systems (case 3.8) also presented two examples. In the first example, the lift railing system had no any beams to fix it with the wall because the beam was in the wrong position which cannot be connected. Second problem focused on the reserved opening which was smaller than the required size of lift box. Regarding the case of beam and sanitary drainage and disposal system (case 3.9), it was found that the route of pipe was across the beam section, which could make beam deflected and cracked. Especially, it was not allowed to run the pipe across the beam section in the middle span of beam. The last case is design errors between beam and wall finish (case 3.10). The alignment of beam and masonry wall should be carefully compared to assure that the wall had beam to support it. Besides, lack of moment inertia of beam could increase the beam deflection. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

In order to obtain the attributes of each case, the examples of design errors between beam and other components were studied as shown in Appendix E. Those examples provide some main factors that can cause the problems. These main factors are the attributes of the cases and they are also highlighted in Appendix E. All attributes of ten cases under design errors between beam and other components are analyzed and cross-checked in Table 5.4.

Table 5.4 Cross-case analysis – Category 3

Category 3: Design errors between beam and other components					
Code	Cases of design errors	Cross-checked			
3.1	Beam and beam [Attributes]	Ex1	Ex2	Ex3	Ex4
	Face bar (middle bar) in the beam	✓			
	Required face bar (middle bar) in design standard	✓			
	Depth of first beam	✓			✓
	Depth of second beam	✓			✓
	Main beam	✓			✓

Table 5.4 Cross-case analysis – Category 3 (continued)

Category 3: Design errors between beam and other components					
Code	Cases of design errors	Cross-checked			
3.1	Beam and beam [Attributes]	Ex1	Ex2	Ex3	Ex4
	Secondary beam	✓			✓
	Beam reinforcement at the connection between two beams (at the support)		✓		
	Beam strength			✓	
	Loads imposed on beams			✓	
3.2	Beam and ceiling works [Attributes]	Ex1	Ex2	Ex3	
	Reinforced concrete slab (RC slab)		✓		
	Precast concrete slab (PC slab)	✓			
	Beam's depth	✓	✓	✓	
	Required ceiling height from the bottom of slab	✓	✓	✓	
	Required space for MEP systems	✓		✓	
3.3	Beam and column [Attributes]	Ex1	Ex2	Ex3	Ex4
	Beam reinforcement at the connection between beam and column (at the support)	✓			
	Column from current floor to lower floor	✓	✓		
	Column from current floor to upper floor	✓			
	Beam with two supports	✓			
	Cantilever beam		✓	✓	✓
	Span of cantilever beam		✓	✓	✓
	Allowable span of cantilever beam in design standard		✓		✓
3.4	Beam and door/window [Attributes]	Ex1	Ex2	Ex3	Ex4
	Reinforced concrete slab (RC slab)				✓
	Precast concrete slab (PC slab)		✓		
	Beam's depth	✓	✓		✓
	Required door/window height	✓	✓		✓
	Required floor height				✓
	Lintel			✓	

Table 5.4 Cross-case analysis – Category 3 (continued)

	Category 3: Design errors between beam and other components			
Code	Cases of design errors	Cross-checked		
3.5	Beam and floor finish [Attributes]	Ex1		
	Gutter for carrying off the water	✓		
	Floor finish level at the gutter	✓		
	Floor finish level at nearby areas	✓		
	Top level of beam for gutter	✓		
	Thickness of floor finish	✓		
3.6	Beam and footing [Attributes]	Ex1	Ex2	Ex3
	Required starter bars to connect beam with footing	✓		
	Cantilever ground beam		✓	✓
	Span of cantilever beam from footing		✓	✓
	Soil compaction details		✓	
	Soil settlement		✓	
	Allowable span of cantilever ground beam in design standard			✓
3.7	Beam and HVAC systems [Attributes]	Ex1	Ex2	Ex3
	Route of the sleeve of HVAC systems across the beam	✓	✓	✓
	Longitudinal direction	✓		
	Transversal direction		✓	
	Beam's depth	✓	✓	✓
	Reinforced Concrete slab thickness		✓	
	Precast Concrete slab			✓
	Diameter of the sleeve of HVAC systems		✓	✓
	Allowable effective cover of beam from the edge of sleeve to the edge of beam		✓	✓
3.8	Beam and lift systems [Attributes]	Ex1	Ex2	
	Position of beams for fixing lift railing systems with the structure	✓		
	Position of beams at the opening of lift		✓	
	Opening size for lift		✓	
	Required size of the opening for lift		✓	

Table 5.4 Cross-case analysis – Category 3 (continued)

Category 3: Design errors between beam and other components					
Code	Cases of design errors	Cross-checked			
3.9	Beam and sanitary drainage and disposal system [Attributes]	Ex1	Ex2	Ex3	
	Route of the pipe of sanitary drainage and disposal system across the beam	✓	✓	✓	
	Longitudinal direction	✓			
	Transversal direction		✓	✓	
	Horizontal route		✓		
	Vertical route		✓		
	Beam's depth	✓	✓		
	Pipe diameter		✓		
	Reinforced Concrete slab		✓		
	Precast Concrete slab		✓		
	Allowable effective cover of beam from the edge of pipe opening to the soffit of beam		✓		
	Position of opening for sewage pipe in the middle span of beam			✓	
3.10	Beam and wall finish [Attributes]	Ex1	Ex2	Ex3	Ex4
	Alignment of beam and wall finish	✓	✓	✓	
	Beam at the side of wall finish			✓	
	Beam in the same alignment of wall finish	✓	✓		
	Beam in different alignment of wall finish	✓	✓		
	Beam at upper floor			✓	
	Beam supports the wall finish	✓	✓		✓
	Beam's depth			✓	
	Height of wall			✓	
	Required height of wall			✓	
	Moment inertia of beam				✓

- **Decision tree development**

The decision tree of the first case between beam and beam (case 3.1) is presented in Appendix F on page 233. The inputs of this decision tree are the depth of beams, the middle bars (face bars) in the beam, main reinforcement of beam, and beam strength. Two types of beam such as main beam and secondary beam also have different conditions because main beam actually has to carry the secondary beam. Therefore, the conditions of this decision tree focus on the required face bars when the depth of beam is high. The complexity of beam reinforcement is another condition which can lead to the conflict between rebar and the loss of concrete cover.

The decision tree of beam and ceiling works (case 3.2) is shown in Appendix F on page 234. Types of slab (Reinforced concrete slab or precast concrete slab), slab thickness, depth of beam, ceiling height, and space for MEP installation are the inputs for this case. One of the conditions is whether the space between the soffit of the beam and the ceiling level is sufficient for installing the MEP systems. The ceiling might not be satisfied if the soffit of beam appears below the ceiling finish level. According to these conditions, the inequations of this decision tree are developed and used to check for the possibility of occurrence of this error.

Next, the decision tree of beam and column (case 3.3) is illustrated in Appendix F on page 235. Type of beam is the main input. If the beam is cantilever, the related inputs are beam reinforcement, span of cantilever beam, and its allowable span in design standard. Its condition is to compare the span of cantilever beam and its allowable span. If the beam has two supports, the complexity of beam reinforcement shall be checked.

For beam and door/window (case 3.4), its decision tree is formulated in Appendix F on page 236. Similarly, types of slab, depth of beam, door/window height, the required floor height, and the existence of lintel are the inputs of this case. Based on the study on the examples of this case, the conditions are related to the reserved height of the opening for door/window. The space from the soffit of beam to the top level of opening is the key condition to check for any conflict or error.

The decision tree of beam and floor finish (case 3.5) is figured in Appendix F on page 237. The existence of gutter on beam, floor finish level for gutter, floor finish level at nearby areas, top level of beam, and floor finish thickness are the main inputs of this decision tree. In order to check for the problem of this case, these inputs are the necessary information. Due to the examples in Appendix E, the top finishing level of beam should be lower than the floor finish level in other areas since the gutter on beam needs slope to carry off the water.

The decision tree of beam and footing (case 3.6) is presented in Appendix F on page 238. This case might lead to the problems when beam is cantilever. The inputs of this case are the span of cantilever beam and its allowable span in design standard, soil compaction details, and the required starter bars to connect beam with footing. The condition of this case is to compare the span of cantilever beam with its allowable span and the soil compaction and required starter bars should be examined.

Another case is beam and HVAC systems (case 3.7). Its decision tree is shown in Appendix F on page 239. The route of sleeve of HVAC systems is the main input. This route can run across the beam in longitudinal or transversal direction. In the condition that the sleeve does not run across the beam, no problems arise between beam and HVAC systems. If it runs across the beam in longitudinal direction, it is not allowed since beam strength can be reduced. In the event that the sleeve of HVAC systems run across the beam transversally, RC slab thickness, depth of beam, sleeve diameter, effective cover of beam from the edge of sleeve to the edge of beam, and its allowable effective cover are the related input information which can be used to check if the problems between beam and HVAC systems can occur.

The decision tree of beam and lift systems (case 3.8) is figured in Appendix F on page 240. The width and length of opening for lift are the inputs which have to be compared with the required size of lift box. If the reserved opening size is different from the required size of lift box, the owner or architect may not satisfy and the lift box cannot be installed properly. The position of beams at the opening for lift is also necessary to be inspected to make sure that the location of the reserved opening is correctly placed with the right size.

For beam and sanitary drainage and disposal system (case 3.9), its decision tree is presented in Appendix F on page 241. The inputs of this case are type of slab, pipe route, pipe route and pipe direction across the beam, position of opening for sewage pipe at the middle span of beam, depth of beam, pipe diameter, slab thickness, and allowable effective cover of beam from the edge of pipe to the soffit of beam. The conditions of this decision tree are based on the route of the pipe. Due to the examples of this case in Appendix E (case 3.9), it is not allowed to run the sewage pipes across the beam vertically or in longitudinal direction. Although the sewage pipe is allowed to run across the beam in transversal direction, the effective cover of beam section have to be checked if it is sufficient.

The decision tree of the last case between beam and wall finish (case 3.10) is illustrated in Appendix F on page 242. For this case, beam has two functions which are beam to support the wall finish (masonry wall…) and beam at upper floor. The conditions for these functions of beam are different. When beam is the support of the wall finish (masonry wall…), the alignment and the moment inertia of beam have to be investigated. If beam functions as the beam at upper floor of the wall finish, depth of beam, wall height, and required wall height are the main inputs for checking the problems between beam at upper floor and the wall finish at current floor. The alignment of beam and wall finish is also necessary to be examined.

5.3.4 Category 4: Design Errors between Column and Other Components

- **Examples of cases of design errors**

Category 4 consists of five cases of design errors such as design errors between column and beam, column and column, column and footing, column and sanitary ware, and column and wall finish. In category 4 of Appendix E, four examples of the case between column and beam were explored. At the support, the complexity of column reinforcement had conflict with the beam reinforcement which could reduce the required concrete cover. Another problem was the lack of column strength to carry the loads from the upper floors. This was because the size of column from current floor to lower floor was found so small by comparing with the width of beam at current floor. Thus, the flexural bending occurred and the column was swayed. In case that the beam was cantilever, the problem was related to the incorrect design of column which was the support of that beam. The column could not carry the eccentric loads imposed by the cantilever beam. Regarding the case of column and column, the size and alignment of the column at current floor and at upper floor were concerned. Most problems were found that the size of column at current floor was smaller than the size of column at upper floor. In this condition, the column at current floor could not sufficiently carry the loads imposed by the column at upper floor; moreover, the column at current floor might be swayed and cracked. For column and footing, the footing had to be resized because of the incorrect load combination. The column was firstly wrongly designed. Later, designer revised the stump column; however, the footing was not studied again. It was noticed that more loads were transferred to the footing which could result in cracking. Another problem was the lap length of starter bars to connect footing with stump column. This lap length was found longer than the required lap length. This could make the starter bars having conflicts with the main bars in the footing. For column and sanitary ware, the problems were resulted from the size of column which was not the same as in architecture. The bigger size of column could affect the installation of lavatory faucet and its position. Sometimes, the route of faucet pipe was not reserved; thus, the faucet pipe could not link with the public sanitary sewer system. The last case is design errors between column and wall finish. Due to design omission, the starter bars to connect the column with the masonry wall were not included when it should have been. The alignment of column sometimes was found not satisfied and affected the architectural design. The size of column was another important factor that designer should carefully manage because the architectural design in the room might be influenced when the size of column was bigger than the thickness of masonry wall. The column might be projected outside the wall and this could create conflict with the wall design in architecture. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

Based on the explanation of every example of all cases of design errors between column and other building components, the main contributing factors were explored. The differences and similarities of each example were analyzed by ticking the related attributes in each example. Table 5.5 lists all attributes (contributing factors) of five cases under design errors between column and other components.

Table 5.5 Cross-case analysis – Category 4

Category 4: Design errors between column and other components					
Code	Cases of design errors	Cross-checked			
4.1	Column and beam [Attributes]	Ex1	Ex2	Ex3	Ex4
	Column reinforcement at the connection between column and beam (at the support)	✓			
	Width of column from current floor to lower floor		✓	✓	
	Loads imposed on column				✓
	Strength of column		✓	✓	✓
	Beam's width		✓	✓	
	Beam with two supports	✓	✓	✓	
	Cantilever beam				✓
	Span of cantilever beam				✓
	Allowable span of cantilever beam in design standard				✓
4.2	Column and column [Attributes]	Ex1	Ex2	Ex3	
	Central alignment of column at current floor	✓	✓		
	Central alignment of column at upper floor	✓	✓		
	Rectangular column			✓	
	Circular column			✓	
	Size of column at current floor			✓	
	Size of column at upper floor			✓	
	Loads imposed on column at current floor			✓	
	Strength of column at current floor			✓	
	Starter bars for the column at upper floor			✓	
4.3	Column and footing [Attributes]	Ex1	Ex2	Ex3	
	Design of stump column	✓			
	Loads transferred to footing	✓			
	Strength of footing	✓			
	Lap length of starter bars for stump column		✓	✓	
	Allowable lap length of starter bars in design standard		✓		

Table 5.5 Cross-case analysis – Category 4 (continued)

Category 4: Design errors between column and other components				
Code	Cases of design errors	Cross-checked		
4.4	Column and sanitary ware [Attributes]	Ex1	Ex2	Ex3
	Size of column in architecture	✓		
	Size of column in structure	✓		
	Position of sanitary ware (lavatory faucet)	✓		
	Reserved space for fixing the sanitary ware (faucet) with the column		✓	
	Reserved opening for running the pipe of sanitary ware (faucet pipe) to the main sanitary drainage and disposal system			✓
4.5	Column and wall finish [Attributes]	Ex1	Ex2	Ex3
	Starter bars to connect the column with the masonry wall	✓		
	Alignment of column		✓	
	Alignment of masonry wall		✓	
	Size of column in structure			✓
	Required size of column in architecture			✓
	Masonry wall thickness			✓

- **Decision tree development**

The first decision tree under the category of column and other building components presents the case between column and beam (case 4.1 – Appendix F on page 243-244). For this case, beam has two functions which are cantilever beam and normal beam with two supports. When beam is cantilever, the inputs are column reinforcement, column strength, column’s width, cantilever beam’s width, span of cantilever beam, and its allowable span. These inputs contribute to the occurrence of problems between column and cantilever beam. The condition of this case is to compare the span of cantilever beam with its allowable span to make sure that the column strength is strong enough to carry the eccentric loads imposed by the cantilever beam. Moreover, the width of column has to compare with the width of beam to clearly assure that the column can support the beam. The complexity of column reinforcement at the support has to be checked as well. When the beam has two supports, the conditions and inputs are quite similar, just excluding the span of cantilever beam.

Next, the decision trees of column and column (case 4.2) are illustrated in Appendix F on page 245-248. In this case, the main input is the shape of column at current floor and upper floor. These shapes can be rectangular or circular. Four decision trees of column and column are then developed due to these different shapes. First, it is the case of rectangular column at current floor and rectangular column at upper floor. Second is the case of rectangular column at current floor and circular column at upper floor. Third is the case of circular column at current floor and rectangular column at upper floor. The last case is circular column at current floor and circular column at upper floor. Other three inputs for these four cases are the central alignment of column at current floor and column at upper floor, starter bars for column at upper floor, and the strength of column at current floor. The condition of these cases is to compare the size of column at current floor with the size of column at upper floor in order to assure that there is enough space for installing starter bars. The investigation on the strength of column and its central alignment is also included.

The third decision tree represents the case between column and footing (case 4.3) which is shown in Appendix F on page 249. The inputs are the design of stump column, footing strength, the lap length of starter bars for stump column and its allowable lap length. The conditions of this decision tree are to examine the design of stump column and footing strength whether they are correct and be able to carry the loads transferred to them. The lap length of starter bars to connect stump column with footing is compared with the allowable lap length as required in the design standard to make sure that the starter bars can be installed with correct requirement.

Fourth, the decision tree of column and sanitary ware (case 4.4) is figured in Appendix F on page 250. The size of column, position of sanitary ware, space for fixing the sanitary ware with the column, and the route for running the pipe of sanitary ware to the public sewer system are the inputs for this decision tree. All of these inputs have to be checked since they can incur the problems.

Last, the decision tree of column and wall finish (case 4.5) is presented in Appendix F on page 251. The alignment of column and masonry wall and the starter bars to connect column with masonry wall shall be the inputs to be investigated. The size of column is also necessary input because it sometimes is found different from the architecture. The column dimension opposite to the thickness of masonry wall has to be examined since the corners of column are found projected outside the wall and this projection might affect the architectural design.

5.3.5 Category 5: Design Errors between Slab and Other Components

- **Examples of cases of design errors**

Category 5 consists of twelve cases of design errors such as design errors between slab and ceiling works, slab and door/window, slab and floor finish, slab and HVAC systems, slab and sanitary drainage and disposal system, slab and sanitary ware, slab and slab, slab and staircase finish, slab and storm drainage system, slab and telephone/datacom system, slab and wall finish, and slab and water supply and distribution system. In category 5 of Appendix E, the first problem of slab and ceiling works was similar to the issue of beam and ceiling works. In this case, it referred to the slab area that had no beam, which also possibly had conflict with the ceiling works. The space from the soffit of slab to the level of ceiling was insufficient for installing MEP systems. The second case was slab and door/window. Due to incorrect level of structural slab at current floor, the height of opening for door/window at current floor was changed and this change influenced the required top level of door/window as required by architect. If it was cantilever slab, the window below that slab could be affected when the cantilever slab with unallowable span was deflected. Third is design error between slab and floor finish. Most problems occurred in the bathroom and kitchen room. Designer frequently forgot to drop the slab level in these rooms. It was found that the water could not flow to the drain properly. The fourth case of slab and HVAC systems also had some problems caused by design errors. The opening of slab was not reserved or it was reserved with incorrect size. When the reserved opening size for running the pipes of HVAC systems was inadequate, the slab opening had to be enlarged by drilling to make hole. For the fifth case of slab and sanitary drainage and disposal system, three examples were found. In the first example, there was conflict with the sewage pipe which had to run under the cover (slab was the cover of the septic tank). It was not possible to run this pipe under the cover of septic tank because the clear height of septic tank would be reduced. If this pipe was changed to run into the slab, it was not allowed since the strength of slab would be not enough. Second example was about the opening for running the sewage pipe which was not reserved and given in details in the design drawing. The third example talked about the wrong position at slab for the route of sewage pipe. Next, the problems of the sixth case of slab and sanitary ware also arose. The reserved opening of slab for toilet sleeve was not given and designer reserved its size incorrectly. Consequently, it was not able to install the toilet sleeve. Besides, the seventh case is slab and slab. This case was not very critical because most problems were related to the incomplete design of the typical details for rebar installation when the slab level was dropped. Designer should also pay much attention on the version of architectural plan of slab that being used. Another case is slab and staircase finish. The slab level of current and lower floor was concerned with the total height of all risers of the stair. It was explored that the level of the top riser of the stair was higher than the structural slab level. The ninth case of this category is slab and storm drainage system. The issues of this case were the inadequate size of the reserved opening for floor drains at roof area. Its position and diameter at the roof slab were also of much concern. The tenth case is slab and telephone/datacom system. For this case, the issue focused on the sleeve penetration at the slab for running the tub wiring of telephone/datacom system. Designer did not provide any details for this penetration; thus, it required to drill a small hole on the slab. Sometimes, the reserved penetration size was smaller than the required size of the cable conduits to be installed. The eleventh case is slab and wall finish. The slab function was important. It was found that the slab was cantilever with an unallowable span. Since there was brick wall laid on that cantilever slab, the slab was deflected and could not carry the loads imposed by the brick wall. Another problem was also found that the masonry wall had no any slab to support it. This was because designer did not notice that the architectural layout plan of slab at current and lower floor were different. They may just copy and paste the structural layout plan of slab at current floor from the plan at lower floor. The last case under this category is slab and water supply and distribution system. Similarly to the previous case of slab and plumbing systems, the position and size of reserved opening at slab for the water pipe was incorrect. Besides, the route of this pipe was found across the slab due to the slope requirement of the pipe. In this situation, the diameter of pipe was almost equal to the slab thickness, which could reduce the concrete cover of the slab. Therefore, the strength of slab might be mitigated. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

In compliance with the examples found in Appendix E, all cases of design errors under this category were analyzed to identify the contributing factors or attributes. Table 5.6 lists all attributes (contributing factors) of twelve cases under design errors between slab and other components.

Table 5.6 Cross-case analysis – Category 5

Category 5: Design errors between slab and other components			
Code	Cases of design errors	Cross-checked	
5.1	Slab and ceiling works [Attributes]	Ex1	
	Required height (space) for MEP from the soffit of slab	✓	
	Required ceiling height from the soffit of slab	✓	
5.2	Slab and door/window [Attributes]	Ex1	Ex2
	Slab level	✓	
	Required top level of door/window	✓	
	Height of opening for door/window	✓	
	Height of door/window	✓	
	Cantilever slab		✓
	Span of cantilever slab		✓
	Top level of door/window		✓
	Bottom level of the cantilever slab		✓
5.3	Slab and floor finish [Attributes]	Ex1	Ex2
	Structural slab level	✓	✓
	Floor finish level	✓	
	Floor finish thickness	✓	
	Structural slab at bathroom		✓

Table 5.6 Cross-case analysis – Category 5 (continued)

Category 5: Design errors between slab and other components				
Code	Cases of design errors	Cross-checked		
5.3	Slab and floor finish [Attributes]	Ex1	Ex2	
	Structural slab at normal areas		✓	
	Required dropped height		✓	
	Slope requirement for slab at bathroom		✓	
5.4	Slab and HVAC systems [Attributes]	Ex1	Ex2	Ex3
	Reserved opening of slab for HVAC systems (air exhaust, HVAC risers...)	✓	✓	✓
	Width of shaft space for HVAC systems (air exhaust, HVAC risers…)		✓	
	Length of shaft space for HVAC systems (air exhaust, HVAC risers…)		✓	
	Reserved size of slab opening for installing HVAC risers (width and length of reserved opening)		✓	
5.5	Slab and sanitary drainage and disposal system [Attributes]	Ex1	Ex2	Ex3
	Reserved opening for running the sewage pipe		✓	
	Position of reserved opening for running the sewage pipe			✓
	Slab functions as the cover of the septic tank	✓		
	Required clear height of septic tank	✓		
	Height of septic tank (from the bottom of septic tank to the top of slab)	✓		
	Sewage pipe across the slab	✓		
	Sewage pipe under the slab	✓		
	Slab thickness	✓		
	Diameter of sewage pipe	✓		
5.6	Slab and sanitary ware [Attributes]	Ex1	Ex2	
	Reserved opening of slab for toilet sleeve	✓		
	Reserved diameter of opening at slab for toilet sleeve		✓	
	Size of toilet sleeve (diameter of toilet sleeve)		✓	
5.7	Slab and slab [Attributes]	Ex1	Ex2	Ex3
	Typical details of rebar installation when the slab level is dropped	✓		
	Last version of architectural plan of slab		✓	
	actual levels of slab that designer has designed			✓

Table 5.6 Cross-case analysis – Category 5 (continued)

Category 5: Design errors between slab and other components					
Code	Cases of design errors	Cross-checked			
5.8	Slab and staircase finish [Attributes]	Ex1			
	Height of each riser of stair	✓			
	Number of all risers of stair	✓			
	Concrete slab level at current floor	✓			
	Concrete slab level at lower floor	✓			
	Required floor height from lower to current floor	✓			
5.9	Slab and storm drainage system [Attributes]	Ex1	Ex2	Ex3	
	Reserved openings for floor drains at roof floor	✓	✓	✓	
	Diameter of reserved openings for floor drains		✓		
	Required diameter of the sleeves for floor drains		✓		
	Positions of the reserved openings for floor drains			✓	
5.10	Slab and telephone/datacom system [Attributes]	Ex1	Ex2		
	Penetration at the slab for installing the telephone/datacom system (cable conduits…)	✓			
	Reserved penetration size for installing the telephone/datacom system (cable conduits…)		✓		
	Required opening size for installing the telephone/datacom system (diameter)		✓		
5.11	Slab and wall finish [Attributes]	Ex1	Ex2		
	Cantilever slab	✓			
	Span of cantilever slab	✓			
	Allowable span of cantilever slab in design standard	✓			
	Normal slab		✓		
	Architectural layout plan of slab		✓		
	Structural layout plan of slab		✓		
	Slab to support the masonry wall		✓		
5.12	Slab and water supply and distribution system [Attributes]	Ex1	Ex2	Ex3	Ex4
	Position of the reserved opening at slab for water pipe	✓			
	Reserved opening at slab for water pipe			✓	
	Diameter of reserved opening to run water pipe				✓

Table 5.6 Cross-case analysis – Category 5 (continued)

Category 5: Design errors between slab and other components					
Code	Cases of design errors	Cross-checked			
5.12	Slab and water supply and distribution system [Attributes]	Ex1	Ex2	Ex3	Ex4
	Route of water pipe across the section of structural slab due to slope requirement		✓		
	Diameter of water pipe		✓		✓
	Slab thickness		✓		
	Concrete cover of slab		✓		

- **Decision tree development**

The decision tree of the first case of slab and ceiling works (case 5.1) is illustrated in Appendix F on page 252. It is not quite different from the case of beam and ceiling works. The inputs such as required space for installing MEP system and the required ceiling height are compared.

Next is the case of slab and door/window (case 5.2). Its decision tree is presented in Appendix F on page 253. Type of slab is the main input for this case. If the slab is cantilever, there are two conditions for the door/window which can be the door/window under the slab and door/window above the slab. The span of cantilever beam, top level of door/window, height of the opening for door/window are the inputs for checking if the door/window can be installed correctly. If slab is normal, the span of slab is excluded from the inputs because it is not irrelevant.

The decision tree of the third case of slab and floor finish (case 5.3) is also described in Appendix F on page 254. The main input for this decision tree is the slab at a specific area which can be the slab at bathroom or slab at normal area. The required dropped height, normal slab level, floor finish thickness and its level, the slope requirement for the dropped slab are the inputs for this case. It is required to check this information in order to compare if the dropped level of the slab is correct.

The fourth case is slab and HVAC systems (case 5.4). Its decision tree is shown in Appendix F on page 255. The inputs are reserved opening at slab for HVAC systems, its size, and the required size of the space for installing the HVAC systems. The reserved size and required size of the opening are compared in order to make sure that the reserved space is sufficient for installing HVAC systems.

For slab and sanitary drainage and disposal system (case 5.5), its decision tree is figured in Appendix F on page 256. There are two conditions based on the function of the slab. In the event that the slab is the cover of septic tank, the route of sewage pipe is important input. If the pipe has to run across this cover, slab thickness and diameter of sewage pipe are to be examined. If the pipe has to run under the slab, the clear height of septic tank is to be checked. When it is normal slab, the reserved opening and its position for sewage pipe are to be investigated.

The decision tree of slab and sanitary ware (case 5.6) is explained in Appendix F on page 257. Likewise the previous case, the condition of this figure is to inspect the reserved diameter of the toilet sleeve and the required size of this sleeve. It is necessary to check if designer already reserves the opening for the toilet sleeve in structural design.

After that, the decision tree of slab and slab (case 5.7) is expressed in Appendix F on page 258. For this case, the typical details of the rebar installation when the slab is dropped, the architectural plan that designer used, and the actual levels of slab are the attributes to be examined before starting the construction of the structural slab.

The decision tree of slab and staircase finish (case 5.8) is shown in Appendix F on page 259. The inputs of this case are the concrete slab level at lower and current floor, required floor height, height of riser, and number of risers. The condition of these inputs is to scrutinize the required floor height with the actual slab level at lower and current floor. The height of stair (height of riser multiplied by the number of all risers) is also studied to make sure that it is consistent with the required floor height and slab levels.

Ninth, the decision tree of slab and storm drainage system (case 5.9) is figured in Appendix F on page 260. For this case, the inputs are the position and the size of reserved opening (hole) for running the rainwater pipe. These inputs are to be investigated if the pipe can be installed properly.

Regarding the case of slab and telephone/datacom system (case 5.10), its decision tree is in Appendix F on page 261. The main input of this case is the opening at slab for installing the telephone/datacom system (cable conduits, wires…). The penetration diameter of the reserved opening has to be compared with the required opening size.

For the case of slab and wall finish (case 5.11), its decision tree is presented in Appendix F on page 262. Type of slab (cantilever slab or normal slab) is the main input. If slab is cantilever, the span of cantilever slab is the critical input to be checked if this span is allowable by the design standard. If it is normal slab, the architectural and structural plan of the slab are compared to assure that the masonry wall has structural slab to support it.

Finally, the decision tree of slab and water supply and distribution system (case 5.12) is illustrated in Appendix F on page 263. Not far different from the case of slab and storm drainage system, the inputs of this decision tree are the position and size of the reserved opening for running the water pipe, the route of pipe, diameter of pipe, slab thickness, and concrete cover of slab. Noticeably, the water pipe is required to run across the slab due to slope requirement. Thus, it is necessary to check if the concrete cover of slab sufficient and the slab reinforcement can be installed properly.

5.3.6 Category 6: Design Errors between Stair and Other Components

- **Examples of cases of design errors**

Category 6 consists of five cases of design errors such as design errors between stair and beam, stair and ceiling works, stair and slab, stair and staircase finish, and stair and wall finish. In category 6 of Appendix E, two examples of the problems between stair and beam were found. The first issue was that the reserved opening for stair was smaller than what was required in architecture. This was because the beams were located in the wrong position that could reduce the width or length of the opening. Second problem was the lack of starter bars to connect beam with the stair. The beam was found cracking and it required to drill the holes for placing the required starter bars. Another case is stair and ceiling works. For this case, the beam functioned as the top riser of the stair. It was found that the soffit of beam were uncovered after finishing the ceiling works. For stair and slab, additional bars (trimmers) at the corners of the slab opening for stair were not installed when it should have been. Slab was then cracked at those corners of the opening. Besides, the total height of all risers of the stair often was found higher than the required height of floor. Next case is stair and staircase finish of which the problems were related to the insufficient reserved size of the stair landing. For staircase finish, the plastering thickness was varied based on the type of finishing material. The reserved plastering thickness sometimes was not sufficient and this could lead to different level of each step of the stair. The last case is stair and wall finish. The position of the stair that designer designed had incorrect position comparing to the architectural plan. From the front view of the masonry wall, it was noticed that the stair was seen around 300mm projected outside the wall. The architect did not satisfy with this error because it affected the esthetic of the stair as well as the wall finish. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

According to all examples of each case between stair and other building components under category 5, the differences and similarities of each case were explored and explained by the cross-checked attributes as described in Table 5.7 below.

Table 5.7 Cross-case analysis – Category 6

Category 6: Design errors between stair and other components			
Code	Cases of design errors	Cross-checked	
6.1	Stair and beam [Attributes]	Ex1	Ex2
	Required width of stair opening	✓	
	Required length of stair opening	✓	
	Span of short beam	✓	
	Span of long beam	✓	
	Starter bars to connect beam with the stair		✓

Table 5.7 Cross-case analysis – Category 6 (continued)

Category 6: Design errors between stair and other components			
Code	Cases of design errors	Cross-checked	
6.2	Stair and ceiling works [Attributes]	Ex1	Ex2
	Beam functions as the top riser of the stair	✓	✓
	Beam's depth	✓	✓
	Reinforced concrete slab (RC slab)	✓	
	Precast concrete slab (PC slab)		✓
	Slab thickness	✓	✓
	Depth of ceiling from the bottom of the slab	✓	✓
6.3	Stair and slab [Attributes]	Ex1	Ex2
	Additional bars at the corners of the slab opening for stair	✓	
	Height of each riser		✓
	Height of floor		✓
	Total height of risers of the stair		✓
6.4	Stair and staircase finish [Attributes]	Ex1	Ex2
	Required width of stair landing	✓	
	Required length of stair	✓	
	Total length of treads from the lower stair to landing	✓	
	Tread's width	✓	
	Number of treads (number of steps)	✓	
	Required plastering thickness of the material used for staircase finish		✓
	Reserved plastering thickness for staircase finish		✓
6.5	Stair and wall finish [Attributes]	Ex1	
	Position of the stair	✓	
	Tread’s width	✓	
	Number of treads (number of steps)	✓	
	Actual width of stair landing	✓	
	Width of masonry wall	✓	

- **Decision tree development**

For stair and beam (case 6.1), its decision tree is shown in Appendix F on page 264. The inputs of this decision tree are starter bars to connect beam with the stair, required width and length of stair opening, and the distance from one beam to the opposite beam. For this case, the required size of the stair opening is compared with the reserved opening (span of short beam and long beam) and the presence of starter bars to connect beam with the stair structure has to be examined.

The decision tree of stair and ceiling works (case 6.2) is illustrated in Appendix F on page 265. The main input of this decision tree is the function of the beam at stair opening. If beam is used as the top riser of the stair, the beam's depth, slab thickness, and required ceiling height from the bottom of slab are the related inputs. Moreover, slab can be reinforced concrete slab (RC slab) or precast concrete slab (PC slab). For PC slab, slab thickness is not related because the depth of beam and thickness of slab are separately designed. The condition of this case is to compare the space from the bottom of beam to ceiling level with the required ceiling height.

The decision tree of stair and slab (case 6.3) is expressed in Appendix F on page 266. Additional bars (trimmers) at the corners of the slab opening for stair, floor height, height of each riser, and the number of risers are the related inputs which are used to check for the possibility of design errors. The total height of all risers are determined and compared with the required floor height.

The decision tree of stair and staircase finish (case 6.4) is presented in Appendix F on page 267. Regarding the staircase finish, the plastering thickness for the steps of stair and its reserved plastering thickness should be equal. For stair landing, its required width, required length of stair, tread's width, and number of treads are related to each other because these inputs are investigated whether the required width of stair landing is sufficient.

Finally, the last case of stair and wall finish (case 6.5) is described in Appendix F on page 268. The position of stair, required width of each tread, number of treads (number of steps), actual width of stair landing, and the width of masonry wall are the important contributing factors to check for the occurrence of the problems. The condition of this case is to compare the width of the masonry wall with the length of the stair whether there is any projected distance of the stair outside the wall.

5.3.7 Category 7: Design Errors between Reinforced Concrete Wall and Other Components

- **Examples of cases of design errors**

Category 7 consists of five cases of design errors such as design errors between reinforced concrete wall (RC wall) and door/window, RC wall and lift systems, RC wall and storm drainage system, RC wall and wall finish, and RC wall and water supply and distribution system. In category 7 of Appendix E, three examples of RC wall and door/window were collected. The size of opening for lift door at the RC wall was found incorrect; thus the exact door could not be installed. Another problem was about the opening at the RC wall for lift maintenance. Engineer forgot to reserve this opening, and then it was very difficult when the maintenance of lift was required. For RC wall and lift systems, the opening for installing the lift box was found different from the required size of the lift box. The problem of lift button also arose because designer placed it in the wrong position and reserved its opening incorrectly. Another case between RC wall and storm drainage systems also had some problems related to the route of the rainwater pipe which was penetrated into the RC wall. This pipe had conflict with the RC wall reinforcement and its big diameter reduced the allowable effective cover of RC wall. As a result, the strength of RC wall might be reduced and it might not be able to install the RC wall reinforcement properly. Next is the case of RC wall and wall finish. It was found that the RC wall thickness after plastering works was greater than the required thickness as mentioned in architecture. This problem dissatisfied the architect because it affected the architectural design and decoration of the wall. Another issue was the incorrect alignment of RC wall and masonry wall nearby. The last case is RC wall and water supply and distribution system. Before construction, it was noticed that the water pipe had conflict with the RC wall because it had to run into the RC wall vertically which was not allowed. If this pipe ran into the RC wall as this case, it would be seriously affected when the pipe was damaged. If the water pipe ran across the RC wall horizontally, the sleeve of water pipe should be pre-installed before pouring the concrete to avoid drilling the RC wall. The cross-case analysis of all cases in this category is explained below.

- **Analysis of differences and similarities of each case's examples**

The differences and similarities of design errors under this category were also analyzed by cross-checking the main contributors of each case. These attributes are clearly described in Table 5.8.

Table 5.8 Cross-case analysis – Category 7

Category 7: Design errors between RC wall and other components						
Code	Cases of design errors	Cross-checked				
7.1	RC wall and door/window [Attributes]	Ex1	Ex2	Ex3		
	Lift wall	✓	✓	✓		
	Size of opening for lift door at RC wall	✓		✓		
	Width of opening for lift door at RC wall			✓		
	Length of opening for lift door at RC wall			✓		
	Size of lift door (width / length)	✓				
	Window opening for lift maintenance		✓			
	Frame thickness			✓		
7.2	RC wall and lift systems [Attributes]	Ex1	Ex2	Ex3	Ex4	Ex5
	Required lift width	✓		✓	✓	
	Required lift length			✓	✓	
	Reserved width for opening of lift	✓		✓	✓	
	Reserved length for opening of lift			✓	✓	
	Position of lift opening			✓		
	Required width of lift button		✓			
	Required length of lift button		✓			
	Reserved width for opening of lift button		✓			
	Reserved length for opening of lift button		✓			
	Position of lift button on RC wall		✓			
	Reserved opening for lift button					✓

Table 5.8 Cross-case analysis – Category 7 (continued)

	Category 7: Design errors between RC wall and other components			
Code	Cases of design errors	Cross-checked		
7.3	RC wall and storm drainage system [Attributes]	Ex1	Ex2	Ex3
	Penetrated pipe into RC wall	✓		
	Route of rainwater pipe across the RC wall	✓	✓	
	Vertical route	✓	✓	
	Horizontal route			✓
	Diameter of rainwater pipe		✓	
	RC wall thickness		✓	
	RC wall reinforcement		✓	
	Allowable effective concrete cover of RC wall		✓	
	Position of sleeve penetrated into RC wall for rainwater pipe			✓
7.4	RC wall and wall finish [Attributes]	Ex1	Ex2	Ex3
	Required RC wall thickness	✓	✓	
	RC wall thickness	✓	✓	
	Plastering thickness	✓	✓	
	Alignment of RC wall			✓
	Alignment of masonry wall			✓
7.5	RC wall and water supply and distribution system [Attributes]	Ex1	Ex2	Ex3
	Penetrated water pipe into RC wall	✓	✓	✓
	Horizontal route	✓		
	Vertical route		✓	
	Reserved opening of pipe route at the RC wall		✓	
	Diameter of reserved opening for water pipe across the RC wall			✓
	Diameter of the water pipe across the RC wall			✓
	Position of the reserved opening for water pipe			✓

- **Decision tree development**

First of all, the decision tree of RC wall and door/window (case 7.1) is shown in Appendix F on page 269. The reserved opening for door/window at RC wall is the main input because designer mostly forgot to consider about the required size, frame, and level of the lift door/window. For this case, the inputs are the width and height of the opening for lift door, required width and length of lift door, and the frame thickness.

The decision tree of RC wall and lift systems (case 7.2) is figured in Appendix F on page 270-271. Two factors are found: lift opening and lift button opening. For these two factors, the inputs are the required width and length of the lift box or lift button, reserved width and length for the opening, and the position of the opening. These inputs are to check if the reserved opening is sufficient for installing the lift box or lift button of lift systems.

For RC wall and storm drainage system (case 7.3), its decision is illustrated in Appendix F on page 272. The main input of this decision tree is the route of rainwater pipe. Based on the examples in Appendix E, the rainwater pipe can run into the beam vertically. Because it does not rain every day, the water rarely flows through this kind of pipe. It means no high impact for running it into the wall. Regarding this case, the RC reinforcement, diameter of pipe, RC wall thickness, and the allowable effective concrete cover of RC wall are the input to check for the problems if the RC wall thickness is sufficient for routing the pipe vertically.

Fourth, the decision tree of RC wall and wall finish (case 7.4) is shown in Appendix F on page 273. The inputs of this case are the alignment of RC wall and masonry wall, plastering thickness, actual RC wall thickness, and its required RC wall thickness. The condition of this case is that the summation of actual RC wall thickness and its plastering thickness shall equal the required RC wall thickness in architecture. To avoid the problem, the alignment of RC wall and masonry wall at upper floor should be checked if it follows the architectural design.

The decision tree of the last case of RC wall and water supply and distribution system (case 7.5) is presented in Appendix F on page 274. The inputs are the penetrated water pipe into RC wall, the route of the water pipe, and the reserved opening of the pipe route at the RC wall. These inputs are required to be examined in order to make sure that the problems regarding the stair and wall finish could occur or could not occur.

5.4 Conclusion

This chapter describes about the development process of knowledge-based models. The purpose of this model is to store the previous knowledge and experience of design errors in construction practices. The model is developed in the form of decision trees of each prioritized case of design errors under all categories. It is established based on the related attributes which are cross-checked by applying the cross-case analysis method. The related attributes of each case are the important inputs of the model to help checking the possibility of occurrence of the problems due to design errors between structure and other building components.

CHAPTER VI

VISUAL BASIC FOR APPLICATIONS OF KNOWLEDGE-BASED MODELS

According to the development of the knowledge-based models for checking design errors, the decision trees of all critical cases of design errors are coded by applying the Visual Basic for Applications (VBA) which refers to the macros in Microsoft Excel. The output is a design error checking system that the practitioners can use to check for the possibility of occurrence of problems caused by design errors between structural elements and other building components. The coding process is explained in this chapter.

6.1 Inputs of Knowledge-Based Models

Due to the decision trees of knowledge-based models as presented in Appendix F, the inputs of Visual Basic for Applications (VBA) are the contributing factors (attributes) which are found from the cross-case analysis in Chapter 5. Based on the decision trees of all 48 critical cases, three different windows were developed in VBA programming. The first window refers to the design errors between each structural element and other components, for instance, design error between beam and ceiling works and so on. In this window, the users of the programme have to select a type of structural element they want to check with another component. Second window lists all contributing attributes which are explored from the examples in Appendix E. These contributing factors are the main inputs to describe the conditions and situations of the cases. The last window focuses on the output of the models. Because the developed models attempt to check for the possibility of occurrence of the problems caused by design errors, the key output is to tell the users whether there would be any errors based on the information they have given in the second window. The conditions of design errors as shown in the decision tree of each case are also written to simulate all entry data provided in the second window in order to obtain the output of the last window.

The following sections of this chapter explain the coding process of these windows into the Visual Basic for Applications (VBA) in Microsoft Excel.

6.2 VBA Programming of Knowledge-Based Models

For this research, the system of the knowledge-based models is called, “design error checking system”. In VBA programming of the models, the codes of all decision trees are written in Visual Basic Editor (VBE) in Microsoft Excel. Thus, the macro is recorded. This macro can be run smoothly according to the VBA codes which are described in details in the following sections.

6.2.1 VBA Codes

Three main steps are conducted to code the decision trees of the models into the system. In the first step, the macro is recorded. Macro is a piece of VBA codes in Visual Basic Editor (VBE). In order to start the programme, macro is required. All codes have to be stored in this macro. For this study, a macro is recorded in a command button which is named, “Start”, in a sheet of Excel file. By just clicking this button, the programme starts and links to the userforms which are created in the next step.

For the second step, a userform is created for each case of design errors. This means that the knowledge of all 48 critical cases is coded in different userforms. Userform is used because it is a dialog box which facilitates the users to entry the data easily and controllably. Simple forms are designed based on the decision tree of each case of design errors. Userforms in this system consist of three types. The first type of the userform is to introduce the users about the utility of the system and the definitions of key terms being used in the system. The second type of the userform is for the users to choose the structural element that they wish to check if it can incur any design errors with another component. Using a combobox to control another combobox, both elements can be chosen by the users and then they can click the command button to go to the next userform which is the third type of this system. This third type of the userform is the most important part because the users have to entry all required data in that userform before clicking a command button to check for the possibility of the problems. After that, they can go back to the previous userform (second type of userform) if they wish to check for other cases between a structural element and other building components. When they finish checking their cases, they can print all results from the system into a new worksheet. However, these functions cannot work if the codes are not written.

Therefore, the last step is to write the codes in the Visual Basic Editor (VBE). In this VBE, VBA statements and VBA functions are used to write the codes into the system. The key VBA statements and VBA functions used in the system are:

- **“Dim Statement”** is to declare the variables and the data types (Walkenbach, 2010). The syntax of “VBA Dim Statement” is:

  ```
  Dim “variable_name” as “variable_type”
  ```

- **“If Statement”** is to proceed statements conditionally (Walkenbach, 2010). The Syntax of “VBA If Statement” is:

  ```
  If “condition_1” Then
      Msgbox “Outcome_1”
  ElseIf “Outcome_2” Then
      Msgbox “message_2”
  Else
  End If
  ```

- **“Select case Statement”** is also to proceed statements conditionally (Walkenbach, 2010). Since this statement can make the VBA codes to run faster and easier to understand, the complex “If Statement” is not used (Kaul, 2012). The Syntax of “VBA Select Case Statement” is:

  ```
  Select Case Condition
      Case Condition_1
          Outcome_1
      Case Condition_2
          Outcome_2
      Case Else
  End Select
  ```

- **"With Statement"** is to set various properties for an object without repeating it many times (Walkenbach, 2010). The syntax of "VBA With Statement" is:

```
With object
        .property
End With
```

- **"MsgBox Function"** is to display a message box based on Walkenbach (2010). This function is used to display the outcomes of the system in the syntaxes of VBA statements. The syntax of "MsgBox Function" is:

```
MsgBox "Outcome"
```

Besides these key VBA statements and VBA functions, other codes are also used such as toolbox controls, unload statement, Hide – Show statement, VBA's data types (Integer, Double, String, Long, Variant,…), and other necessary operators for coding the conditions of all inputs in each decision tree of the knowledge-based models. Finally, the report of the VBA results can be generated.

6.2.2 VBA Results

After coding the conditions of all decision trees (Appendix F), the result is a VBA programming of "design error checking system". This system consists of 48 different cases which the users can check as many cases as they wish to. After the users finish their checks, they can retrieve and print their results from the system. The report of their results would be very useful for them to take action on time for improving their design as well as for reducing the occurrence of design errors in their projects.

6.3 Discussion

The design error checking system of all cases in this research is different from a checklist of traditional method. Using traditional checklist, the users just check the attributes one by one and they are not able to see the conditions which can lead to the problem. It seems that the users cannot capture the knowledge of each attribute. It is quite direct when they just check those attributes to see if there is problem or not. After checking the attributes in the checklist, the users can know that there is problem; however, they cannot know exactly what kind of problem it is. Differently, the design error checking system can tell the users not only that there is a problem but also tell the details of several possible problems. That is because this system is developed by using the knowledge of each case study to classify the possibility of occurrence of the problems. Moreover, the users can check design errors in a systematic way without checking its conditions which might need to spend longer time by traditional calculation. Most importantly, engineers or designers who have less experience in building construction projects cannot effectively use their own traditional checklist or knowledge to check the possibility of occurrence of design errors. Thus, the design error checking system of this research can help them to improve their experience and knowledge in checking design errors between structural elements and other building components.

6.4 Conclusion

This chapter explains how the system of the knowledge-based models can be developed and coded into the Visual Basic for Applications in Microsoft Excel. Using VBA codes and VBA syntaxes, the design error checking system was accomplished. However, this system contains only the decision trees of 48 most important cases of design errors. For the development of the models, the other possible cases can be included by adapting the research methodology of part 2 of this study.

CHAPTER VII
RESEARCH CONCLUSIONS

7.1 Research Findings

Design errors caused by designers such as design omissions, design conflicts, and design mistakes are common and inevitable problems in building construction projects in Cambodia. This research aims at developing the knowledge-based models for checking design errors which can occur at construction sites during construction practices. All the findings of this research were derived from the experience of contractors who have been working in building construction projects.

The first output is a list of groups of design errors and all cases under each group of design errors that are possible to occur in building construction projects in Cambodia. According to the data collection of part 1 which was conducted with 11 engineers of contractors in 11 various building construction projects in Cambodia, 122 cases of design errors possibly arise during construction practices among 154 cases obtained from literature reviews and other articles.

The second output is the percentage occurrence of groups of design errors and their cases. By using the percentage formulas, the number of cases is converted to the percentage occurrence for each sampling project. The percentage occurrence of each group of design errors are (1) P_A = 36.25% for design errors between structure and architecture (group A), (2) P_B = 34.71% for design errors between structure and structure (group B), (3) P_E = 16.29% for design errors between structure and plumbing works (group E), (4) P_C = 8.46% for design errors between structure and mechanical works (group C), and (5) P_D = 4.29% for design errors between structure and electrical works (group D).

The third output is the impact level of groups of design errors and their cases. Applying simple grading method of bell-curve, the levels of impact score are interpreted. The results show the different impact levels of groups of design errors whereas design errors between structure and mechanical works (group C) are the first priority, followed by design errors between structure and plumbing works (group E), design errors between structure and architecture (group A), design errors between structure and structure (group B), and design errors between structure and electrical works (group D).

The fourth output of this research is a list of critical cases of design errors that occur in building construction projects in Cambodia. This list is shown in Appendix C. The critical cases of design errors are obtained by studying on its percentage occurrence and impact. In the list, all critical cases of design errors are ranked based on different nine priority zones. It is found that there is no any case under zone I, while zone II consists of only one case of design errors between reinforced concrete wall (RC wall) and lift systems. There are 48 cases of design errors were found as critical cases which were prioritized and selected for further studies. These findings respond to the first objective of this study.

The fifth output is the decision trees of the knowledge-based models for checking design errors (Appendix F). Obtaining from data collection of part 2, the attributes and conditions of each critical case of design errors are the inputs of these decision trees. These attributes and conditions are the key results from the data collection of part 2 which responds to the second objective of this research.

The final output of the research is the system of knowledge-based models for checking design errors by applying the Visual Basic for Applications in Microsoft Excel. The decision trees of all 48 critical cases of design errors are coded in the programme which is named, “design error checking system”.

7.2 Research Contribution

The outputs of this research provide several benefits for Cambodian engineers. First, the critical cases of design errors between structural elements and other building components gives a view of the most prioritized and critical design errors occurring in building construction projects in Cambodia. The detailed knowledge of the 48 critical cases in current practices is useful for structural engineers or designers to mitigate the occurrence of design errors which have the high impact. Engineers moreover can understand and learn in details what design errors should be firstly solved. Designers shall take action carefully to reduce the occurrence of the most critical design errors during design processes. Whereas contractors shall pay much attention on those design errors prior to construction in their future construction projects.

More importantly, the knowledge-based models of this research will be a helpful mechanism for both designers and contractors to check for the possibility of occurrence of problems due to design errors between structure and other building components. Since the models store the knowledge of all 48 critical cases from the previous experience, fresh engineers, who are lack of actual practices regarding building construction projects, shall be able to learn some critical cases of design errors from the models and the system. In the context of traditional cast-in-place RC structures and less developing construction industry in Cambodia, the models provides a guideline for the practitioners to check the design before the construction start-up if the structures have any design errors with architecture or MEP systems.

7.3 Research Limitation

The knowledge-based models were developed under certain limitation such as:

(A) The number of design errors which occurred in each sampling project was not really precise because the respondents were asked after the construction was finished. This was suggested to follow up the problems of design errors in the whole construction process.

(B) The examples of design errors' cases, which were used to develop the knowledge-based models, were collected only from a limited number of engineers of contractors. There might be more examples from designers, owners, consultants, and other relevant stakeholders.

(C) This study covered only seven structural elements such as retaining wall, footing, beam, column, slab, stair, and reinforced concrete wall. The other structural elements and other building components are needed to be explored.

(D) The sample size was small and inadequate because only reinforced concrete structures were studied. The actual design errors occurring in the other characteristics of structures remain unknown. The other characteristics of structures can be post-tension or pre-tension projects.

(E) Even though the models and the design error checking system were successfully developed and coded by the Visual Basic programming in Microsoft Excel, it does not mean that all practitioners such as designers, contractors, or other stakeholders completely satisfy with the models or the design error checking system. Therefore, their opinions and suggestions on the applicability of the models and system are to be investigated.

7.4 Further Studies

The suggestions of further studies for this research are:

(A) The studies of the identification of the critical cases of design errors between structural elements and other building components from different characteristics of construction building projects are still necessary to be conducted.

(B) An update of the knowledge-based models to suit with the development of the building construction projects might be important for the studies in the future.

(C) The prototype of the knowledge-based models can be further improved by adding the hyperlinks with AutoCAD, Autodesk Revit, or other relevant programs.

(D) The integration of the models to the Building Information Modeling (BIM) is suggested for further studies because the knowledge-based models (decision trees of the critical cases of design errors) might be an effective tool to help checking the significant design errors which have the most frequency and highest impact in current practices by focusing on their related attributes and conditions.

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APPENDICES

APPENDIX A

DATA COLLECTION OF PART 1:

SURVEY QUESTIONNAIRE 1

SURVEY QUESTIONNAIRE

DESIGN ERRORS IN BUILDING CONSTRUCTION PROJECTS

No: ______________________________

Date: ____________________________

Description

This survey is conducted in the purpose of prioritizing the important design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing) in building construction projects. According to this objective, the questionnaires are divided into two following parts.

Part 1: General information

Please fill your general information in the following blanks:

Background of respondents

1. Name: ____
2. Gender: ☐Male ☐Female
3. Organization/Company: ____
4. Position:____
5. Education: ☐Bachelor ☐Master ☐Ph.D.
6. Years of experience: ____
7. Tel: ________________________________ E-mail: ________________________________

Project characteristics

1. Project name:______________________________ Total Area____________ Square meters
2. Number of floors:__________________________ Total height:________________ meters
3. Type of project: ☐Precast concrete (PC) ☐Reinforced concrete (RC)
   ☐Composite structure ☐Other: __________________________

Part 2: Evaluation of design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing)

Instruction: Please provide the right number of cases (column P) and score (column I) in each cell of table A, B, C, D, and E, respectively based on your own experience.

- **Column (P)** focuses on the ***occurrence*** of design errors in ***a building construction project*** which you have worked for and has been already finished. Please provide the ***number of cases of design errors*** that you have experienced such as design errors between structure and other building components, which occurred in that project.

- **Column (I)** focuses on the ***impact*** of design errors on project performance. If any design errors you think they can cause any problems in construction, please give the right score as being described in table 2.1.

Table 2.1 – Evaluation score for impact of design errors on project performance

Description	Scenario				Score
	This error required the design revision	This error needs time for solving	This error can incur more cost	Construction cannot be continued	
Disastrous	Yes	Yes	Yes	Yes	5
Severe	Yes	Yes	Yes	No	4
Substantial	Yes	Yes	No	No	3
Marginal	Yes	No	No	No	2
Negligible	No	No	No	No	1

- ***If any design errors cannot cause any problems, please keep it blank.***

Table A – Design errors between structure and architecture (A)

A		Architecture											
		Wall finish		Floor finish		Ceiling works		Staircase finish		Door/ Window		Sanitary ware	
		(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)
Structure	Retaining wall												
	Footing												
	Beam												
	Column												
	Slab												
	Stair												
	RC wall												

Table B – Design errors between structure and structure (B)

B		Structure													
		Retaining wall		Footing		Beam		Column		Slab		Stair		RC wall	
		(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)
Structure	Retaining wall														
	Footing														
	Beam														
	Column														
	Slab														
	Stair														
	RC wall														

Table C – Design errors between structure and mechanical works (C)

C		Mechanical works			
		HVAC systems		Lift systems	
		(P)	(I)	(P)	(I)
Structure	Retaining wall				
	Footing				
	Beam				
	Column				
	Slab				
	Stair				
	RC wall				

Key terms:

HVAC systems include the following basic components: (1) Heat-generating system, (2) Cooling system, (3) Air-handling system, (4) Control system for hand adjusting and/or automatic monitoring of the system operation. HVAC systems include the removing of dust and odors, freshening with outdoor air, adjustment of the temperature, and adjustment of the relative humidity.

Lift systems include the major lift components such as prime mover (electric machine or hydraulic pump), lift car (car frame), counterweight, guide rails, entrances/doors, safety gear & overspeed governor, buffers (energy accumulation, energy dissipation), roping systems (compensating ropes, traction systems), car & landing fixtures (buttons, indicators & switches).

Table D – Design errors between structure and electrical works (D)

D		**Electrical works**			
		Electrical system		Telephone/ datacom system	
		(P)	(I)	(P)	(I)
Structure	Retaining wall				
	Footing				
	Beam				
	Column				
	Slab				
	Stair				
	RC wall				

Key terms:

Electrical system is categorized into supply, distribution, and lighting.

Telephone/datacom system use fiber optic lines.

Table E – Design errors between structure and plumbing works (E)

E		Plumbing works									
		Water supply & distribution system		Sanitary drainage & disposal system		Storm drainage system		Fire protection system		Fuel and gas piping system	
		(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)	(P)	(I)
Structure	Retaining wall										
	Footing										
	Beam										
	Column										
	Slab										
	Stair										
	Concrete wall										

Key terms:

Water supply and distribution system consists of *cold* and *hot water distribution system.*

1) Cold water distribution system: *Upfeed water distribution, downfeed or gravity system,* and *hydro pneumatic system (air pressure system).*
2) Types of hot water distribution system: *Upfeed and gravity return system, downfeed and gravity return system,* and *pump circuit system.*

Sanitary drainage and disposal system consists of *waste collection system* and *ventilation system.*

Storm drainage system consists of *the independent system, the combined system,* and *the natural system.*

Fire protection system is to make the building resistant by fire and to facilitate the evacuation process when there is fire.

Fuel and gas piping system includes gas supply for laboratories, hospitals, manufacturing facilities and other buildings. The toxic gas can be released through the process piping system.

This is the end of survey questionnaire. Thanks you very much for your participation.

APPENDIX B

DATA COLLECTION OF PART 1

Data Collection of Part 1:

No.	Code	Design errors between structure and other building components	Project 1 (Hotel)		Project 2 (Hotel)		Project 3 (Hotel)		Project 4 (Hotel)		Project 5 (Condominium)		Project 6 (Apartment)		Project 7 (Apartment)		Project 8 (Commercial Building)		Project 9 (Commercial Building)		Project 10 (Commercial Building)		Project 11 (Shopping Center)		Average Score		*Risk Analysis*
			No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	Percentage Occurrence	Impact	*R = P x I*
	A - Design errors between structure and architecture																										
1	A1	Retaining wall & Wall finish	3	2.00			4	2.00	2	2.00	2	1.00			1	2.00			2	4.00	4	4.00	5	4.00	0.0101	2.63	0.0265
2	A2	Retaining wall & Floor finish													1	1.00	6	4.00			4	3.00			0.0054	2.67	0.0143
3	A3	Retaining wall & Ceiling works																							0.0000	0.00	0.0000
4	A4	Retaining wall & Staircase finish					2	2.00													3	1.00			0.0015	1.50	0.0023
5	A5	Retaining wall & Door/Window																					3	3.00	0.0013	3.00	0.0039
6	A6	Retaining wall & Sanitary ware																							0.0000	0.00	0.0000
7	A7	Footing & Wall finish																							0.0000	0.00	0.0000
8	A8	Footing & Floor finish															2	3.00							0.0012	3.00	0.0035
9	A9	Footing & Ceiling works																							0.0000	0.00	0.0000
10	A10	Footing & Staircase finish																							0.0000	0.00	0.0000
11	A11	Footing & Door/Window																							0.0000	0.00	0.0000
12	A12	Footing & Sanitary ware																							0.0000	0.00	0.0000
13	A13	Beam & Wall finish	2	4.00			22	1.00	6	1.00	8	1.00	9	3.00	2	2.00			9	2.67	6	3.00			0.0325	2.21	0.0717
14	A14	Beam & Floor finish	4	4.00					8	1.00	1	1.00			2	2.00					5	3.00			0.0104	2.20	0.0229
15	A15	Beam & Ceiling works	13	3.00			6	2.00	7	4.00	1	1.00	2	1.00	2	2.00	13	4.00	6	3.00	5	1.00	4	3.00	0.0305	2.40	0.0733
16	A16	Beam & Staircase finish	3	3.50					2	1.00					1	2.00					5	2.00			0.0047	2.13	0.0100
17	A17	Beam & Door/Window	4	3.00	8	2.00	2	1.00							1	2.00	4	3.00	6	3.00			4	4.00	0.0175	2.57	0.0450
18	A18	Beam & Sanitary ware									4	3.00	3	1.00	2	2.00									0.0053	2.00	0.0106
19	A19	Column & Wall finish	1	2.00			102	1.00	4	3.00	12	2.00	5	1.00	2	2.00					4	3.00	4	3.00	0.0478	2.13	0.1016
20	A20	Column & Floor finish																							0.0000	0.00	0.0000
21	A21	Column & Ceiling works																							0.0000	0.00	0.0000
22	A22	Column & Staircase finish			4	3.00									1	2.00					3	2.00			0.0046	2.33	0.0108
23	A23	Column & Door/Window	1	4.00	1	4.00					4	2.00			2	3.00							4	3.00	0.0057	3.20	0.0181
24	A24	Column & Sanitary ware			4	4.00																			0.0031	4.00	0.0124
25	A25	Slab & Wall finish					6	4.33					2	3.00	2	2.00					4	4.00			0.0059	3.33	0.0197
26	A26	Slab & Floor finish	11	4.00	20	3.00			2	1.00	6	4.00	3	1.00	2	2.00	14	4.00	2	3.00	6	4.00	5	4.00	0.0410	3.00	0.1231
27	A27	Slab & Ceiling works	7	3.00					2	2.00					2	2.00			2	2.00	3	1.00	3	2.00	0.0090	2.00	0.0179
28	A28	Slab & Staircase finish			1	3.00							4	2.00	1	2.00	4	1.00			4	2.00			0.0083	2.00	0.0166
29	A29	Slab & Door/Window	1	4.00											1	2.00							3	4.00	0.0022	3.33	0.0075
30	A30	Slab & Sanitary ware			4	3.00			2	2.00	19	4.00	5	4.00	2	2.00					6	4.00			0.0195	3.17	0.0617
31	A31	Stair & Wall finish											7	4.00	1	1.00			2	4.00	4	3.00	3	3.00	0.0105	3.00	0.0315
32	A32	Stair & Floor finish			1	2.00							5	2.00	1	1.00					4	3.00			0.0068	2.00	0.0136
33	A33	Stair & Ceiling works	4	2.00	2	2.00							2	1.00	1	1.00			10	4.00					0.0128	2.00	0.0256
34	A34	Stair & Staircase finish	10	2.50					2	4.00					1	1.00	2	3.00	4	1.00	8	4.00	4	3.00	0.0142	2.64	0.0375
35	A35	Stair & Door/Window	5	3.00											1	1.00									0.0024	2.00	0.0049
36	A36	Stair & Sanitary ware																							0.0000	0.00	0.0000
37	A37	RC wall & Wall finish	2	4.00					10	2.00			2	2.00	2	2.00	21	2.00			6	4.00	4	4.00	0.0268	2.86	0.0767
38	A38	RC wall & Floor finish																							0.0000	0.00	0.0000
39	A39	RC wall & Ceiling works													2	2.00							3	3.00	0.0024	2.50	0.0061
40	A40	RC wall & Staircase finish													2	3.00					3	1.00	4	4.00	0.0038	2.67	0.0102
41	A41	RC wall & Door/Window			1	4.00									2	1.00	4	4.00	6	1.00	4	4.00	4	4.00	0.0118	3.00	0.0353
42	A42	RC wall & Sanitary ware																			8	1.00	2	2.00	0.0034	1.50	0.0050
		A : Total No. of cases / Mean value of I	***71***	***3.20***	***46***	***3.00***	***144***	***1.90***	***47***	***2.09***	***57***	***2.11***	***49***	***2.08***	***40***	***1.81***	***70***	***3.11***	***49***	***2.77***	***99***	***2.71***	***59***	***3.31***			

No.	Code	Design errors between structure and other building components	Project 1 (Hotel)		Project 2 (Hotel)		Project 3 (Hotel)		Project 4 (Hotel)		Project 5 (Condominium)		Project 6 (Apartment)		Project 7 (Apartment)		Project 8 (Commercial Building)		Project 9 (Commercial Building)		Project 10 (Commercial Building)		Project 11 (Shopping Center)		Average Score		*Risk Analysis*
			No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	Percentage Occurrence	Impact	*R = P x I*
	B - Design errors between structure and structure																										
43	B1	Retaining wall & Retaining wall			4	3.00	4	4.00			1	1.00			2	2.00			4	2.00	3	3.00	3	4.00	0.0111	2.71	0.0302
44	B2	Retaining wall & Footing	1	3.00											2	3.00	8	4.00					2	4.00	0.0071	3.50	0.0249
45	B3	Retaining wall & Beam	2	3.00	3	3.00	4	3.00	6	2.00					1	2.00	2	1.00			2	1.00			0.0110	2.14	0.0237
46	B4	Retaining wall & Column													2	2.00	4	4.00	1	1.00	1	2.00			0.0046	2.25	0.0103
47	B5	Retaining wall & Slab													1	2.00					2	2.00	2	3.00	0.0021	2.33	0.0048
48	B6	Retaining wall & Stair																							0.0000	0.00	0.0000
49	B7	Retaining wall & RC wall	1	3.00					2	2.00					2	2.00					3	3.00			0.0039	2.50	0.0098
50	B8	Footing & Retaining wall	3	2.00											2	2.00	4	2.00			2	1.00	2	4.00	0.0061	2.20	0.0135
51	B9	Footing & Footing	2	2.00			4	2.00	4	2.00					2	4.00	4	4.00	2	4.00	3	3.00			0.0108	3.00	0.0325
52	B10	Footing & Beam	5	3.00			4	2.00	2	3.00	19	1.00					6	4.00			2	1.00	3	4.00	0.0177	2.57	0.0456
53	B11	Footing & Column	3	2.00	2	1.00	4	2.00			19	2.00			2	3.00	4	4.00			1	2.00	4	4.00	0.0172	2.50	0.0429
54	B12	Footing & Slab	4	2.00			4	2.00													2	1.00			0.0034	1.67	0.0056
55	B13	Footing & Stair																							0.0000	0.00	0.0000
56	B14	Footing & RC wall	3	2.00											2	1.00					1	1.00			0.0026	1.33	0.0034
57	B15	Beam & Retaining wall	2	2.33	3	1.00	4	3.00			1	1.00									1	2.00	4	3.00	0.0068	2.06	0.0139
58	B16	Beam & Footing	4	2.50			4	4.00			19	1.00	4	2.00	2	2.00					2	3.00	3	3.00	0.0169	2.50	0.0422
59	B17	Beam & Beam	6	3.50	4	3.00	8	2.00	6	2.00	1	1.00	5	2.00	2	3.00	10	3.00	2	1.00	3	3.00	3	4.00	0.0276	2.50	0.0689
60	B18	Beam & Column	6	3.00	4	4.00					19	1.00			2	3.00	6	3.00	2	1.00	4	4.00	4	4.00	0.0222	2.88	0.0639
61	B19	Beam & Slab	3	3.00											2	2.00			2	1.00	4	4.00	3	3.00	0.0063	2.60	0.0164
62	B20	Beam & Stair	2	3.00											2	2.00					3	3.00	3	4.00	0.0041	3.00	0.0124
63	B21	Beam & RC wall	1	4.00					2	1.00	1	2.00			2	2.00					3	3.00	3	3.00	0.0056	2.50	0.0140
64	B22	Column & Retaining wall	4	2.00													2	1.00			1	2.00	4	3.00	0.0047	2.00	0.0095
65	B23	Column & Footing	4	2.00	2	3.00							2	1.00	2	3.00					2	3.00	4	4.00	0.0082	2.67	0.0220
66	B24	Column & Beam	3	2.50					10	3.00	19	1.00			3	3.00	12	4.00		1.00	3	4.00	4	4.00	0.0276	2.81	0.0775
67	B25	Column & Column	3	3.50	4	2.00	4	2.00	2	2.00	19	1.00	2	4.00	2	2.00			2	1.00	6	2.00	3	4.00	0.0221	2.35	0.0520
68	B26	Column & Slab	5	2.00	1	2.00									2	2.00					5	4.00	3	4.00	0.0067	2.80	0.0186
69	B27	Column & Stair	2	2.00											2	1.00					3	2.00			0.0028	1.67	0.0047
70	B28	Column & RC wall	4	2.00											2	2.00					2	1.00	3	4.00	0.0046	2.25	0.0103
71	B29	Slab & Retaining wall	3	2.00			4	3.00													1	2.00	2	3.00	0.0035	2.50	0.0088
72	B30	Slab & Footing	2	2.00																	1	3.00			0.0011	2.50	0.0027
73	B31	Slab & Beam	3	3.00											3	3.00	2	2.00			2	4.00	3	3.00	0.0059	3.00	0.0178
74	B32	Slab & Column	2	2.00	2	2.00									2	2.00					2	3.00	3	4.00	0.0054	2.60	0.0140
75	B33	Slab & Slab					4	2.00	2	1.00	1	1.00	5	2.00	2	2.00			2	1.00	2	3.00	2	3.00	0.0114	1.88	0.0214
76	B34	Slab & Stair	1	4.00	2	3.00									2	2.00					2	3.00	2	4.00	0.0046	3.20	0.0146
77	B35	Slab & RC wall	1	4.00							1	1.00			2	2.00					1	2.00			0.0022	2.25	0.0050
78	B36	Stair & Retaining wall																							0.0000	0.00	0.0000
79	B37	Stair & Footing																							0.0000	0.00	0.0000
80	B38	Stair & Beam	3	4.50	4	4.00									2	2.00					3	4.00			0.0063	3.63	0.0229
81	B39	Stair & Column	2	4.00	3	4.00									2	2.00					1	2.00	4	4.00	0.0063	3.20	0.0201
82	B40	Stair & Slab	2	3.00	2	2.00							4	1.00	2	2.00			2	2.00	2	3.00	2	3.00	0.0098	2.29	0.0224
83	B41	Stair & Stair					4	2.00							2	2.00					5	4.00			0.0039	2.67	0.0105
84	B42	Stair & RC wall							2	3.00					2	2.00					1	1.00			0.0029	2.00	0.0058
85	B43	RC wall & Retaining wall																							0.0000	0.00	0.0000
86	B44	RC wall & Footing	1	3.00											2	1.00					2	1.00			0.0021	1.67	0.0036
87	B45	RC wall & Beam													3	3.00					1	2.00	3	3.00	0.0033	2.67	0.0089
88	B46	RC wall & Column	2	2.00											2	2.00					3	3.00	3	3.00	0.0041	2.50	0.0103
89	B47	RC wall & Slab					4	2.00	2	1.00					2	2.00					2	3.00			0.0044	2.00	0.0089
90	B48	RC wall & Stair																							0.0000	0.00	0.0000

No.	Code	Design errors between structure and other building components	Project 1 (Hotel)		Project 2 (Hotel)		Project 3 (Hotel)		Project 4 (Hotel)		Project 5 (Condominium)		Project 6 (Apartment)		Project 7 (Apartment)		Project 8 (Commercial Building)		Project 9 (Commercial Building)		Project 10 (Commercial Building)		Project 11 (Shopping Center)		Average Score		*Risk Analysis*
			No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	Percentage Occurrence	Impact	*R = P x I*
91	B49	RC wall & RC wall					4	3.00					2	3.00	1	1.00			2	2.00	3	4.00			0.0059	2.60	0.0154
		B: Total No. of cases / Mean value of I	***95***	***2.73***	***40***	***2.64***	***64***	***2.53***	***40***	***2.00***	***120***	***1.17***	***24***	***2.14***	***74***	***2.16***	***64***	***3.00***	***21***	***1.55***	***98***	***2.55***	***84***	***3.57***			
	C - Design errors between structure and mechanical works																										
92	C1	Retaining wall & HVAC systems	2	3.00			2	4.00	2	3.00											2	1.00	2	2.00	0.0043	2.60	0.0112
93	C2	Retaining wall & Lift systems	1	4.00																	1	1.00			0.0007	2.50	0.0017
94	C3	Footing & HVAC systems																					2	3.00	0.0009	3.00	0.0026
95	C4	Footing & Lift systems									2	4.00											2	3.00	0.0017	3.50	0.0059
96	C5	Beam & HVAC systems	3	4.00					6	3.00			4	3.00	2	2.00			15	2.00	2	2.00	4	4.00	0.0236	2.86	0.0675
97	C6	Beam & Lift systems	3	4.00	2	4.00							6	2.00	2	2.00					3	2.00			0.0098	2.80	0.0274
98	C7	Column & HVAC systems	1	2.00																	2	2.00	2	4.00	0.0019	2.67	0.0050
99	C8	Column & Lift systems			1	4.00													4	4.00	1	1.00			0.0041	3.00	0.0123
100	C9	Slab & HVAC systems	7	4.00			20	4.00	2	1.00			1	4.00	2	2.00					5	4.00	3	3.00	0.0151	3.14	0.0474
101	C10	Slab & Lift systems							2	2.00					2	2.00					3	3.00			0.0035	2.33	0.0082
102	C11	Stair & HVAC systems																							0.0000	0.00	0.0000
103	C12	Stair & Lift systems																							0.0000	0.00	0.0000
104	C13	RC wall & HVAC systems	4	3.67											1	1.00					4	3.00	2	3.00	0.0042	2.67	0.0112
105	C14	RC wall & Lift systems	5	3.00			24	4.00	2	5.00	2	4.00			2	2.00					3	3.00	3	4.00	0.0149	3.57	0.0532
		C : Total No. of cases / Mean value of I	***26***	***3.46***	***3***	***4.00***	***46***	***4.00***	***14***	***2.80***	***4***	***4.00***	***11***	***3.00***	***11***	***1.83***	***0***	***0.00***	***19***	***3.00***	***26***	***2.20***	***20***	***3.25***			
	D - Design errors between structure and electrical works																										
106	D1	Retaining wall & Electrical system	2	4.00											3	3.00					1	1.00			0.0028	2.67	0.0074
107	D2	Retaining wall & Telephone/Datacom system																							0.0000	0.00	0.0000
108	D3	Footing & Electrical system																							0.0000	0.00	0.0000
109	D4	Footing & Telephone/Datacom system																							0.0000	0.00	0.0000
110	D5	Beam & Electrical system	3	3.50	4	2.00									1	1.00					1	2.00			0.0051	2.13	0.0109
111	D6	Beam & Telephone/Datacom system																							0.0000	0.00	0.0000
112	D7	Column & Electrical system	4	4.00																	3	2.00	2	3.00	0.0033	3.00	0.0099
113	D8	Column & Telephone/Datacom system																			1	1.00	2	3.00	0.0012	2.00	0.0024
114	D9	Slab & Electrical system	3	3.50							1	3.00	2	2.00	2	2.00					4	4.00	4	4.00	0.0073	3.08	0.0226
115	D10	Slab & Telephone/Datacom system											2	2.00	2	2.00			12	3.00	3	4.00	4	4.00	0.0145	3.00	0.0435
116	D11	Stair & Electrical system																			1	2.00	3	3.00	0.0016	2.50	0.0040
117	D12	Stair & Telephone/Datacom system																					3	3.00	0.0013	3.00	0.0039
118	D13	RC wall & Electrical system	2	4.00											1	1.00					2	4.00	3	4.00	0.0032	3.25	0.0106
119	D14	RC wall & Telephone/Datacom system													1	1.00					2	4.00	3	4.00	0.0025	3.00	0.0075
		D : Total No. of cases / Mean value of I	***14***	***3.80***	***4***	***2.00***	***0***	***0.00***	***0***	***0.00***	***1***	***3.00***	***4***	***2.00***	***10***	***1.67***	***0***	***0.00***	***12***	***3.00***	***18***	***2.67***	***24***	***3.50***			
	E - Design errors between structure and plumbing works																										
120	E1	Retaining wall & Water supply and distribution system																							0.0000	0.00	0.0000
121	E2	Retaining wall & Sanitary drainage and disposal system	3	3.50			2	4.00							3	4.00					3	1.00	2	3.00	0.0052	3.10	0.0163
122	E3	Retaining wall & Storm drainage system					2	4.00			1	2.00													0.0010	3.00	0.0031
123	E4	Retaining wall & Fire protection system	1	2.00																					0.0004	2.00	0.0008
124	E5	Retaining wall & Fuel and gas piping system					6	4.00							2	2.00									0.0030	3.00	0.0089
125	E6	Footing & Water supply and distribution system	1	4.00																					0.0004	4.00	0.0015
126	E7	Footing & Sanitary drainage and disposal system							8	2.00			2	2.00									2	4.00	0.0084	2.67	0.0223
127	E8	Footing & Storm drainage system	2	2.00					8	2.00													2	4.00	0.0074	2.67	0.0198

No.	Code	Design errors between structure and other building components	Project 1 (Hotel)		Project 2 (Hotel)		Project 3 (Hotel)		Project 4 (Hotel)		Project 5 (Condominium)		Project 6 (Apartment)		Project 7 (Apartment)		Project 8 (Commercial Building)		Project 9 (Commercial Building)		Project 10 (Commercial Building)		Project 11 (Shopping Center)		Average Score		*Risk Analysis*
			No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	No. of cases	I	Percentage Occurrence	Impact	*R = P x I*
128	E9	Footing & Fire protection system							2	5.00									3	2.00					0.0037	3.50	0.0130
129	E10	Footing & Fuel and gas piping system																							0.0000	0.00	0.0000
130	E11	Beam & Water supply and distribution system	1	4.00											2	2.00					3	1.00			0.0024	2.33	0.0057
131	E12	Beam & Sanitary drainage and disposal system	3	3.00	3	4.00					4	2.00	4	4.00	2	2.00	6	4.00			1	1.00			0.0134	2.86	0.0384
132	E13	Beam & Storm drainage system	1	3.00							8	3.00									3	1.00			0.0046	2.33	0.0106
133	E14	Beam & Fire protection system	3	3.00											2	2.00			1	4.00	2	3.00	3	3.00	0.0049	3.00	0.0148
134	E15	Beam & Fuel and gas piping system													1	1.00					2	2.00			0.0012	1.50	0.0018
135	E16	Column & Water supply and distribution system	4	2.00																	1	1.00			0.0018	1.50	0.0027
136	E17	Column & Sanitary drainage and disposal system	5	2.00																	2	1.00			0.0025	1.50	0.0038
137	E18	Column & Storm drainage system	1	3.00											2	1.00					1	1.00			0.0018	1.67	0.0030
138	E19	Column & Fire protection system																							0.0000	0.00	0.0000
139	E20	Column & Fuel and gas piping system																							0.0000	0.00	0.0000
140	E21	Slab & Water supply and distribution system			15	3.00	4	4.00	2	2.00			8	2.00	2	2.00					5	4.00			0.0238	2.83	0.0673
141	E22	Slab & Sanitary drainage and disposal system			2	2.00	4	4.00	2	2.00	19	1.00	2	5.00	2	3.00	10	3.00	11	3.00	4	4.00			0.0302	3.00	0.0905
142	E23	Slab & Storm drainage system	3	4.00			24	4.00	2	2.00	8	1.00	4	2.00	1	1.00					1	1.00	3	3.00	0.0188	2.25	0.0422
143	E24	Slab & Fire protection system			4	2.00					2	1.00			2	2.00					4	4.00			0.0063	2.25	0.0142
144	E25	Slab & Fuel and gas piping system																							0.0000	0.00	0.0000
145	E26	Stair & Water supply and distribution system																							0.0000	0.00	0.0000
146	E27	Stair & Sanitary drainage and disposal system													2	2.00					1	1.00	1	2.00	0.0019	1.67	0.0031
147	E28	Stair & Storm drainage system																							0.0000	0.00	0.0000
148	E29	Stair & Fire protection system																							0.0000	0.00	0.0000
149	E30	Stair & Fuel and gas piping system																							0.0000	0.00	0.0000
150	E31	RC wall & Water supply and distribution system	4	3.00													2	4.00			3	4.00	2	3.00	0.0045	3.50	0.0157
151	E32	RC wall & Sanitary drainage and disposal system	4	3.00													2	4.00			5	2.00			0.0042	3.00	0.0127
152	E33	RC wall & Storm drainage system																	5	4.00	3	3.00	3	3.00	0.0060	3.33	0.0200
153	E34	RC wall & Fire protection system																			4	3.00	2	3.00	0.0021	3.00	0.0063
154	E35	RC wall & Fuel and gas piping system													2	2.00					3	3.00	2	3.00	0.0029	2.67	0.0078
		E : Total No. of cases / Mean value of I	*36*	*2.96*	*24*	*2.75*	*42*	*4.00*	*24*	*2.50*	*42*	*1.67*	*20*	*3.00*	*25*	*2.00*	*20*	*3.75*	*20*	*3.25*	*51*	*2.16*	*22*	*3.10*			
	Total		**242**		**117**		**296**		**125**		**224**		**108**		**160**		**154**		**121**		**292**		**209**				

APPENDIX C

RANKING OF CASES OF DESIGN ERRORS UNDER NINE PRIORITY ZONES

Ranking Of Cases Of Design Errors Under Nine Priority Zones						
No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Zone I (N/A)				
		Zone II				
1	C14	RC wall and Lift systems	1.49%	3.57	0.0532	1
		Zone III				
2	B2	Retaining wall and Footing	0.71%	3.50	0.0249	1
3	B38	Stair and Beam	0.63%	3.63	0.0229	2
4	E33	RC wall and Storm drainage system	0.60%	3.33	0.0200	3
5	A25	Slab and Wall finish	0.59%	3.33	0.0197	4
6	E31	RC wall and Water supply and distribution system	0.45%	3.50	0.0157	5
7	E9	Footing and Fire protection system	0.37%	3.50	0.0130	6
8	A24	Column and Sanitary ware	0.31%	4.00	0.0124	7
9	A29	Slab and Door/Window	0.22%	3.33	0.0075	8
10	C4	Footing and Lift systems	0.17%	3.50	0.0059	9
11	E6	Footing and Water supply and distribution system	0.04%	4.00	0.0015	10
		Zone IV				
12	A26	Slab and Floor finish	4.10%	3.00	0.1231	1
13	A19	Column and Wall finish	4.78%	2.13	0.1016	2
14	E22	Slab and Sanitary drainage and disposal system	3.02%	3.00	0.0905	3
15	B24	Column and Beam	2.76%	2.81	0.0775	4
16	A37	RC wall and Wall finish	2.68%	2.86	0.0767	5
17	A15	Beam and Ceiling works	3.05%	2.40	0.0733	6
18	A13	Beam and Wall finish	3.25%	2.21	0.0717	7
19	B17	Beam and Beam	2.76%	2.50	0.0689	8
20	C5	Beam and HVAC systems	2.36%	2.86	0.0675	9
21	E21	Slab and Water supply and distribution system	2.38%	2.83	0.0673	10
22	B18	Beam and Column	2.22%	2.88	0.0639	11
23	A30	Slab and Sanitary ware	1.95%	3.17	0.0617	12
24	B25	Column and Column	2.21%	2.35	0.0520	13
25	B10	Footing and Beam	1.77%	2.57	0.0456	14
26	A17	Beam and Door/Window	1.75%	2.57	0.0450	15
27	B11	Footing and Column	1.72%	2.50	0.0429	16
28	E23	Slab and Storm drainage system	1.88%	2.25	0.0422	17
29	B16	Beam and Footing	1.69%	2.50	0.0422	18

Ranking Of Cases Of Design Errors Under Nine Priority Zones

No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Zone V				
30	C9	Slab and HVAC systems	1.51%	3.14	0.0474	1
31	D10	Slab and Telephone/Datacom system	1.45%	3.00	0.0435	2
32	E12	Beam and Sanitary drainage and disposal system	1.34%	2.86	0.0384	3
33	A34	Stair and Staircase finish	1.42%	2.64	0.0375	4
34	A41	RC wall and Door/Window	1.18%	3.00	0.0353	5
35	B9	Footing and Footing	1.08%	3.00	0.0325	6
36	A31	Stair and Wall finish	1.05%	3.00	0.0315	7
37	B1	Retaining wall and Retaining wall	1.11%	2.71	0.0302	8
38	C6	Beam and Lift systems	0.98%	2.80	0.0274	9
39	A1	Retaining wall and Wall finish	1.01%	2.63	0.0265	10
40	A33	Stair and Ceiling works	1.28%	2.00	0.0256	11
41	B3	Retaining wall and Beam	1.10%	2.14	0.0237	12
42	A14	Beam and Floor finish	1.04%	2.20	0.0229	13
43	B40	Stair and Slab	0.98%	2.29	0.0224	14
44	E7	Footing and Sanitary drainage and disposal system	0.84%	2.67	0.0223	15
45	B23	Column and Footing	0.82%	2.67	0.0220	16
46	B33	Slab and Slab	1.14%	1.88	0.0214	17
47	A27	Slab and Ceiling works	0.90%	2.00	0.0179	18
48	A28	Slab and Staircase finish	0.83%	2.00	0.0166	19
		Zone VI				
49	D9	Slab and Electrical system	0.73%	3.08	0.0226	1
50	B39	Stair and Column	0.63%	3.20	0.0201	2
51	E8	Footing and Storm drainage system	0.74%	2.67	0.0198	3
52	B26	Column and Slab	0.67%	2.80	0.0186	4
53	A23	Column and Door/Window	0.57%	3.20	0.0181	5
54	B31	Slab and Beam	0.59%	3.00	0.0178	6
55	B19	Beam and Slab	0.63%	2.60	0.0164	7
56	E2	Retaining wall and Sanitary drainage and disposal system	0.52%	3.10	0.0163	8

Ranking Of Cases Of Design Errors Under Nine Priority Zones						
No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Zone VI				
57	B49	RC wall and RC wall	0.59%	2.60	0.0154	9
58	E14	Beam and Fire protection system	0.49%	3.00	0.0148	10
59	B34	Slab and Stair	0.46%	3.20	0.0146	11
60	A2	Retaining wall and Floor finish	0.54%	2.67	0.0143	12
61	E24	Slab and Fire protection system	0.63%	2.25	0.0142	13
62	B21	Beam and RC wall	0.56%	2.50	0.0140	14
63	B32	Slab and Column	0.54%	2.60	0.0140	15
64	B15	Beam and Retaining wall	0.68%	2.06	0.0139	16
65	A32	Stair and Floor finish	0.68%	2.00	0.0136	17
66	B8	Footing and Retaining wall	0.61%	2.20	0.0135	18
67	E32	RC wall and Sanitary drainage and disposal system	0.42%	3.00	0.0127	19
68	B20	Beam and Stair	0.41%	3.00	0.0124	20
69	C8	Column and Lift systems	0.41%	3.00	0.0123	21
70	C1	Retaining wall and HVAC systems	0.43%	2.60	0.0112	22
71	C13	RC wall and HVAC systems	0.42%	2.67	0.0112	23
72	D5	Beam and electrical system	0.51%	2.13	0.0109	24
73	A22	Column and Staircase finish	0.46%	2.33	0.0108	25
74	E13	Beam and Storm drainage system	0.46%	2.33	0.0106	26
75	A18	Beam and Sanitary ware	0.53%	2.00	0.0106	27
76	D13	RC wall and Electrical system	0.32%	3.25	0.0106	28
77	B41	Stair and Stair	0.39%	2.67	0.0105	29
78	B46	RC wall and Column	0.41%	2.50	0.0103	30
79	B28	Column and RC wall	0.46%	2.25	0.0103	31
80	B4	Retaining wall and Column	0.46%	2.25	0.0103	32
81	A40	RC wall and Staircase finish	0.38%	2.67	0.0102	33
82	A16	Beam and Staircase finish	0.47%	2.13	0.0100	34
83	D7	Column and Electrical system	0.33%	3.00	0.0099	35

Ranking Of Cases Of Design Errors Under Nine Priority Zones

No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Zone VI				
84	B7	Retaining wall and RC wall	0.39%	2.50	0.0098	36
85	B22	Column and retaining wall	0.47%	2.00	0.0095	37
86	E5	Retaining wall and Fuel and gas piping system	0.30%	3.00	0.0089	38
87	B47	RC wall and Slab	0.44%	2.00	0.0089	39
88	B45	RC wall and Beam	0.33%	2.67	0.0089	40
89	B29	Slab and Retaining wall	0.35%	2.50	0.0088	41
90	C10	Slab and Lift systems	0.35%	2.33	0.0082	42
91	E35	RC wall and Fuel and gas piping system	0.29%	2.67	0.0078	43
92	D14	RC wall and Telephone/Datacom system	0.25%	3.00	0.0075	44
93	D1	Retaining wall and Electrical system	0.28%	2.67	0.0074	45
94	E34	RC wall and Fire protection system	0.21%	3.00	0.0063	46
95	A39	RC wall and Ceiling works	0.24%	2.50	0.0061	47
96	B42	Stair and RC wall	0.29%	2.00	0.0058	48
97	E11	Beam and Water supply and distribution system	0.24%	2.33	0.0057	49
98	B12	Footing and Slab	0.34%	1.67	0.0056	50
99	B35	Slab and RC wall	0.22%	2.25	0.0050	51
100	C7	Column and HVAC systems	0.19%	2.67	0.0050	52
101	A35	Stair and Door/Window	0.24%	2.00	0.0049	53
102	B5	Retaining wall and Slab	0.21%	2.33	0.0048	54
103	B27	Column and Stair	0.28%	1.67	0.0047	55
104	D11	Stair and Electrical system	0.16%	2.50	0.0040	56
105	A5	Retaining wall and Door/Window	0.13%	3.00	0.0039	57
106	D12	Stair and Telephone/datacom system	0.13%	3.00	0.0039	58
107	B44	RC wall and Footing	0.21%	1.67	0.0036	59
108	A8	Footing and Floor finish	0.12%	3.00	0.0035	60
109	E27	Stair and Sanitary drainage and disposal system	0.19%	1.67	0.0031	61
110	E3	Retaining wall and Storm drainage system	0.10%	3.00	0.0031	62

Ranking Of Cases Of Design Errors Under Nine Priority Zones

No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Zone VI				
111	E18	Column and Storm drainage system	0.18%	1.67	0.0030	63
112	B30	Slab and Footing	0.11%	2.50	0.0027	64
113	C3	Footing and HVAC systems	0.09%	3.00	0.0026	65
114	D8	Column and Telephone/datacom system	0.12%	2.00	0.0024	66
115	C2	Retaining wall and Lift systems	0.07%	2.50	0.0017	67
116	E4	Retaining wall and Fire protection system	0.04%	2.00	0.0008	68
		Zone VII (N/A)				
		Zone VIII (N/A)				
		Zone IX				
117	A42	RC wall and Sanitary ware	0.34%	1.50	0.0050	1
118	E17	Column and Sanitary drainage and disposal system	0.25%	1.50	0.0038	2
119	B14	Footing and RC wall	0.26%	1.33	0.0034	3
120	E16	Column and Water supply and distribution system	0.18%	1.50	0.0027	4
121	A4	Retaining wall and Staircase finish	0.15%	1.50	0.0023	5
122	E15	Beam and Fuel and gas piping system	0.12%	1.50	0.0018	6
		Impossible to Occur				
123	A3	Retaining wall and Ceiling works	N/A	N/A	N/A	N/A
124	A6	Retaining wall and Sanitary ware	N/A	N/A	N/A	N/A
125	A7	Footing and Wall finish	N/A	N/A	N/A	N/A
126	A9	Footing and Ceiling works	N/A	N/A	N/A	N/A
127	A10	Footing and Staircase finish	N/A	N/A	N/A	N/A
128	A11	Footing and Door/Window	N/A	N/A	N/A	N/A
129	A12	Footing and Sanitary ware	N/A	N/A	N/A	N/A
130	A20	Column and Floor finish	N/A	N/A	N/A	N/A
131	A21	Column and Ceiling works	N/A	N/A	N/A	N/A
132	A36	Stair and Sanitary ware	N/A	N/A	N/A	N/A

Ranking Of Cases Of Design Errors Under Nine Priority Zones						
No.	Code	Design errors between structure and other building components	Percentage Occurrence	Impact	R=PxI	Ranking
		Impossible to Occur				
133	A38	RC wall and Floor finish	N/A	N/A	N/A	N/A
134	B6	Retaining wall and Stair	N/A	N/A	N/A	N/A
135	B13	Footing and Stair	N/A	N/A	N/A	N/A
136	B36	Stair and Retaining wall	N/A	N/A	N/A	N/A
137	B37	Stair and Footing	N/A	N/A	N/A	N/A
138	B43	RC wall and Retaining wall	N/A	N/A	N/A	N/A
139	B48	RC wall and Stair	N/A	N/A	N/A	N/A
140	C11	Stair and HVAC systems	N/A	N/A	N/A	N/A
141	C12	Stair and Lift systems	N/A	N/A	N/A	N/A
142	D2	Retaining wall and Telephone/datacom system	N/A	N/A	N/A	N/A
143	D3	Footing and Electrical system	N/A	N/A	N/A	N/A
144	D4	Footing and Telephone/datacom system	N/A	N/A	N/A	N/A
145	D6	Beam and Telephone/datacom system	N/A	N/A	N/A	N/A
146	E1	Retaining wall and Water supply and distribution system	N/A	N/A	N/A	N/A
147	E10	Footing and Fuel and gas piping system	N/A	N/A	N/A	N/A
148	E19	Column and Fire protection system	N/A	N/A	N/A	N/A
148	E20	Column and Fuel and gas piping system	N/A	N/A	N/A	N/A
150	E25	Slab and Fuel and gas piping system	N/A	N/A	N/A	N/A
151	E26	Stair and Water supply and distribution system	N/A	N/A	N/A	N/A
152	E28	Stair and Storm drainage system	N/A	N/A	N/A	N/A
153	E29	Stair and Fire protection system	N/A	N/A	N/A	N/A
154	E30	Stair and Fuel and gas piping system	N/A	N/A	N/A	N/A

APPENDIX D

DATA COLLECTION OF PART 2:

SURVEY QUESTIONNAIRE 2

Chulalongkorn University
จุฬาลงกรณ์มหาวิทยาลัย
Pillar of the Kingdom

Faculty of Engineering
Department of Civil Engineering
Construction Engineering and Management Division

SURVEY QUESTIONNAIRE

CASES OF DESIGN ERRORS IN BUILDING CONSTRUCTION PROJECTS

Case Study: Cambodia

No: ______________________________

Date: ____________________________

Description

This survey questionnaire is conducted in order to deeply study about the conditions of the important design errors between structure and other building components such as structure, architecture, and MEP systems (Mechanical/Electrical/Plumbing) in building construction projects. According to this objective, the questionnaires are prepared and divided into two following sections.

Section 1: General information

Please fill your general information in the following blanks:

Background of respondents

1. Name (Mr/Ms/Mrs): ____
2. Organization/Company: ____
3. Position:____
4. Education: ☐Bachelor ☐Master ☐Ph.D.
5. Years of experience: ____
6. Tel: ______________________ E-mail: ______________________

Section 2: Description of design errors' cases

Instruction: Please tick in the right column in the following table if you used to meet any case of design errors in building construction projects based on your experience. Next, you will be requested to describe each case of design errors you have ticked. The key terms and some examples are also provided for you as a guideline in the last three pages.

No.	Cases of Design Errors	Tick if you used to meet
	Retaining wall and other components	
1	Retaining wall and Beam	
2	Retaining wall and Footing	
3	Retaining wall and Retaining wall	
4	Retaining wall and Wall finish	
	Footing and other components	
5	Footing and Beam	
6	Footing and Column	
7	Footing and Fire protection system	
8	Footing and Footing	
9	Footing and Water supply and distribution system	
10	Footing and Lift systems	
11	Footing and Sanitary drainage and disposal system	
	Beam and other components	
12	Beam and Beam	
13	Beam and Ceiling works	
14	Beam and Column	
15	Beam and Door/Window	
16	Beam and Floor finish	
17	Beam and Footing	
18	Beam and HVAC systems (duct/vent/exhaust…)	
19	Beam and Lift systems	
20	Beam and Sanitary drainage and disposal system	
21	Beam and Wall finish	

No.	**Cases of Design Errors**	**Tick if you used to meet**
	Column and other components	
22	Column and Beam	
23	Column and Column	
24	Column and Footing	
25	Column and Sanitary ware (restroom/kitchen materials)	
26	Column and Wall finish	
	Slab and other components	
27	Slab and Ceiling works	
28	Slab and Door/Window	
29	Slab and Floor finish	
30	Slab and HVAC systems (duct/vent/exhaust…)	
31	Slab and Sanitary drainage and disposal system	
32	Slab and Sanitary ware (restroom/kitchen materials)	
33	Slab and Slab	
34	Slab and Staircase finish (stair handrail, steps…)	
35	Slab and Storm drainage system	
36	Slab and Telephone/Datacom system	
37	Slab and Wall finish	
38	Slab and Water supply and distribution system	
	Stair and other components	
39	Stair and Beam	
40	Stair and Ceiling works	
41	Stair and Slab	
42	Stair and Staircase finish (stair handrail, steps…)	
43	Stair and Wall finish	
	RC wall and other components **(Shear wall, lift wall…)**	
44	RC wall and Door/Window	
45	RC wall and Lift systems	
46	RC wall and Storm drainage system	
47	RC wall and Wall finish	
48	RC wall and Water supply and distribution system	

Please describe your cases of design errors that you have ticked in the following table. Case 1 and 2 are given as examples.

No.	**Structural Elements**	**Other Components**	**Problems**
1	*Beam*: The depth of beam is 500mm (including slab thickness 150mm)	*Ceiling works*: Required ceiling height below slab is 300mm	The level of bottom of beam is lower than the required ceiling level 50mm. This problem occurs because the depth of beam is higher than it should be to suit the ceiling design.
2	*Beam*: Depth of beam	*Ceiling works*: Ceiling level	The space between the bottom of beam and required ceiling level is not enough for MEP installation.

No.	Structural Elements	Other Components	Problems

This is the end of questionnaire. Thanks you very much for your cooperation.

KEY TERMS:

- ***HVAC systems*** include the following basic components: (1) Heat-generating system, (2) Cooling system, (3) Air-handling system, (4) Control system for hand adjusting and/or automatic monitoring of the system operation. HVAC systems include the removing of dust and odors, freshening with outdoor air, adjustment of the temperature, and adjustment of the relative humidity.

- ***Lift systems*** include the major lift components such as prime mover (electric machine or hydraulic pump), lift car (car frame), counterweight, guide rails, entrances/doors, safety gear & overspeed governor, buffers (energy accumulation, energy dissipation), roping systems (compensating ropes, traction systems), car & landing fixtures (buttons, indicators & switches).

- ***Electrical system*** is categorized into supply, distribution, and lighting.

- ***Telephone/datacom system*** use fiber optic lines.

- ***Water supply and distribution system*** consists of *cold* and *hot water distribution system.*
  1) Cold water distribution system: *Upfeed water distribution, downfeed or gravity system,* and *hydro pneumatic system (air pressure system).*
  2) Types of hot water distribution system: *Upfeed and gravity return system, downfeed and gravity return system,* and *pump circuit system.*

- ***Sanitary drainage and disposal system*** consists of *waste collection system* and *ventilation system.*

- ***Storm drainage system*** consists of *the independent system, the combined system,* and *the natural system.*

- ***Fire protection system*** is to make the building resistant by fire and to facilitate the evacuation process when there is fire.

- ***Fuel and gas piping system*** includes gas supply for laboratories, hospitals, manufacturing facilities and other buildings. The toxic gas can be released through the process piping system.

EXAMPLES OF DESIGN ERRORS BETWEEN STRUCTURE AND OTHER BUILDING COMPONENTS

CASE 1:

Case 1: Design errors between beams and ceiling works (Figure 1 and 2)	
Example 1	There is error between **beam height** and **ceiling level**. Because slab is Precast Concrete (PC), Reinforced Concrete beam is installed under the **PC slab**. Designer forgets to consider about this, the remaining **space between the soffit of beam and ceiling level** is not enough to install the **MEP systems**. Then, the design of ceiling has to be changed.
Example 2	The **depth of beam** affects the **ceiling works**. For example, the **required height of ceiling** is 300mm, but the **depth of beam** is 500mm and the **RC slab thickness** is 150mm. Thus, the soffit of beam is lower than the ceiling level 50mm. This error forces the architect to re-design the ceiling.
Example 3	Designer did not consider about the **space for MEP systems**. So, the **remaining space between soffit of beam and ceiling level** is not enough for installing MEP systems. To deal with this problem, **ceiling finish** has to drop off its level. So, the **height of beam** is very important to be considered during design process in order to avoid this issue.

CASE 2:

Case 2: Design errors between beam and doors/windows (Figure 3 and 4)	
Example 1	The **depth of beam** affects the door/window installation. For example, there is only 2.80m height from the floor to the soffit of the beam. However, the **required height of door/window** is more than 2.80m (e.g. 2.85m). This error dissatisfies the architect and owner because architect has to re-design and change the specification of the door/window to match with the structural design.
Example 2	There is error between **beam height** and the **height of door/window**. Because slab is Precast Concrete (PC), Reinforced Concrete beam is installed under the **PC slab**. Designer forgets to consider about this, there is no enough opening for door/window since **the soffit of beam is lower than the top level of door/window**. Thus, the required door/window is not able to be installed.
Example 3	Designer forgets to put **lintel** (beam) for door/window. So, there may be cracking at the top corners of that door/window.
Example 4	Because the **required floor height** is fixed and the **size of door/window** is also required by the architect/owner, designer has to adjust the **beam's depth** and **slab thickness** to make sure that the size of opening for door/window is enough. However, designer sometimes forgets to consider about this, beam overlaps the space for installing the door/window. Thus, the door/window cannot be installed.

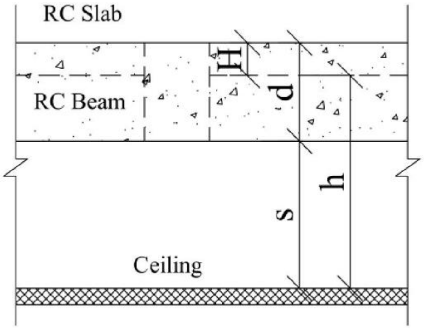


Figure 1. Case 1 (RC slab)

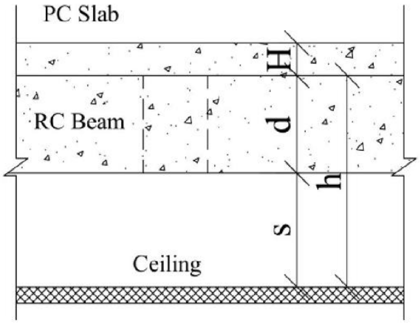


Figure 2. Case 1 (PC slab)

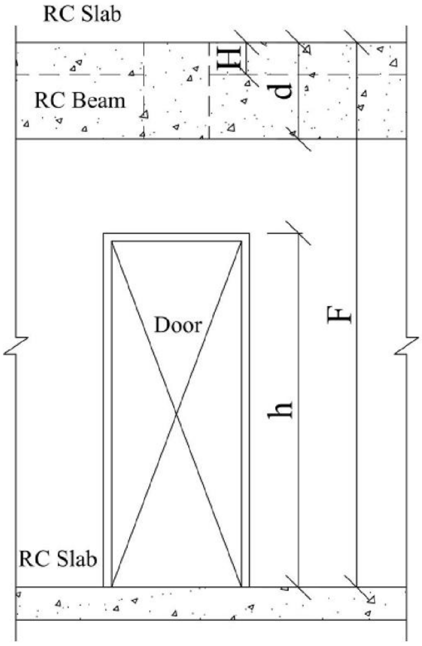


Figure 3. Case 2 (RC slab)

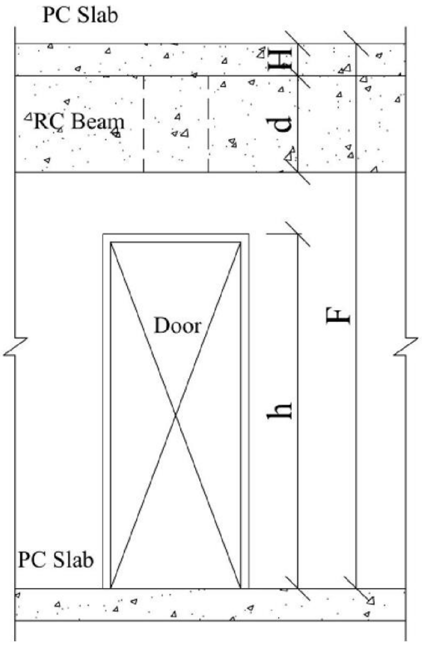


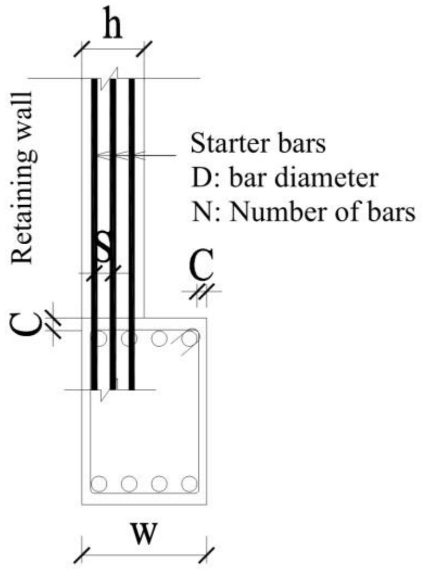
Figure 4. Case 2 (PC slab)

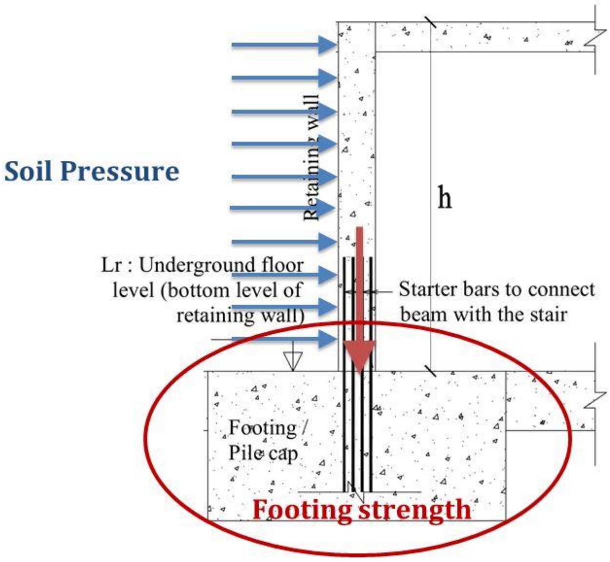
APPENDIX E

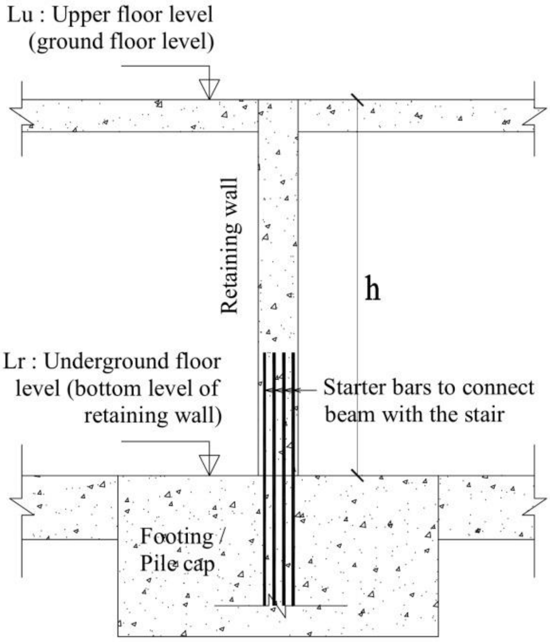
DATA COLLECTION OF PART 2:

EXAMPLES OF CASES OF DESIGN ERRORS

Examples of Cases of Design Errors

Code	**Cases**	**Problems**
Category 1: Design errors between retaining wall and other components		
1.1	**Retaining wall and beam**	
	Ex 1 [2]	The starter bars for retaining wall were not sufficient because the **beam's width** which supported that retaining wall was so small comparing to the **retaining wall thickness** and it could not install all **required starter bars to connect this beam with retaining wall**. So, the retaining wall could not stand and might be cracked. 
	Ex 2 [2]	The **location of retaining wall** was different from architectural plan, so it did not stand in the right position on the beam as mentioned in architectural layout plan.
	Ex 3 [9, 11]	Designer included only the typical designs without considering about the soil condition. The beam was wrongly designed for supporting retaining wall. The **beam strength** could not support the retaining wall effectively because designer did not consider about **soil pressure on retaining wall**. The torsion of beam occurred and the wall was cracked or might be torn.

	Ex 4 [3, 13]	The design of retaining wall was changed. The height of this wall was modified from 3m to 5m. However, the **designed beam (beam strength)** could not resist with **more loads of retaining wall**. More loads on the beam caused the cracks and the fissures on the retaining wall.
1.2	**Retaining wall and footing**	
	Ex 1 [2]	Rebar of retaining wall had to be connected from the footing. Designer did not put any **starter bars** to connect the retaining wall with footing. In this case, the fissures appeared on that wall at the joint of retaining wall and footing.
	Ex 2 [3, 11]	The problem was that piles were not used and footing was designed with 500mm depth for supporting the retaining wall. Designer did not include the **soil pressure on retaining wall**. Thus, the designed footing (**footing strength)** was found insufficient to resist with more loads. This case resulted in cracking on that wall, especially at the joint of retaining wall and footing. 
	Ex 3 [13]	The **required generator room's height at the underground floor** should equals 4m according to the generator's size and the **required upper floor level** is +0.00m due to architecture.

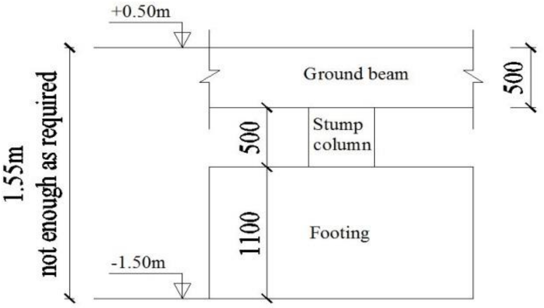
	Ex 3 [13] Continued	Designer forgot this requirement and just put -3.00m as the **underground floor level (bottom level of retaining wall)**. The height of underground floor or the height of retaining wall was not 4m as required. To deal with this problem, the level of retaining wall was dropped 1m that also reduced the footing thickness and its strength. That is why the deeper excavation was needed and moreover this affected the existing footing of the old building nearby. Contractor had to spend much time and faced a lot of difficulties in doing soil protection system. 
1.3	**Retaining wall and retaining wall**	
	Ex 1 [2]	Designer did not consider about the **water stop details** for **retaining walls** in the specification. Following to this design, the water stop at the joint between retaining walls was not installed; the walls were then fissured and the water was leaked after the structure was built.
	Ex 2 [9]	Designer forgot to give the **rebar details of the retaining wall in the specification.** The **rebar specification** for bending the reinforcement at the corner of retaining walls was not given in details about the required length and angle for bending.

1.4	**Retaining wall and wall finish**	
	Ex 1 [2]	Without considering about the **sewage pipes running through the retaining wall**, designer designed the retaining wall with very **thin thickness** (100mm). After pouring the concrete, the plastering work was starting. Then it was found that the strength of retaining wall was low which made the wall fissured. So, the water was leaked through those fissures.
	Ex 2 [6]	In design process, season was a factor which should be also considered. Designer did not know about this factor, and then the retaining wall was just designed with common structure (**thickness**) based on normal dry condition. When **the ground water level** was lower than **the bottom level of retaining wall** in dry season, the retaining wall had no any problem. While the rainy season arrives, **the ground water level becomes higher than the bottom level of retaining wall** and made the decorative wall (wall finish) spoiled or damaged due to the water leaking through the hairline cracks (fissures) of that retaining wall.
	Ex 3 [13]	Designer designed the **retaining wall with 200mm thickness** when the **required thickness of the masonry wall at the upper level** was only 160mm. Including another **10mm of plastering for each side for this masonry wall**, its exact thickness was 180mm. Based on architectural design, this masonry wall had to stand on the same central axe of retaining wall. This different thickness could create different alignment for both retaining wall and masonry wall. The solution was to increase masonry wall thickness from 160mm to 180mm. After plastering works on this masonry wall, its thickness was equal to the retaining wall thickness. The architect actually did not satisfy with the larger thickness of the masonry wall; however, the retaining wall was already built.

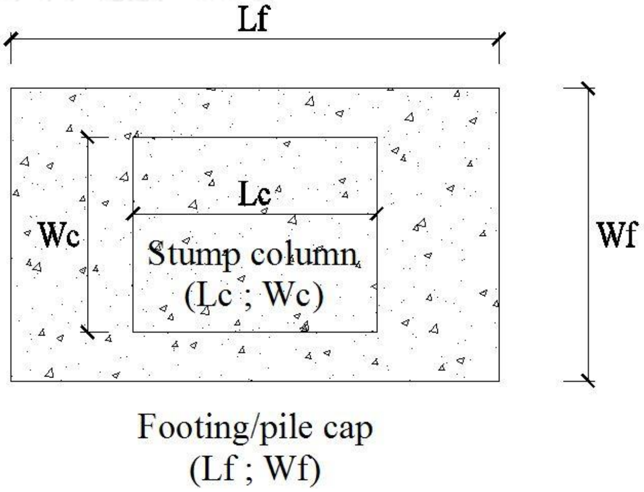
Category 2: Design errors between footing and other components

2.1 Footing and beam

Ex 1 [11] This case was related to the errors of level. The **depth of footing** is 1,100mm, whereas the **depth of ground beam** was 500mm. Between that ground beam and footing, there was a **stump column with the height of 500mm**. The **total height from the top level of beam to the bottom level of footing** should be 2.10m. The typical design only showed that the **bottom level of footing** was -1.50m. Contractor just excavated the soil and built that footing as in the design. Since footing was already built due to that incorrect level, it was then found that the **required top level of beam** was +0.05m; so the total height from the top level of beam to the bottom level of footing was only 1.55m which was not enough. Consequently, there was no space for stump column and the level of beam was dropped into the footing 50mm.



Ex 2 [11, 13] In this design, there was **no stump column**. Designer made mistake on the **top level of pile cap**. Based on the structural design, the **top level of pile cap** was 800mm lower than the **top level of beam at the basement**. In fact, both levels should be equal and there should not have any free space. Because the depth of beam was 500mm, so the free space between the bottom level of beam and the top level of pile cap was 300mm. The solution of this issue was to extrude that pile cap 800mm up to the top level of beam since the pile head was already cut.

	Ex 3 [13]	In this issue, designer did not properly study about the site condition and environment. The piles could not be bored because the **position of pile cap** was too close to the **existing building** nearby. It means the pile cap was just connected with that existing building. Then designer just redesigned it by moving the position of pile cap and piles in a safety distance of 500mm from the boundary line and the cantilever beam was designed to support the added column next to that existing building.
2.2	**Footing and column**	
	Ex 1 [2]	The **size of footing** was 1000mm x 600mm and **the size of stump column** was 600mm x 600mm. The **width of column and footing** was equal to 600mm. This indicated that there was no any **safety space between stump column and footing**. 
	Ex 2 [13]	Designer did not carefully consider about the neighboring condition during design process. The **position of footing** was too close to the boundary line of the neighboring **existing building**. The conflict between the contractor and neighbor arose due to this design. Therefore, the footings along the boundary line were moved inside in a satisfied distance to avoid serious conflict. So, the stump column was redesigned by applying the eccentric loads on footing.

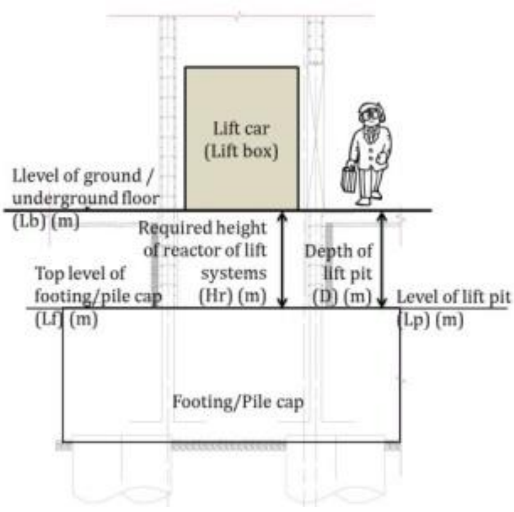
2.3	**Footing and fire protection system**	
	Ex1 [9]	This case was similar to the problem between footing and water supply and distribution system. Before construction, it was found that the **footing is placed above the pipe of fire protection system**. If this pipe was placed under the footing, it is impossible because the pipe might be damaged and the water might be leaked because of the loads from the footing. After design revision, this pipe passed **above the footing**; so the pipe did not receive any load from the footing.
	Ex 2 [12]	This is similar to the first example. **The pipe of fire protection system** required the slope. So, it was found that this pipe has to run **across the footing section**. Without considering about this system, the pipe had conflict with the **footing section** and this pipe was impossible to be installed. Last, it was decided to run that pipe **above the footing** and passed through the stump column instead.
2.4	**Footing and footing**	
	Ex 1 [2]	Two footings had conflict with each other. A footing went through and overlapped the other footing because of lack of attention from designer. For this issue, the **position of both footings** had to be checked.
	Ex 2 [4]	The **size of footing** was of much concern. The **required distribution bars for footing (longitudinal and transversal reinforcement)** could not be installed properly because there was no **spacing between those bars** due to the big **bar diameter** and **its number**. This meant that the space for placing the required reinforcement for footing itself was not adequate and many conflicts among those bars occurred. Too much reinforcement reduced the **concrete cover for footing** that might influence the strength of concrete.

	Ex 3 [8, 11, 13]	Regardless of the constructability consideration, two large footings were designed very close to each other. The size of these footings was 1,800mm x 1,800mm x 1,000mm. **The space between these footings** was only 400mm. This close space affected the excavation works, which needed a lot time and efforts spending on excavation. These two large footings should be combined together. However, this combination was not allowed if it was at the construction joint.
2.5	**Footing and water supply and distribution system**	
	Ex 1 [12]	The water pipes of water supply and distribution system ran in the substructure to pump the water from the public water supply system and then the water was distributed to the building. The **route of these pipes** had conflict with the footing. Before construction, it was found that these pipes ran **under the footing**. Because the loads from footing imposed on these pipes, the pipes would be damaged if it was placed under the footing. The water might be leaked and the water could not sufficiently supply for utilities. Thus, the design of the route of water pipe was changed to run **above the footing**.
	Ex2 [12]	It was very difficult for maintenance the pipe of water supply and distribution system. When this pipe was damaged, the water could not supply sufficiently to the users. The problem was that the **pipe of water supply and distribution system** was found having conflict with **the footing section**. Since the pipe needed slope to pump the water from the main water supply to the water tank, it was found that this pipe had to run across the footing section. Actually, it was not allowed to run the pipe in the footing section. Thus, the route of this pipe was changed to run **above the footing** to avoid the clash with footing.

2.6 Footing and lift systems

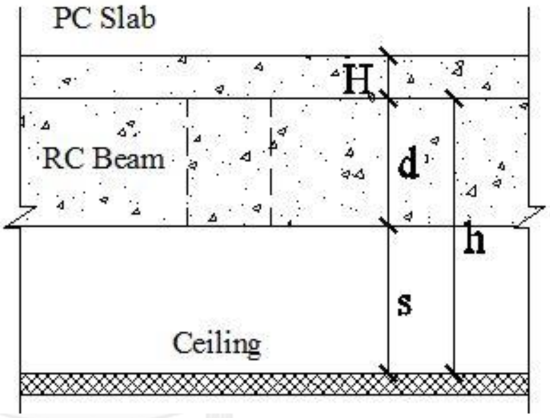
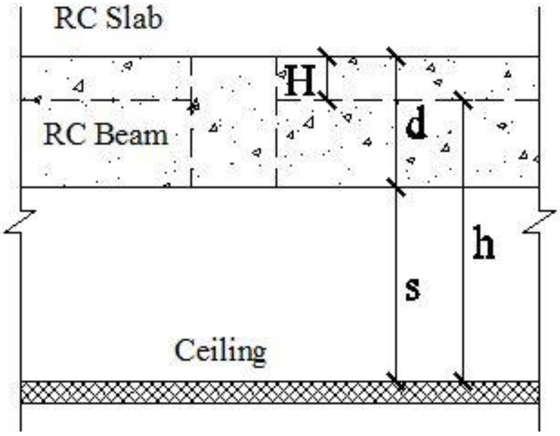
Ex 1 [9] Under the lift box, there should have a **lift pit** at the ground floor. Without considering about the requirement of lift pit, designer just designed the **footing with a high level** which influenced the **depth of lift pit**. The lift used in this building was a kind of **hydraulic lift**, the **reactor of the system thus requires a height** of 1.60m. This lift pit had conflict with the reactor of lift system because the **depth of lift pit** was only 1.40m which was less than the requirement of the reactor. For this case, it was unsafe because the reactor could not work properly. Besides, if it was a kind of **electric lift**, there was no any design error between footing and lift systems since the motor for lift system was installed at the top of the lift.

Ex 2 [10] The **top level of footing** was -1.50m and the **correct level of ground floor** was +0.00m. Without considering about the level of standing for people, designer put the **depth of lift pit** only 1.20m when it should be 1.50m (this 1.50m was the **required height of reactor of lift systems**). The issue was that the level for passengers to stand in the lift box was higher than the **level of ground floor** when the lift car (lift box) was operated and reached the ground floor. Actually, these levels should be equal.

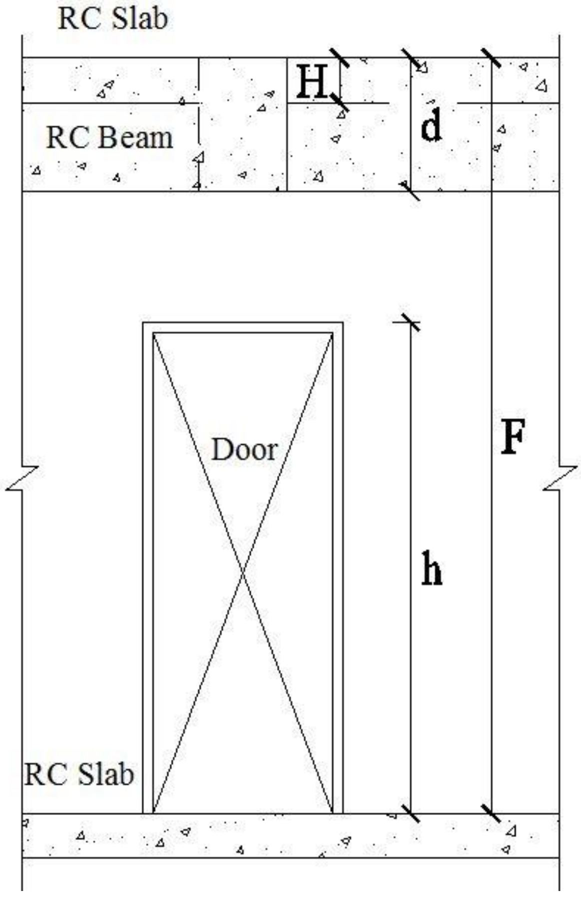


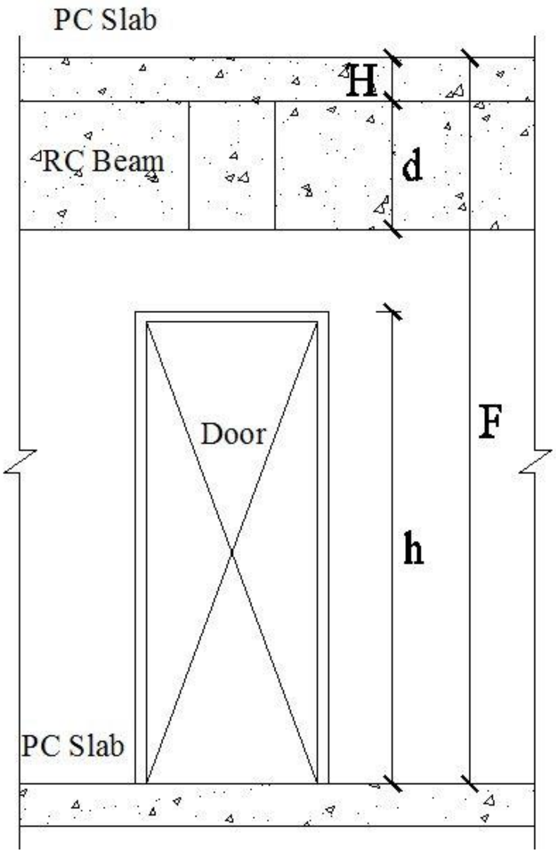
	Ex 3 [13]	Structural engineer designed the pile cap to support the **lift pit** directly without putting stump column or ground beam. Because of the incorrect **top level of pile cap**, the **level of lift pit** was located lower than the top level of pile cap. It was found that there was free space from the top level of pile cap to the level of lift pit. For this case, designer decided to cast one more slab above that lift pit to fill the free space and to install the lift systems properly.
2.7	**Footing and sanitary drainage and disposal system**	
	Ex 1 [3, 9, 13]	The waste water and disposal were disposed to septic tank in substructure. Before pouring the concrete of footing, it was found that the **pipe of waste water** ran across the **footing section** because designer forgot to consider about the **position of pipe nearby the footing**. This pipe was not allowed to run across the section of footing. Then the position of this pipe was moved **above the footing** to avoid any conflicts.
	Ex 2 [8, 9]	Before construction, contractor had found that the **pipe of disposal system** was located **under the footing**. If this pipe was under the footing, the water might be leaked because that pipe could not carry the loads from the footing. Thus, that pipe was moved to the **upper level of the footing** to avoid the water leakage.
	Ex 3 [6]	The level of footing affected the pipe route under the toilet area. Before pouring the concrete of footing, it was found that the **pipe of sanitary drainage and disposal system** hit the **footing section**. To run this pipe properly, the level of footing was dropped 450mm based on the pipe requirement. Thus, the pipe was run **above the footing** to avoid this conflict.
Category 3: Design errors between beam and other components		
3.1	**Beam and beam**	

	Ex 1 [3]	For beams, there should have the **face bars** (**middle bars) in the beam** in order to strengthen the stirrup and to prevent from torsion. The **main beam** dimension was 400mm width x **1,200mm depth**. And the **secondary beam** dimension was 300mm width x **500mm depth**. According to the **design standard** that designer uses, the **face bars (middle bars) were required** when the **depth of beam** was equals to or greater than 700mm (ACI code). For this case, designer did not put any middle rebar in the main beam. As a result, this main beam was cracked.
	Ex 2 [3, 5]	The **beam reinforcement** could not be installed properly at the **connection between two beams** since the **reinforcement was very complicated**. The aggregates of concrete cannot flow into the structure of beams during concrete casting. Consequently, the beam section lost its concrete cover. After pouring the concrete, the first beam was cracked before removing its scaffolding because of shrinkage.
	Ex 3 [5]	Structural engineer designed a beam with the dimension of 0.50m x 1.50m x 27m. This span of beam was too long of which the **strength** could not resist with the **loads from the structure**. Consequently, the beam was deflected and bended. Many cracks occurred. Later, this beam was demolished and its span was changed to 18m.
	Ex 4 [8, 11]	The first beam (**secondary beam**) was designed with dimension of 200mm width x 200mm depth, whereas the other beam was designed with 200mm width x 300mm depth (**main beam**). Designer did not provide the information how to install the main bars in the bottom layer of the first and second beam. For this issue, the installation of these main bars had conflict with the second beam at the connection between the first and second beam. This was because the **depth of first beam** was

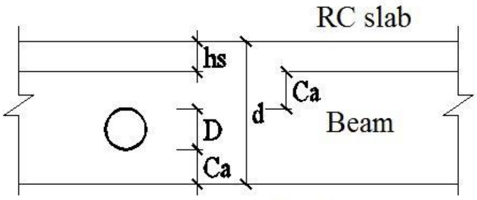
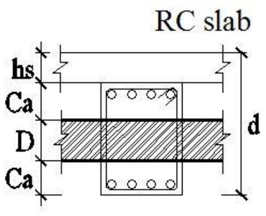
	Ex 4 [8, 11] Continued	shorter than the **second beam's**. According to constructability, contractor suggested designer to change the depth of the first beam to 300mm equal to the depth of the second beam.
3.2	**Beam and ceiling works**	
	Ex 1 [2, 3]	There was error between **beam height** and **ceiling level**. Because slab was Precast Concrete (PC), Reinforced Concrete beam was installed under the **PC slab**. Designer forgot to consider about the levels, the remaining **space between the soffit of beam and ceiling level** was not enough to install the **MEP systems**. Then, the design of ceiling had to be changed. 
	Ex 2 [8]	The **depth of beam** affected the **ceiling works**. For example, the **required height of ceilin**g was 300mm, but the **depth of beam** was 500mm and the **RC slab thickness** was 150mm. Thus, the soffit of beam was lower than the ceiling level 50mm. This error forced the architect to re-design the ceiling. 

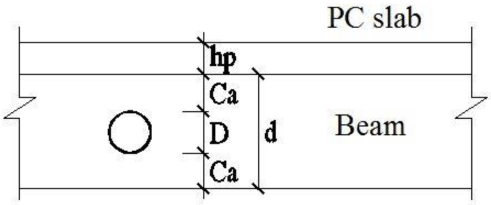
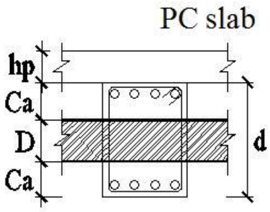
	Ex 3 [3, 11, 13]	Designer did not consider about the **space for MEP systems**. So, the **remaining space between soffit of beam and ceiling level** was not enough for installing MEP systems. To deal with this problem, **ceiling finish** had to drop off its level. So, the **height of beam** was very important to be considered during design process in order to avoid this issue.
3.3	**Beam and column**	
	Ex 1 [2, 9]	The beam reinforcement was very complicated. There were many complicated **rebar at the connection between that beam and column**. Therefore, the **complexity of beam reinforcement with two supports** had conflict with the reinforcement of column at that support. It was then impossible to install those rebar effectively. In this case, designer had to redesign the reinforcement of beam and column by considering about the possibility of rebar installation.
	Ex 2 [3, 6, 13]	Structural engineer designed the **cantilever beam with very long span** which was not allowed by the **design standard**. Regarding the **column functioned as the support of this beam (column from this floor to the lower floor)**, its design could not resist with the loads from this cantilever beam and it was found that this beam was deflected. To solve this issue, another reinforced concrete column was added to reduce the span of this cantilever beam and also to help supporting the eccentric loads imposed by that cantilever beam.
	Ex 3 [13]	Structural engineer designed a **long curve cantilever roof beam without the column to support it** from the ground floor until the roof floor. Later, this beam was cracked and deflected due to the load combinations imposed on it. It was then suggested to add a steel column at the corner to help supporting this cantilever beam.

	Ex 4 [13]	Structural engineer tried to put the location of column the same as what the architect required. However, the **span of cantilever beam** was longer than **the allowable span** that the column cannot carry the eccentric loads imposed on it. Since the cantilever beam was deflected, designer moved the location of that column to reduce the span of the cantilever beam. Architect was not satisfied with this change, but it is required.
3.4	**Beam and door/window**	
	Ex 1 [1, 2]	The **depth of beam** affected the door/window installation. For example, there was only 2.80m height from the floor to the soffit of the beam. However, the **required height of door/window** was more than 2.80m (e.g. 2.85m). This error dissatisfied the architect and owner because architect had to re-design and changed the specification of the door/window to match with the structural design. 

Ex 2 [5, 11]	There was error between **beam height** and the **height of door/window**. Because slab was Precast Concrete (PC), Reinforced Concrete beam was installed under the **PC slab**. Designer forgot to consider about this, there was no enough opening for door/window since the **soffit of beam was lower than the top level of door/window**. Thus, the required door/window was not able to be installed. 
Ex 3 [9]	Designer forgot to put **lintel (beam)** for door/window. So, there may be cracking at the top corners of that door/window.
Ex 4 [1, 2, 13]	Because the **required floor height** was fixed and the **size of door/window** was also required by the architect/owner, designer had to adjust the **beam's depth** and **slab thickness** to make sure that the size of opening for door/window was enough. However, designer sometimes forgot to consider about this case, beam overlapped the space for installing the door/window. Thus, the door/window could not be installed.

3.5	**Beam and floor finish**	
	Ex 1 [13]	Along the corridor of the building, there was a **small gutter**. Actually, the **floor finish level at the gutter** should be lower than the **floor finish level at nearby areas**. Designer forgot to drop the **level of beam for this gutter**. Consequently, the water could not be carried off from the slab of corridor. Because the structure of beam and slab at this gutter area were already finished, this level was adjusted by reducing the **thickness of floor finish** of that beam.
3.6	**Beam and footing**	
	Ex 1 [9]	During construction, it was found that the footing reinforcement was included normally; however, there was **no any starter bars for beam at the connection between beam and footing**. Designer seemed so careless with the typical designs. Without starter bars, the fissures could appear at the joint between beam and footing. Because the footing was already built, it required to drill the holes for placing the starter bars for beam.
	Ex 2 [13]	The **cantilever ground beam** was designed with the **span** of 4m from the edge of footing. Because of **unclear soil compaction** due to the infiltration of underground water, it was noticed that the cantilever beam is subsided by the **soil settlement**. For this case, designer redesigned it by adding the footing to support that beam.
	Ex 3 [11, 13]	Designer designed the **ground beam with long span of cantilever** from the footing**.** That designed span was too long which was not allowed by the **design standard**. Consequently, that cantilever ground beam was deflected.
3.7	**Beam and HVAC systems**	

	Ex 1 [4, 8]	HVAC systems had clashed with the **depth of beam** because designer did not check the **route of the sleeve for this system** carefully. It was then found that the **sleeve of HVAC systems has to run across the beam** in **longitudinal direction**. For this case, it was not allowed because beam could be deflected and cracked due to insufficient strength to carry the loads. The only solution was to change the design of the HVAC systems which also influenced the architectural design.
	Ex 2 [12]	The **depth of beam** was 700mm including the **RC slab thickness** of 150mm. The **diameter of sleeve of HVAC system** was 200mm. Due to HVAC system requirement, the opening for this sleeve had to **be drilled in the beam along the direction of beam's width (transversal direction)**. Along this direction, this opening was located 175mm from the edge of the opening to the soffit of beam. Because 175mm was not allowable for the **effective cover of beam** (1.5D) with large opening, the strength of beam could not carry the loads imposed on it and the beam was cracked.  Sleeve across the beam in transversal direction  Beam section
	Ex 3 [12]	This problem was similar to the case as explained in example 2. Because it was **precast concrete slab**, PC slab thickness

	Ex 3 [12] Continued	was not related in this case. The **beam's depth** was 500mm and the **diameter of the sleeve of HVAC systems** was 200mm. This sleeve was forced to **run across the beam** section since the depth of beam had clashed with the **route of the sleeve**. Consequently, running this sleeve across the beam reduced the **effective cover of beam** and the beam deflection could occur.  Sleeve across the beam in transversal direction  Beam section
3.8	**Beam and lift systems**	
	Ex 1 [13]	The **position of beams to fix the lift railing systems with the structure** was wrongly designed. These beams were casted in the wrong position for fixing the structure with lift systems. To deal with this problem, designer decided to cast new beams following to the right location based on the requirement of lift systems.
	Ex 2 [15]	The **position of beams at the opening of lift** was found different and had clashed with the **opening of lift box**. So, the **opening size for lift was smaller than the requirement** and it was not able to install the lift box. To solve this issue, that beam was demolished and new beam was installed in the right position as required by the architecture.

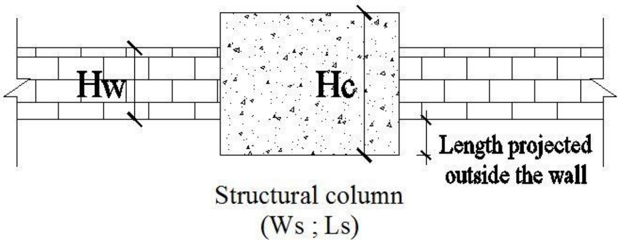
3.9	**Beam and sanitary drainage and disposal system**	
	Ex 1 [3, 4]	The issue was similar to the beam and HVAC systems in example 1. Because the **depth of beam** was so high, the **route of pipe of sanitary drainage and disposal system** had to **run across the beam** in **longitudinal direction**. In the design, it was not allowed to run the pipe like this case since beam could be deflected and cracked by the insufficient strength.
	Ex 2 [9, 11]	The pipe of sanitary drainage and disposal system could be run vertically or horizontally. It was not allowed to run the pipe across the beam in **vertical route** because it could affect the other structure and beam strength. Running the pipe horizontally also had problem with beam. In this issue, the **sewage pipe runs across the beam** in **transversal direction**. The dimension of beam was 200mm width x **300mm depth** and the **pipe diameter** was 60mm. Excluding the **RC slab thickness** of 150mm, only 150mm of beam's depth was for running the pipe. So, the **effective cover of beam from the edge of pipe to the soffit of beam** was only 45mm lower than the **allowable effective cover** (1.5D = 90mm). This lower effective cover could reduce the beam strength. For precast concrete slab, its thickness did not affect the effective cover since it was separately designed from the RC beam.
	Ex 3 [12, 13]	Without studying about the **route of sewage pipes of sanitary drainage and disposal system**, It was found that the **position of opening for this sewage pipe runs across the beam transversally** and in **the middle span (L/2) of beam** which was the critical area of beam. Consequently, the strength of beam was not strong because it was the compression zone in the middle of span. Drilling the opening at this position made the beam deflected and cracked. Therefore, the position of sewage pipe had to be revised.

3.10	**Beam and wall finish**	
	Ex 1 [1, 3]	Designer forgot to check the architectural layout plan. The brick walls were **not in the same alignment** as the brick wall at lower floor. In structural design, the **alignment of beam for supporting this brick wall** was straight and stood on **the same alignment** with the brick wall at lower floor. Thus, the brick wall of this floor had no beam to support since the alignment of beam was incorrect and just followed the beam at lower floor.
	Ex 2 [1]	Based on the architectural design, the edge of all slabs was not in the same alignment. Since designer designed all **beams in the same alignment**, there was problem with the **alignment of brick wall installation**. It was found that there was no any structure (slab or beam) to support the brick wall. Designer then extended the cantilever slab from the beam for supporting the brick wall.
	Ex 3 [7]	In architecture, beam at upper floor was in the same central alignment of brick wall. In structure, **beam at upper floor was located at the side of brick wall**, which was not in the same central alignment. Since designer forgot to check it carefully, the **height of brick wall** was changed to 3.40m when **its required height in architecture** was only 3.00m. This was because the **depth of beam** was 400mm. Architect did not satisfy with this change since it affected the ceiling design.
	Ex 4 [10]	A **beam** with span of 10m and width of 150mm had to **support the mirror wall**. After finishing this construction, that beam was later deflected and bended due to **lack of moment inertia** (I = b*h^3/12) and the mirror was also cracked. When this moment was bigger, the deflection (deflection = WL^3/48EI) was small. To solve this problem, an I steel beam was placed under the reinforced concrete beam.

Category 4: Design errors between column and other components		
4.1	**Column and beam**	
	Ex 1 [2, 3, 5, 9]	The column reinforcement was so complicated. **At the joint of column and beam (at the support**), the **complexity of column reinforcement** had clashed with beam reinforcement and this clash obstructed the rebar installation and the concrete cover for both column and beam was less than the requirement.
	Ex 2 [5]	The **size of column from current floor to lower floor** was 300mm x 300mm. The **width of column** was found so small to support the bigger **width of beam** with the span of 18m. Because of insufficient **column strength**, this column was cracked and repaired.
	Ex 3 [11, 12]	Designer put the **width of column from current floor to lower floor** smaller than the **width of beam**. It was impossible that the column which had to support the beam had smaller size because **its strength** was not sufficient. Then the flexural bending occurred and the column was swayed.
	Ex 4 [13]	It was designer's mistake that **RC column** could not support long **cantilever beam**. The **span of cantilever beam** was allowed by **design standard**. However, **strength of the column** was insufficient to carry the **loads imposed on it**. It was found that column was cracked and swayed. Due to this problem, designer redesigned the structure by adding more reinforcing steel or increased the section of column.
4.2	**Column and column**	
	Ex 1 [3, 14]	The **central alignment of column at current floor** and the **central alignment of column at upper floor** were not the same as the requirement of architecture. This incorrect alignment dissatisfied the architect and it influenced the architectural design.

	Ex 2 [9]	The column at current floor had bigger size (700mm x 700mm) than the column at upper floor (400mm x 400mm). At the edge of slab, the **central alignment of column at current floor and upper floor** was not the same. Based on architectural plans, the balcony was located 1.20m from the **central alignment of the column at current floor**. Actually, it should be located 1.35m from the **central alignment of the column at upper floor**. However, designer just copied and pasted, the width of balcony in upper floor was not 1.35m as required by the architectural design.
	Ex 3 [13]	The **size of column at upper floor** was 400mm x 800mm (**rectangular column**) and **column at current floor** had diameter of 600mm (**circular column**). The **starter bars for column at upper floor** could not be installed sufficiently due to **small column at current floor**. Moreover, the **strength of small column at current floor** could not sufficiently carry the **loads** imposed on it. This column was then swayed and cracked. Therefore, designer added more starter bars by drilling the holes and embedding those bars into deep beam.
4.3	**Column and footing**	
	Ex 1 [13]	Structural designer designed the **stump column** incorrectly. A steel column was then added next to the stump column on the same footing for supporting the loads; however, the footing was not studied again. Therefore, the **strength of the footing** was not strong enough (more **loads are transferred to this footing**). Consequently, the footing was cracked.
	Ex 2 [3, 5]	For stump column, the **lap length of starter bars into the footing** should have a limited lap length according to the **design standard**. This problem was that the length of starter bars for stump column was extended until the bottom of footing, which was more than required.

	Ex 3 [3]	In footing design, designer did not include any typical details of **lap length of starter bars for stump column**. Contractor had to request for information. Construction was not delayed anyways; but, it was the responsibility of designer.
4.4	**Column and sanitary ware**	
	Ex 1 [2]	In architecture, the **size of column** was 500mm x 500mm. In structure, the **size of column** was 800mm x 800mm. The bigger size of column affected the lavatory faucet installation in bathroom. It resulted in the wrong **position of lavatory faucet** which was fixed with that column. Architect did not satisfy with this bigger column because it had conflict with the required space in bathroom. Moreover, the location of the main sanitary drainage and disposal system connected to that faucet had to be changed due to the wrong position of the faucet.
	Ex 2 [13]	**Lavatory faucet** had to be fixed directly with column. There was no any **reserved space for fixing this faucet**, a 110mm brick wall was then laid on the surface of column in order to form a space for installing the faucet. This affected the position of faucet and also influenced the architectural design in toilet.
	Ex 3 [13]	The column was designed without **reserving a route for running the faucet pipe**. Thus, the faucet pipe could not be run to the sanitary system. To solve this issue, additional masonry wall was laid on a surface of column to make the route for running the faucet pipe to the main sanitary system.
4.5	**Column and wall finish**	
	Ex 1 [1, 9]	At the connection between reinforced concrete column and the masonry wall, designer did not put any **starter bars to connect the column with the wall** when it should have. Then the column was drilled to make the hole for placing those starter bars. When there was no these bars, the fissures on the wall may appear at this joint.

	Ex 2 [11, 15]	Designer put **structural column** in the wrong **alignment** comparing to the **alignment of brick wall**. Column was found in the middle of masonry wall and the corners of column were projected outside the wall. Architect did not prefer this design since it affected the decoration of wall. Designer should also consider about the architecture of the wall nearby that column.
	Ex 3 [11]	Designer designed a **column with bigger size** (**300mm width x 400mm length**) when it should be only **200mm width x 400mm length** based on the **requirement of architecture**. Designer forgot to submit this change to architect since he had a lot of works to do at that time. Because of this mistake, column was just built with 300mm x 400mm. When **brick wall of 200mm thicknes**s was being laid, 50mm of column concrete was appeared outside for all four corners of column. This case dissatisfied the owner as well as the architect because it affected the architectural design in the room.
		
Category 5: Design errors between slab and other components		
5.1	**Slab and ceiling works**	
	Ex 1 [5]	In the absence of structural beam, structural slab also had conflict with ceiling finish. This case was similar to the case of beam and ceiling works. Due to the **required ceiling height from the soffit of slab**, t**he space from the soffit of slab to the level of ceiling finish** was not sufficient for installing MEP systems. To solve this error, the slab level had to be increased in order to maintain the required height of the mezzanine floor.

5.2	**Slab and door/window**	
	Ex 1 [5]	The structural slab was designed with incorrect level as required in architecture. The constructed **slab level** was higher than the requirement in architecture; so it had conflict with the **height of opening for door**. The **required top level of door/window** was changed due to higher slab level; therefore, the **height of door/window** was modified in order to keep the top level of door/window as required. This modification upset the architect as well as the owner who preferred the previous height of door/window. However, it required to change since the structure of slab was already finished.
	Ex 2 [13]	Designer designed a **cantilever slab with long span**. This long cantilever slab then had deflected. Under that slab, there was a window of which the height was extended until the bottom of the slab. In this case, the window could be affected because of the deflection of slab. Thus, the **top level of this window** was reduced 20mm lower than the **bottom level of the cantilever slab**. This 20mm was filled by the sealant joint to reserve for the deflection of the cantilever slab.
5.3	**Slab and floor finish**	
	Ex 1 [4, 5, 9, 12]	The **structural slab level** should be less than the **floor finish level** 50mm. However, designer just put the level of structural slab equals the floor finish level without considering about the **thickness of tiling works (floor finish thickness)**. This case dissatisfied the architect and the level of upper floors had to be increased. Some architectural designs at upper floors were also affected and modified.
	Ex 2 [8, 11, 13]	In order to make sure that the water could not flow to other areas, the **structural slab level at the bathroom** should be dropped 50mm lower than the **structural slab level at normal areas**. Moreover, the **structural slab at bathroom** needed the

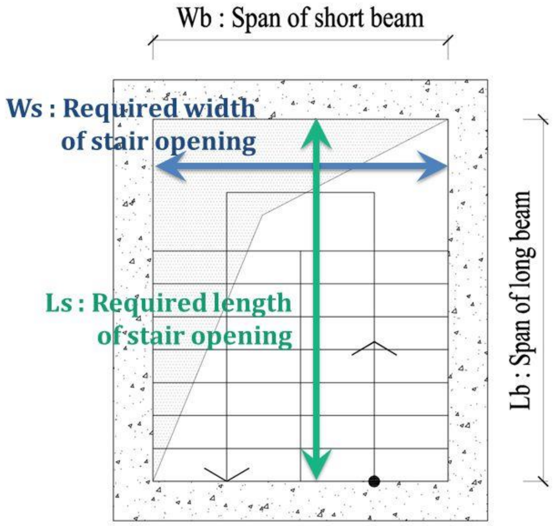
	Ex 2 [8, 11, 13] Continued	**slope** of 5% to assure that the water could flow easily to the drain. However, structural designer did not pay much attention on these **dropped height and slope requirement**. Designer just put the structural slab level at the bathroom the same as the slab level at normal areas.
5.4	**Slab and HVAC systems**	
	Ex 1 [1, 2]	The **exhaust pipe of HVAC systems** was designed to run across all floors in the building. Designer did not reserve the **opening of slab for placing this pipe** in a floor. Then it required to drill the slab to make the opening for this exhaust pipe.
	Ex 2 [7, 9]	The dimension of slab was 1,750mm width x 3,040mm length. For HVAC systems, the **size of ELEC riser** was 610mm **width** x 950mm **length**. In design drawing, the **reserved size of slab opening for installing this ELEC riser** was 950mm **width** x 1,000mm **length**. This indicated that the reserved opening was bigger, which did not match with the **size of ELEC riser**. To solve this error, the slab was enlarged to fill the reserved opening to match with the required size of opening.
	Ex 3 [13]	The **reserved slab opening for the exhaust pipe of HVAC systems** was insufficient. The slab opening had to be enlarged by drilling to make a hole for installing this pipe.
5.5	**Slab and sanitary drainage and disposal system**	
	Ex 1 [5]	For septic tank, **the slab which functioned as the cover of the tank** had 200mm thickness. The sewage pipe of sanitary and disposal system with diameter of 120mm was changed to run in the slab horizontally because the **required clear height of septic tank** would be reduced if the sewage pipe was installed **under that slab** (septic tank cover). Because the **diameter of**

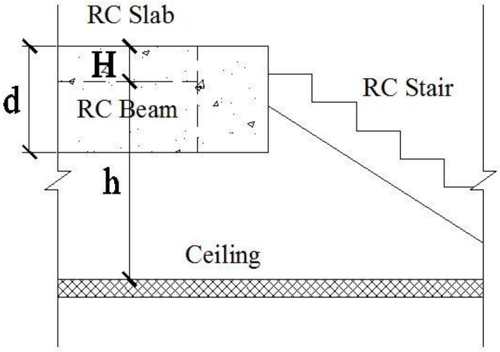
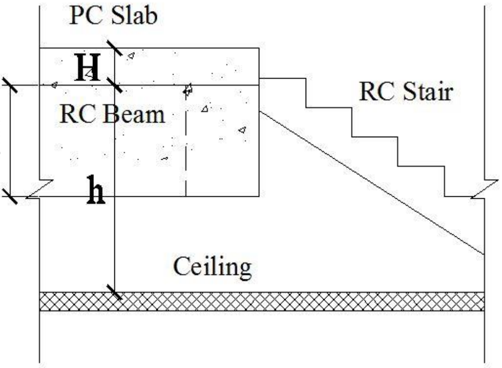
	Ex 1 [5] Continued	**the pipe** was big in comparison with the **slab thickness**, the concrete cover was lost. Thus, the strength of slab was decreased which made the slab cracked in some areas nearby the route of the pipe. That is why **it was not allowed to run the sewage pipe into the slab**. Therefore, designer should well-design the septic tank cover with a correct level to make sure that the **required clear height of septic tank** was correct.
	Ex 2 [11, 14]	In structural slab, designer did not give the details of any **reserved opening for running the pipes of sanitary drainage and disposal system**. Because it was necessary to put the pipe across the slab vertically, the slab was drilled to make the opening for the route of the pipe.
	Ex 3 [13]	The opening was reserved in the wrong **position of the route of sewage pipe**. Consequently, the slab was drilled at the right position and that wrong reserved opening was filled by concrete slab.
5.6	**Slab and sanitary ware**	
	Ex 1 [3, 5]	The **reserved opening of slab for toilet sleeve** was not given. Before pouring the concrete of that slab, the contractor just noticed that there should be an opening for toilet. The slab had to be drilled to make a hole for putting the sleeve of toilet. And the plans had to be revised.
	Ex 2 [13]	Due to unclear design by designer, the **reserved size of opening for toilet sleeve** was not sufficient because the **required size of sleeve for toilet** was bigger.
5.7	**Slab and slab**	
	Ex 1 [1,14]	This issue was that the **typical details of rebar installation when the slab level was dropped** were not given by the designers. As a result, it was found that concrete cover of the slab in higher level was over the allowable concrete cover.

	Ex 2 [10]	Because of human mistakes, designer did not use **the last version of architectural plan of slab**. The previous version was used instead. The problem was that the 4m of cantilever slab still existed when there was no this cantilever slab in the last version of architectural plan.
	Ex 3 [11]	In the first floor, there were 5 different **levels of slab**. However, designer just put only one level for all areas in that floor. The architect did not satisfy with this mistake because the incorrect slab level affected the function of the room.
5.8	**Slab and staircase finish**	
	Ex 1 [11, 13]	The **height of each riser of stair** was 160mm, whereas the **number of all risers of stair** was 19. Thus, the total height of all risers of stair equaled 160 x 19 = 3.04m. The **slab level at current floor** was +6.65m and the **slab level at lower floor** was +3.55m. So, the actual floor height was 3.10m which was higher than the total height of all risers and which was not satisfied since the **required floor height** in architecture was only 3m. To deal with this wrong level of slab, a small step of riser was added to fill the opening.
5.9	**Slab and storm drainage system**	
	Ex 1 [1, 11]	Designer did not reserve the **opening for floor drains at the roof floor.** Consequently, the slab was drilled to make holes for this sleeve. This opening is for running the pipe of storm drainage system across the slab to drain the rainwater into the storm water tank at underground level. If the openings for floor drains at the roof area did not exist, the rainwater could not flow and the roof would be flooded.
	Ex 2 [9, 13]	Designer put the **wrong diameter of reserved opening for floor drains** at **roof area**. The **diameter of sleeve for floor drains** should be bigger, while the reserved opening have smaller diameter. The slab then was drilled to enlarge the hole.

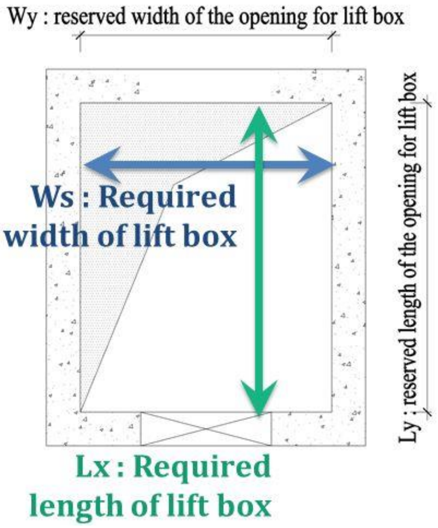
	Ex 2 [13]	In the design drawing, it was found that the **reserved openings for floor drains** at the **roof area** were in the **wrong positions** from the design of plumbing systems.
5.10	**Slab and telephone/datacom system**	
	Ex 1 [3, 11]	Mostly, the wires of telephone/datacom system had to run across the slab from each floor to another floor. This was because designer did not provide any details of the **sleeve penetration at the slab for running the tube wiring of telephone/datacom system**. So it required to drill a small hole on the slab. After drilling, it was found that the fissures appeared on the slab.
	Ex 2 [4, 13]	The **reserved penetration size for installing the cable conduits of the telephone/datacom system** was smaller than the **required size of cable conduits**.
5.11	**Slab and wall finish**	
	Ex 1 [1]	Designer designed a **cantilever slab with long span** which was greater than the **allowable span** in design standard. The brick wall was laid on the edge of that cantilever slab. That slab was deflected around 60mm after laying the brick wall.
	Ex 2 [15]	The **architectural layout plan of slab** at current floor and lower floor were different. Since designer did not pay much attention on this difference, the **structural layout plans of slab** at both floors were the same. It was then found that the masonry wall from current floor to upper floor could not be laid because there was no any **structure (slab) to support this masonry wall**. Architect did not want to move the masonry wall because it could affect the design of the room. To solve this error, the slab at current floor was extended to make sure that the masonry wall could be laid.

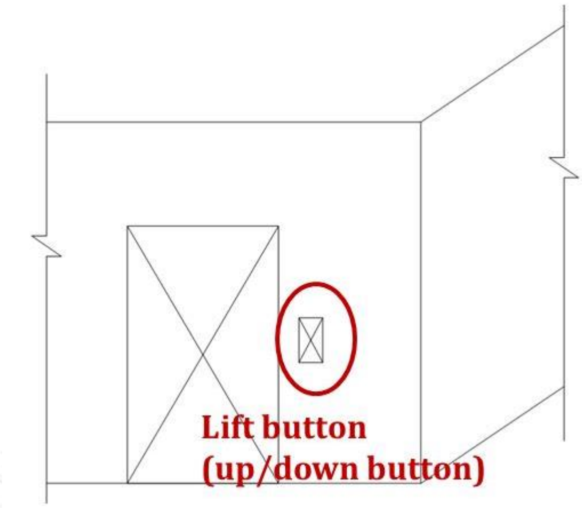
5.12	**Slab and water supply and distribution system**	
	Ex 1 [4]	The **position of reserved opening at slab for the water pipe** was incorrectly placed. As a result, it required to drill the slab to make the correct hole and that incorrect opening was then filled by concrete slab.
	Ex 2 [9]	The water pipe should run under the slab in the ceiling space. The problem in this case was that the **route of pipe of water supply and distribution system** was **across the section of structural slab**. Due to **slope requirement**, the route of this pipe could be avoided from the slab section. Consequently, the slab was cracked and oxidized because the **diameter of pipe** was almost equal to the **slab thickness**. Moreover, the **cover of concrete slab** was lost and the slab reinforcement could not be properly installed.
	Ex 3 [11]	Designer did not put the **reserved opening at slab for the pipe of water supply and distribution system**. So, it required to drill the slab to make the hole for routing that pipe. This pipe had to run under the slab and went to supply the water for every floor of the building.
	Ex 4 [13]	The penetrations at slab for installing the water supply and distribution system were not put in details. The **diameter of the reserved opening for water pipe** was not enough. The slab was then drilled to enlarge the **size (diameter) of reserved opening** to match with the **required diameter of the pipe**.
Category 6: Design errors between stair and other components		
6.1	**Stair and beam**	
	Ex 1 [1]	The error was related to the size of stair opening. The **required width of this opening** was 900mm, whereas its **required length** was 1,200mm. **The span of short beam** was

	Ex 1 [1] Continued	at 800mm and the **span of long beam** was at only 1,100 mm from the other side of the opening. These distances were not enough for the required size of stair opening. Those beams were then demolished and new ones were built by moving out 100mm from the previous ones. 
	Ex 2 [9]	The typical details of **starter bars to connect beam with stair** were not provided in design drawing. The concrete at the joint of stair and beam was cracked when there was no starter bars. In this case, the beam was drilled to make the holes for placing the required starter bars. This took more time and incurred more costs because the concrete pouring had to be done twice.
6.2	**Stair and ceiling works**	
	Ex 1 [1]	This case was similar to the problem of beam and ceiling works in example 2. The **beam functions as the top riser of the stair**. This **beam's depth** affected the ceiling finish. The **beam's depth** (excluding the **reinforced concrete slab thickness**) was deeper than the **depth of ceiling from the bottom of the slab**. It was noticed that the corners at the soffit of the beam were still uncovered after finishing the ceiling. The architect did not satisfy with this error; however, architect had to re-design the ceiling since the stair was already casted.

		
	Ex 2 [1, 5]	The case was quite similar as in the example 1. Because the slab was **precast concrete**, the **slab thickness** was not quite related. However, the **depth of beam in the top riser of stair** was deeper than the **depth of ceiling**. Therefore, the ceiling works had to be modified. 
6.3	**Stair and slab**	
	Ex 1 [6, 9]	The problem was related to the **additional bars (trimmers) at the corners of the slab opening for stair**. Designer did not put those bars in the design where it should have been. Without the additional bars, the slab was cracked at those corners of the slab opening.
	Ex 2 [11, 13]	According to the designed **height of each riser**, the **height of floor** was lower than the **total height of all risers of the stair**. Consequently, the slab level was different from the required level which dissatisfied the architect. The **height of riser** did not follow the requirement.

6.4	**Stair and staircase finish**	
	Ex 1 [2, 9]	The reserved width of stair landing was not equal to the required width in architecture. The problem was that the **required width of stair landing** was 1m. The **required length of stair** was 3.03m. However, the **total length of treads from the lower stair to landing** was 2.32m (each **tread's width** of 290mm multiplied by 8 which was the **number of treads**). It was found that only 0.71m remained for the width of landing which was insufficient.
	Ex 2 [13]	In architecture, the epoxy was used as a type of material for staircase finish of each step. It needed to reserve only 20mm for **plastering thickness** of epoxy. Designer did not clearly study about this **requirement**, so 50mm was left for the epoxy plastering. Finally, it was noticed that the plastering applied to each step of the stair was so thick and moreover it was quite difficult to maintain the level of each step.
6.5	**Stair and wall finish**	
	Ex 1 [4, 8, 10, 15]	Designer put the structural stair in the wrong **position**. For this case, the **width of each tread of the stair** was 250mm and the **number of treads** was 9. Including the **actual width of stair landing** of 1.3m, the total length of the stair was 3.55m ((250mmx9) + 1.3m = 3.55m). Actually, the **width of masonry wall** was only 3.25m; but with the wrong position of the stair, the total length of the stair was found projected about 300mm outside the masonry wall at a side of that stair. The architect did not satisfy with this case because it affected the esthetic of that stair and wall finish.
Category 7: Design errors between reinforced concrete wall and other components		
7.1	**Reinforced concrete wall and door/window**	

	Ex 1 [2]	In structural design, the **size of opening for lift door at the RC wall** was incorrect in comparison with the **size of lift door**. The exact door had bigger size which could not be fit with the **size of opening for that lift door.**
	Ex 2 [3]	For **lift wall**, it required to have a **small window (opening) for lift maintenance**. In this case, structural engineer did not reserve any opening. When the lift system was needed to be checked for maintenance, it was found that there was no entrance to reach the lift systems. The only solution was to demolish a part of RC wall to be the entrance.
	Ex 3 [5]	Designer reserved the wrong **size of opening for lift door at RC wall**. The **width of opening for lift door at RC wall** was only 800mm, whereas **its height** was only 2,100mm. Including the **frame thickness** of 100mm, the width and height of the opening were not sufficient to install the door because the size of lift door was 900mm x 2,200mm. This error affected the architecture which required to change the size of lift door.
7.2	**Reinforced concrete wall and lift systems**	
	Ex 1 [2, 14]	The **required width of lift** was 2,300m. In structural design, the **reserved width of the opening for lift** was only 2,200m which was not enough. 

	Ex 2 [2]	The **opening** that was reserved for the **lift button** (up and down button) on the RC wall was not in the same **position**. Moreover, that **opening size** was also incorrect. 
	Ex 3 [3]	Designer forgot to check the design with the **required size of lift box**. So the RC wall which was already built was located in the wrong **position** with wrong **size of required lift box**.
	Ex 4 [13]	Based on the structural design, shop drawing was already issued with wrong **lift dimension** of about 25mm. This causes a little adjustment from the center of the lift comparing to the correct central axe.
	Ex 5 [1, 13]	There was no any **reserved opening/space** for **lift button** at the RC wall. So it required to drill the RC wall for installing this up/down button.
7.3	**Reinforced concrete wall and storm drainage system**	
	Ex 1 [3]	The **rainwater pipe** had to be penetrated **into the RC wall vertically**. In design drawing, designer did not show how to install this rainwater pipe. So, the rainwater pipes were not placed into the RC wall before casting the concrete. This problem dissatisfied the engineers of MEP systems because the design of rainwater pipe had to be revised by changing its route and laying the brick wall to create its route.

	Ex 2 [3]	For this problem, the **diameter of rainwater pipe** was 60mm and the **RC wall thickness** was 200mm. The rainwater pipe was penetrated into RC wall in **vertical route** according to MEP design. This pipe had conflict with the RC wall reinforcement because the pipe diameter was so big comparing to the RC wall thickness. Since the pipe diameter was 60mm, there was only 140mm for the concrete effective covers of both sides. Because the **allowable effective cover** required 1.5 of pipe diameter (1.5 x 60 = 90mm), the actual effective cover of each side remained only 70mm (140 /2 = 70mm). This case may affect the strength of RC wall and it might not be able to install the RC wall reinforcement properly.
	Ex 3 [13]	The **position of sleeve** for storm drainage system that was penetrated across the RC wall in **horizontal route** was in the wrong level. It was not able to connect this pipe with the storm drainage system.
7.4	**Reinforced concrete wall and wall finish**	
	Ex 1 [2, 8]	The architect required the **RC wall thickness** of 200mm including finishing works. Because structural designer forgot to consider about the **plastering thickness**, RC wall was designed with the thickness of 200mm. After plastering works, **RC wall thickness** was greater than what was required. This was not really a big problem; however, the architect did not satisfy with this error.
	Ex 2 [3, 7]	The **required thickness of RC wall** at current floor after finishing was only 200mm. In structural design, **RC wall thickness** was found 250mm including **plastering thickness**. Because designer did not pay much attention on the required wall thickness at current floor and just followed the one at lower floor, the RC wall thickness (including plastering finish) at current floor was thicker than the required thickness 50mm.

	Ex 2 [3, 7] Continued	Designer may just copy and paste the structural layout plan of the lower floor to be the layout plan for the current floor.
	Ex 3 [3, 15]	Based on architecture, the **alignment of RC wall** was different from the **alignment of masonry wall** at current floor. At lower floor, RC wall and masonry wall had the same alignment due to the room function. Without paying much attention, designer just put the RC wall and masonry wall in the same alignment at current floor. This incorrect alignment affected the architectural design.
7.5	**Reinforced concrete wall and water supply and distribution system**	
	Ex 1 [3, 13]	The water pipe was found having conflict with the RC wall. The **pipes had to run into the RC wall vertically** when it was not allowed. If this pipe ran into the RC wall, it would be very difficult for maintenance. The water pipe usually was very busy to supply the water to the building every day. So, it had high occurrence of water leaking if the pipe ran into the RC wall. Therefore, the masonry wall was laid to form a route for running the water pipe at that RC wall.
	Ex 2 [8]	Based on the plumbing design, the **sleeve of water pipe had to be penetrated across the RC wall horizontally**. Because designer did not reserve any **opening of pipe route at the RC wall**, this wall was drilled to make a hole for running the pipe. Drilling the wall was not recommended because it might create the fissures on the wall.
	Ex 3 [3, 12]	The **reserved opening for water pipe at RC wall** was smaller than the **diameter of the water pipe**. The **position of this reserved opening** was also not correctly placed. Enlarging the opening was required; so the wall had to be drilled.

APPENDIX F

DECISION TREES OF KNOWLEDGE-BASED MODELS

1.1 Retaining wall and beam

Retaining wall → Beam

Required starter bars to connect beam with retaining wall :

- Starter bar diameter (D)
- Number of required starter bars (N)
- Required concrete cover (C)
- Required spacing between starter bars (S)

Beam's width (w)

Retaining wall thickness (h)

Is the beam strong enough to carry the loads of retaining wall and soil pressure that are imposed?

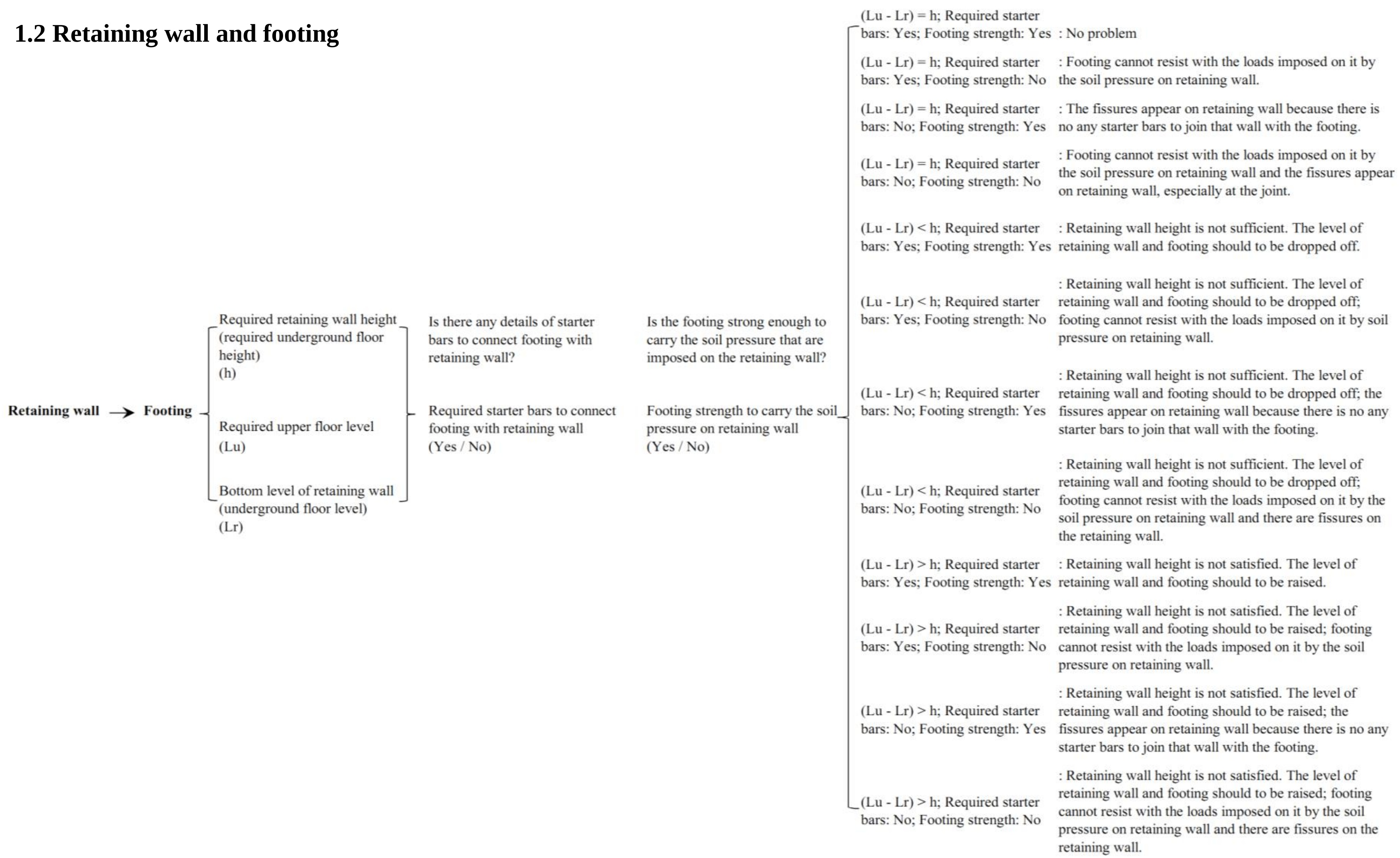
Beam strength to carry the loads of retaining wall and soil pressure (Yes / No)

Is the location of retaining wall the same as what the architect requires?

Location of retaining wall with architecture (Yes / No)

w >= h; (w-2C) >= ND + S(N-1) Beam strength: Yes; Correct location	: No problem
w >= h; (w-2C) >= ND + S(N-1) Beam strength: Yes; Incorrect location	: The location of retaining wall has to be re-checked with the architecture to make sure that it can stand in the right position on beam.
w >= h; (w-2C) >= ND + S(N-1) Beam strength: No; Correct location	: The torsion of beam occurs and the retaining wall can be cracked or might be torn. Beam has to be re-designed.
w >= h; (w-2C) >= ND + S(N-1) Beam strength: No; Incorrect location	: The location of retaining wall has to be re-checked. The torsion of beam occurs and the retaining wall can be cracked or might be torn.
w >= h; (w-2C) < ND + S(N-1) Beam strength: Yes; Correct location	: Required starter bars to connect beam with retaining wall cannot be installed because the width of beam is so small.
w >= h; (w-2C) < ND + S(N-1) Beam strength: Yes; Incorrect location	: Required starter bars to connect beam with retaining wall cannot be installed and the location of retaining wall has to be re-checked.
w >= h; (w-2C) < ND + S(N-1) Beam strength: No; Correct location	: Required starter bars to connect beam with retaining wall cannot be installed. The torsion of beam occurs and the retaining wall can be cracked or torn.
w >= h; (w-2C) < ND + S(N-1) Beam strength: No; Incorrect location	: Required starter bars to connect beam with retaining wall cannot be installed. The location of retaining wall has to be re-checked. The torsion of beam occurs and the retaining wall can be cracked or might be torn.
w < h; Beam strength: Yes; Correct location	: Required starter bars to connect beam with retaining wall cannot be installed because the width of beam is so small.
w < h; Beam strength: Yes; Incorrect location	: Required starter bars to connect beam with retaining wall cannot be installed and the location of retaining wall has to be re-checked.
w < h; Beam strength: No; Correct location	: Required starter bars to connect beam with retaining wall cannot be installed. The torsion of beam occurs and the retaining wall can be cracked or torn.
w < h; Beam strength: No; Incorrect location	: Required starter bars to connect beam with retaining wall cannot be installed. The location of retaining wall has to be re-checked. The torsion of beam occurs and the retaining wall can be cracked or might be torn.

1.2 Retaining wall and footing



Retaining wall → **Footing**

Required retaining wall height (required underground floor height) (h)

Required upper floor level (Lu)

Bottom level of retaining wall (underground floor level) (Lr)

Is there any details of starter bars to connect footing with retaining wall?

Required starter bars to connect footing with retaining wall (Yes / No)

Is the footing strong enough to carry the soil pressure that are imposed on the retaining wall?

Footing strength to carry the soil pressure on retaining wall (Yes / No)

(Lu - Lr) = h; Required starter bars: Yes; Footing strength: Yes : No problem

(Lu - Lr) = h; Required starter bars: Yes; Footing strength: No : Footing cannot resist with the loads imposed on it by the soil pressure on retaining wall.

(Lu - Lr) = h; Required starter bars: No; Footing strength: Yes : The fissures appear on retaining wall because there is no any starter bars to join that wall with the footing.

(Lu - Lr) = h; Required starter bars: No; Footing strength: No : Footing cannot resist with the loads imposed on it by the soil pressure on retaining wall and the fissures appear on retaining wall, especially at the joint.

(Lu - Lr) < h; Required starter bars: Yes; Footing strength: Yes : Retaining wall height is not sufficient. The level of retaining wall and footing should to be dropped off.

(Lu - Lr) < h; Required starter bars: Yes; Footing strength: No : Retaining wall height is not sufficient. The level of retaining wall and footing should to be dropped off; footing cannot resist with the loads imposed on it by soil pressure on retaining wall.

(Lu - Lr) < h; Required starter bars: No; Footing strength: Yes : Retaining wall height is not sufficient. The level of retaining wall and footing should to be dropped off; the fissures appear on retaining wall because there is no any starter bars to join that wall with the footing.

(Lu - Lr) < h; Required starter bars: No; Footing strength: No : Retaining wall height is not sufficient. The level of retaining wall and footing should to be dropped off; footing cannot resist with the loads imposed on it by the soil pressure on retaining wall and there are fissures on the retaining wall.

(Lu - Lr) > h; Required starter bars: Yes; Footing strength: Yes : Retaining wall height is not satisfied. The level of retaining wall and footing should to be raised.

(Lu - Lr) > h; Required starter bars: Yes; Footing strength: No : Retaining wall height is not satisfied. The level of retaining wall and footing should to be raised; footing cannot resist with the loads imposed on it by the soil pressure on retaining wall.

(Lu - Lr) > h; Required starter bars: No; Footing strength: Yes : Retaining wall height is not satisfied. The level of retaining wall and footing should to be raised; the fissures appear on retaining wall because there is no any starter bars to join that wall with the footing.

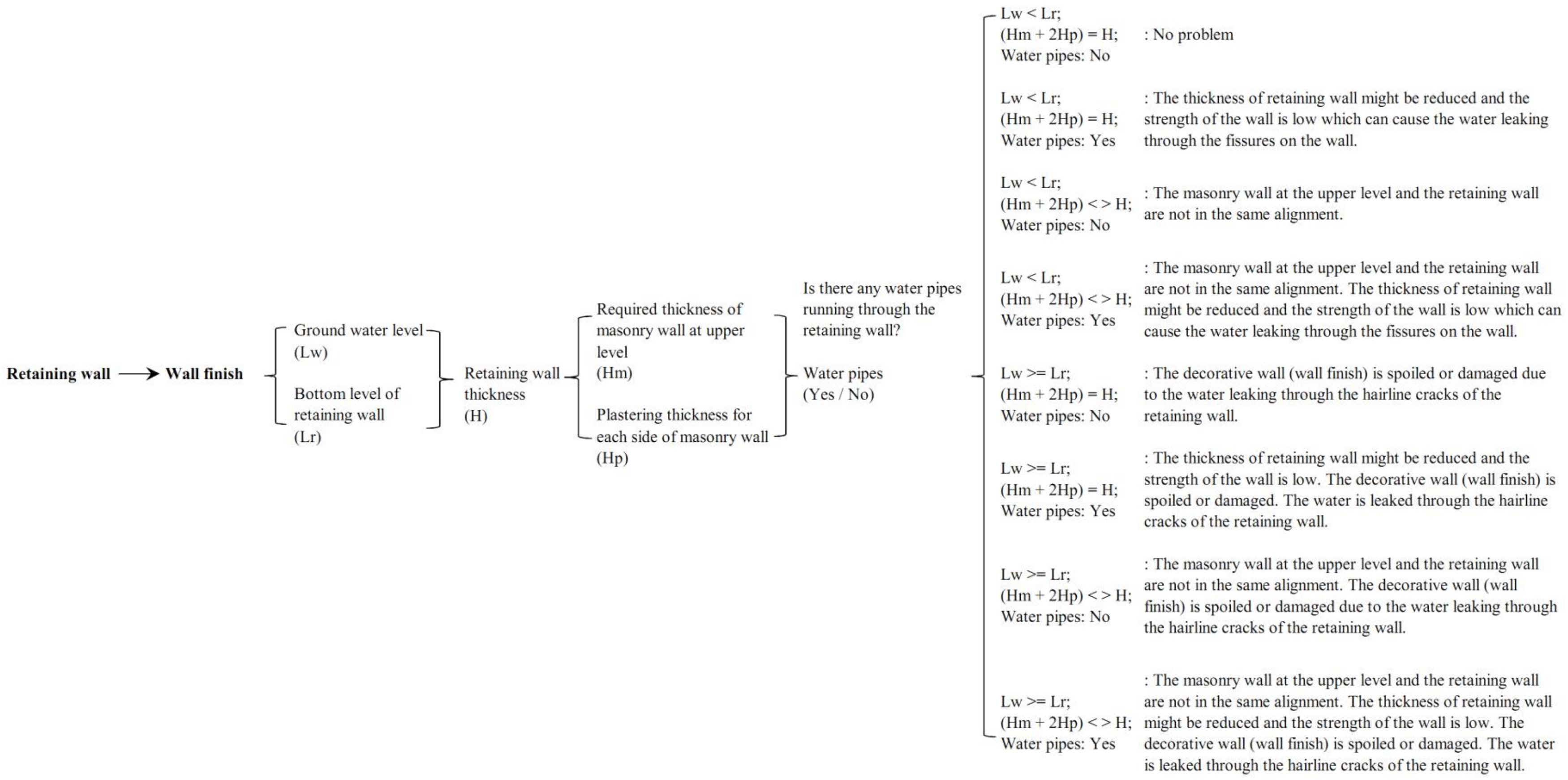
(Lu - Lr) > h; Required starter bars: No; Footing strength: No : Retaining wall height is not satisfied. The level of retaining wall and footing should to be raised; footing cannot resist with the loads imposed on it by the soil pressure on retaining wall and there are fissures on the retaining wall.

1.3 Retaining wall and retaining wall

Retaining wall → **Retaining wall** → Water stop details (Yes / No) Rebar details (Rebar bending in specifications) (Yes / No)

Water stop details: Yes; Rebar details: Yes;	: No problem
Water stop details: Yes; Rebar details: No;	: The rebar details of the retaining walls should be re-checked.
Water stop details: No; Rebar details: Yes;	: The fissures appear at the joint between the retaining walls and the water might be leaked through those fissures at the joint.
Water stop details: No; Rebar details: No;	: The fissures appear at the joint between the retaining walls and the water might be leaked through those fissures. The rebar details of the retaining walls should be re-checked.

1.4 Retaining wall and wall finish



Lw < Lr;
(Hm + 2Hp) = H;
Water pipes: No
: No problem

Lw < Lr;
(Hm + 2Hp) = H;
Water pipes: Yes
: The thickness of retaining wall might be reduced and the strength of the wall is low which can cause the water leaking through the fissures on the wall.

Lw < Lr;
(Hm + 2Hp) < > H;
Water pipes: No
: The masonry wall at the upper level and the retaining wall are not in the same alignment.

Lw < Lr;
(Hm + 2Hp) < > H;
Water pipes: Yes
: The masonry wall at the upper level and the retaining wall are not in the same alignment. The thickness of retaining wall might be reduced and the strength of the wall is low which can cause the water leaking through the fissures on the wall.

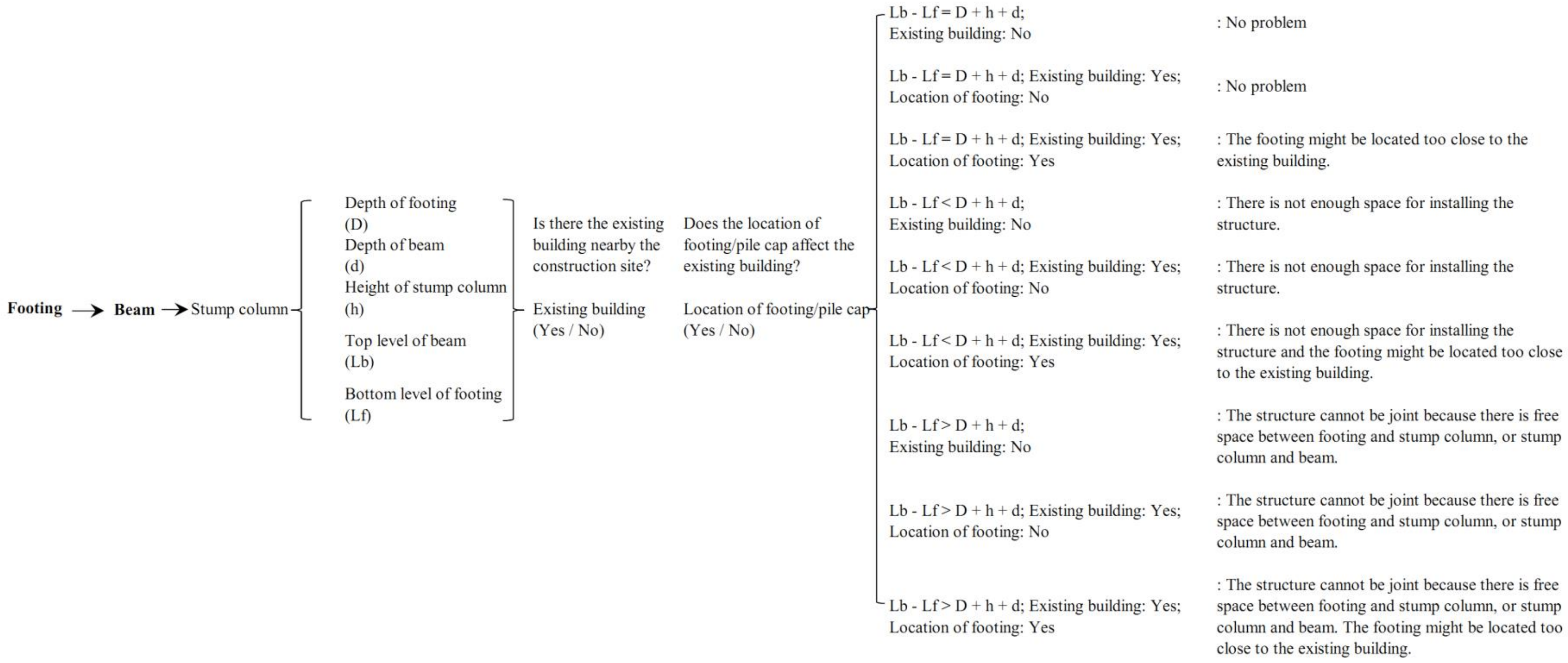
Lw >= Lr;
(Hm + 2Hp) = H;
Water pipes: No
: The decorative wall (wall finish) is spoiled or damaged due to the water leaking through the hairline cracks of the retaining wall.

Lw >= Lr;
(Hm + 2Hp) = H;
Water pipes: Yes
: The thickness of retaining wall might be reduced and the strength of the wall is low. The decorative wall (wall finish) is spoiled or damaged. The water is leaked through the hairline cracks of the retaining wall.

Lw >= Lr;
(Hm + 2Hp) < > H;
Water pipes: No
: The masonry wall at the upper level and the retaining wall are not in the same alignment. The decorative wall (wall finish) is spoiled or damaged due to the water leaking through the hairline cracks of the retaining wall.

Lw >= Lr;
(Hm + 2Hp) < > H;
Water pipes: Yes
: The masonry wall at the upper level and the retaining wall are not in the same alignment. The thickness of retaining wall might be reduced and the strength of the wall is low. The decorative wall (wall finish) is spoiled or damaged. The water is leaked through the hairline cracks of the retaining wall.

2.1 Footing and beam (1)



Footing → Beam → Stump column

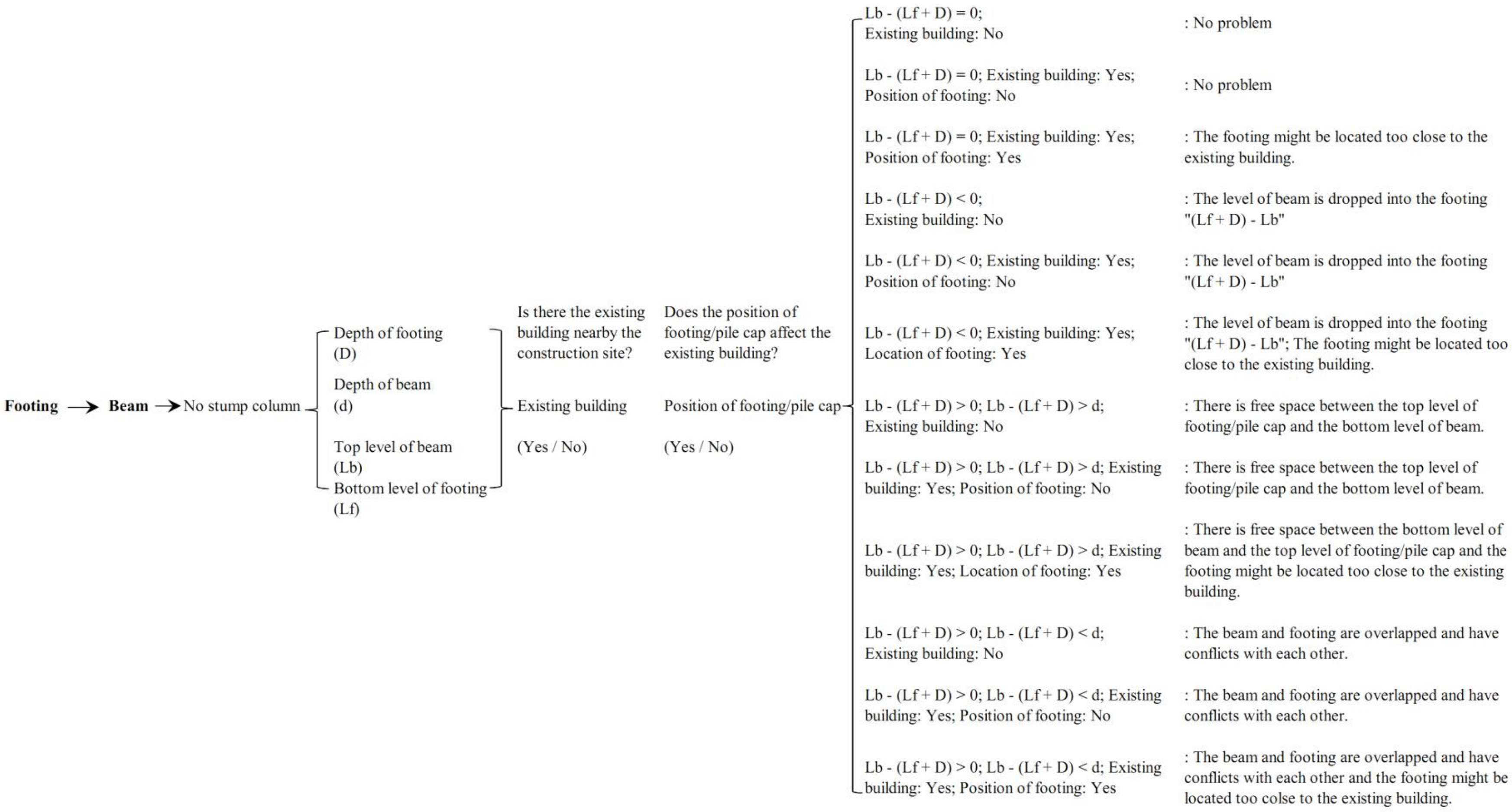
Depth of footing (D)
Depth of beam (d)
Height of stump column (h)
Top level of beam (Lb)
Bottom level of footing (Lf)

Is there the existing building nearby the construction site?
Existing building (Yes / No)

Does the location of footing/pile cap affect the existing building?
Location of footing/pile cap (Yes / No)

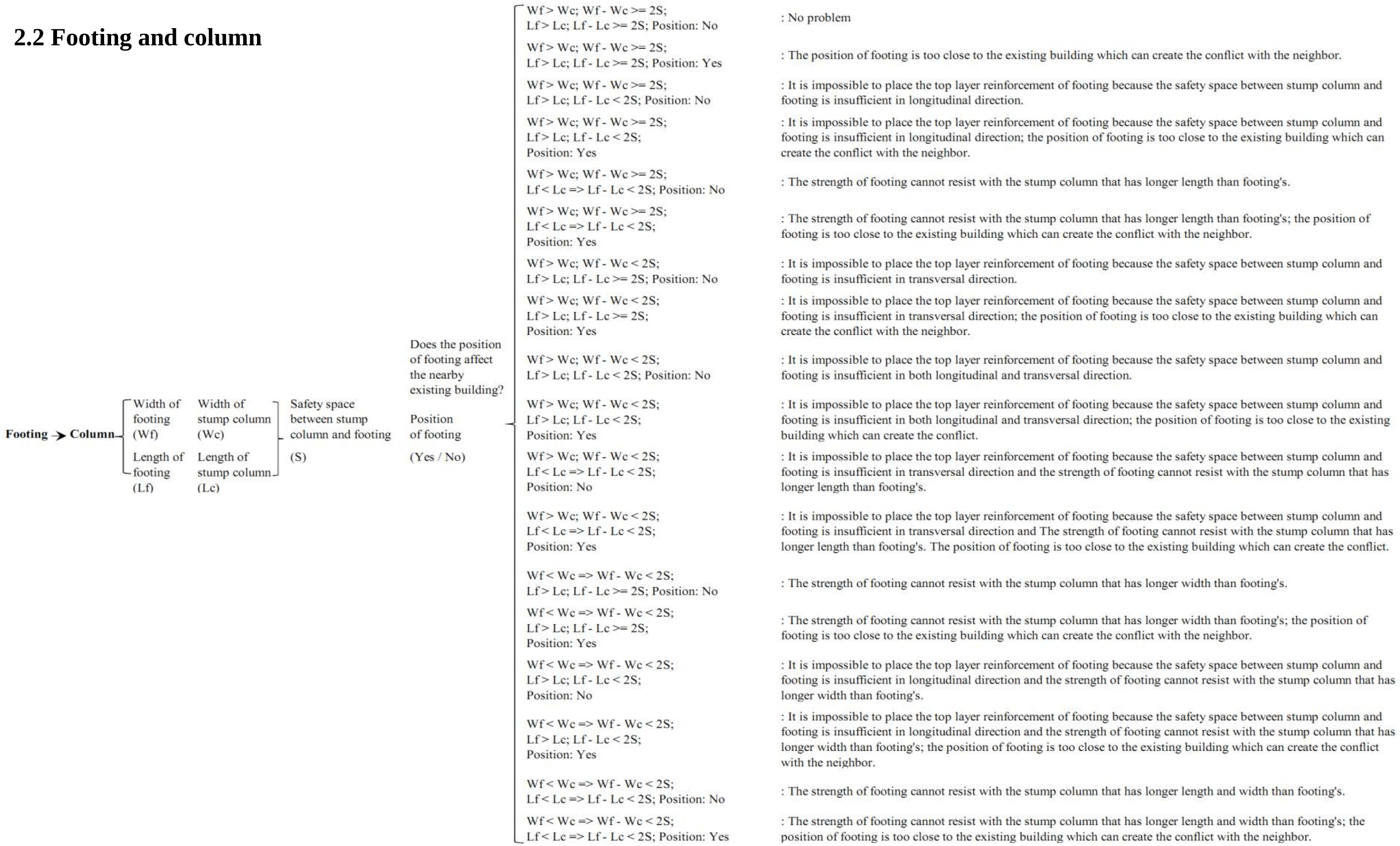
Lb - Lf = D + h + d; Existing building: No	: No problem
Lb - Lf = D + h + d; Existing building: Yes; Location of footing: No	: No problem
Lb - Lf = D + h + d; Existing building: Yes; Location of footing: Yes	: The footing might be located too close to the existing building.
Lb - Lf < D + h + d; Existing building: No	: There is not enough space for installing the structure.
Lb - Lf < D + h + d; Existing building: Yes; Location of footing: No	: There is not enough space for installing the structure.
Lb - Lf < D + h + d; Existing building: Yes; Location of footing: Yes	: There is not enough space for installing the structure and the footing might be located too close to the existing building.
Lb - Lf > D + h + d; Existing building: No	: The structure cannot be joint because there is free space between footing and stump column, or stump column and beam.
Lb - Lf > D + h + d; Existing building: Yes; Location of footing: No	: The structure cannot be joint because there is free space between footing and stump column, or stump column and beam.
Lb - Lf > D + h + d; Existing building: Yes; Location of footing: Yes	: The structure cannot be joint because there is free space between footing and stump column, or stump column and beam. The footing might be located too close to the existing building.

2.1 Footing and beam (2)



Lb - (Lf + D) = 0; Existing building: No	: No problem
Lb - (Lf + D) = 0; Existing building: Yes; Position of footing: No	: No problem
Lb - (Lf + D) = 0; Existing building: Yes; Position of footing: Yes	: The footing might be located too close to the existing building.
Lb - (Lf + D) < 0; Existing building: No	: The level of beam is dropped into the footing "(Lf + D) - Lb"
Lb - (Lf + D) < 0; Existing building: Yes; Position of footing: No	: The level of beam is dropped into the footing "(Lf + D) - Lb"
Lb - (Lf + D) < 0; Existing building: Yes; Location of footing: Yes	: The level of beam is dropped into the footing "(Lf + D) - Lb"; The footing might be located too close to the existing building.
Lb - (Lf + D) > 0; Lb - (Lf + D) > d; Existing building: No	: There is free space between the top level of footing/pile cap and the bottom level of beam.
Lb - (Lf + D) > 0; Lb - (Lf + D) > d; Existing building: Yes; Position of footing: No	: There is free space between the top level of footing/pile cap and the bottom level of beam.
Lb - (Lf + D) > 0; Lb - (Lf + D) > d; Existing building: Yes; Location of footing: Yes	: There is free space between the bottom level of beam and the top level of footing/pile cap and the footing might be located too close to the existing building.
Lb - (Lf + D) > 0; Lb - (Lf + D) < d; Existing building: No	: The beam and footing are overlapped and have conflicts with each other.
Lb - (Lf + D) > 0; Lb - (Lf + D) < d; Existing building: Yes; Position of footing: No	: The beam and footing are overlapped and have conflicts with each other.
Lb - (Lf + D) > 0; Lb - (Lf + D) < d; Existing building: Yes; Position of footing: Yes	: The beam and footing are overlapped and have conflicts with each other and the footing might be located too colse to the existing building.

2.2 Footing and column



Wf > Wc; Wf - Wc >= 2S; Lf > Lc; Lf - Lc >= 2S; Position: No	: No problem
Wf > Wc; Wf - Wc >= 2S; Lf > Lc; Lf - Lc >= 2S; Position: Yes	: The position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf > Wc; Wf - Wc >= 2S; Lf > Lc; Lf - Lc < 2S; Position: No	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in longitudinal direction.
Wf > Wc; Wf - Wc >= 2S; Lf > Lc; Lf - Lc < 2S; Position: Yes	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in longitudinal direction; the position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf > Wc; Wf - Wc >= 2S; Lf < Lc => Lf - Lc < 2S; Position: No	: The strength of footing cannot resist with the stump column that has longer length than footing's.
Wf > Wc; Wf - Wc >= 2S; Lf < Lc => Lf - Lc < 2S; Position: Yes	: The strength of footing cannot resist with the stump column that has longer length than footing's; the position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf > Wc; Wf - Wc < 2S; Lf > Lc; Lf - Lc >= 2S; Position: No	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in transversal direction.
Wf > Wc; Wf - Wc < 2S; Lf > Lc; Lf - Lc >= 2S; Position: Yes	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in transversal direction; the position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf > Wc; Wf - Wc < 2S; Lf > Lc; Lf - Lc < 2S; Position: No	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in both longitudinal and transversal direction.
Wf > Wc; Wf - Wc < 2S; Lf > Lc; Lf - Lc < 2S; Position: Yes	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in both longitudinal and transversal direction; the position of footing is too close to the existing building which can create the conflict.
Wf > Wc; Wf - Wc < 2S; Lf < Lc => Lf - Lc < 2S; Position: No	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in transversal direction and the strength of footing cannot resist with the stump column that has longer length than footing's.
Wf > Wc; Wf - Wc < 2S; Lf < Lc => Lf - Lc < 2S; Position: Yes	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in transversal direction and The strength of footing cannot resist with the stump column that has longer length than footing's. The position of footing is too close to the existing building which can create the conflict.
Wf < Wc => Wf - Wc < 2S; Lf > Lc; Lf - Lc >= 2S; Position: No	: The strength of footing cannot resist with the stump column that has longer width than footing's.
Wf < Wc => Wf - Wc < 2S; Lf > Lc; Lf - Lc >= 2S; Position: Yes	: The strength of footing cannot resist with the stump column that has longer width than footing's; the position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf < Wc => Wf - Wc < 2S; Lf > Lc; Lf - Lc < 2S; Position: No	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in longitudinal direction and the strength of footing cannot resist with the stump column that has longer width than footing's.
Wf < Wc => Wf - Wc < 2S; Lf > Lc; Lf - Lc < 2S; Position: Yes	: It is impossible to place the top layer reinforcement of footing because the safety space between stump column and footing is insufficient in longitudinal direction and the strength of footing cannot resist with the stump column that has longer width than footing's; the position of footing is too close to the existing building which can create the conflict with the neighbor.
Wf < Wc => Wf - Wc < 2S; Lf < Lc => Lf - Lc < 2S; Position: No	: The strength of footing cannot resist with the stump column that has longer length and width than footing's.
Wf < Wc => Wf - Wc < 2S; Lf < Lc => Lf - Lc < 2S; Position: Yes	: The strength of footing cannot resist with the stump column that has longer length and width than footing's; the position of footing is too close to the existing building which can create the conflict with the neighbor.

2.3 Footing and fire protection system

Footing → **Fire protection system** → Pipe of fire protection system → Position of pipe

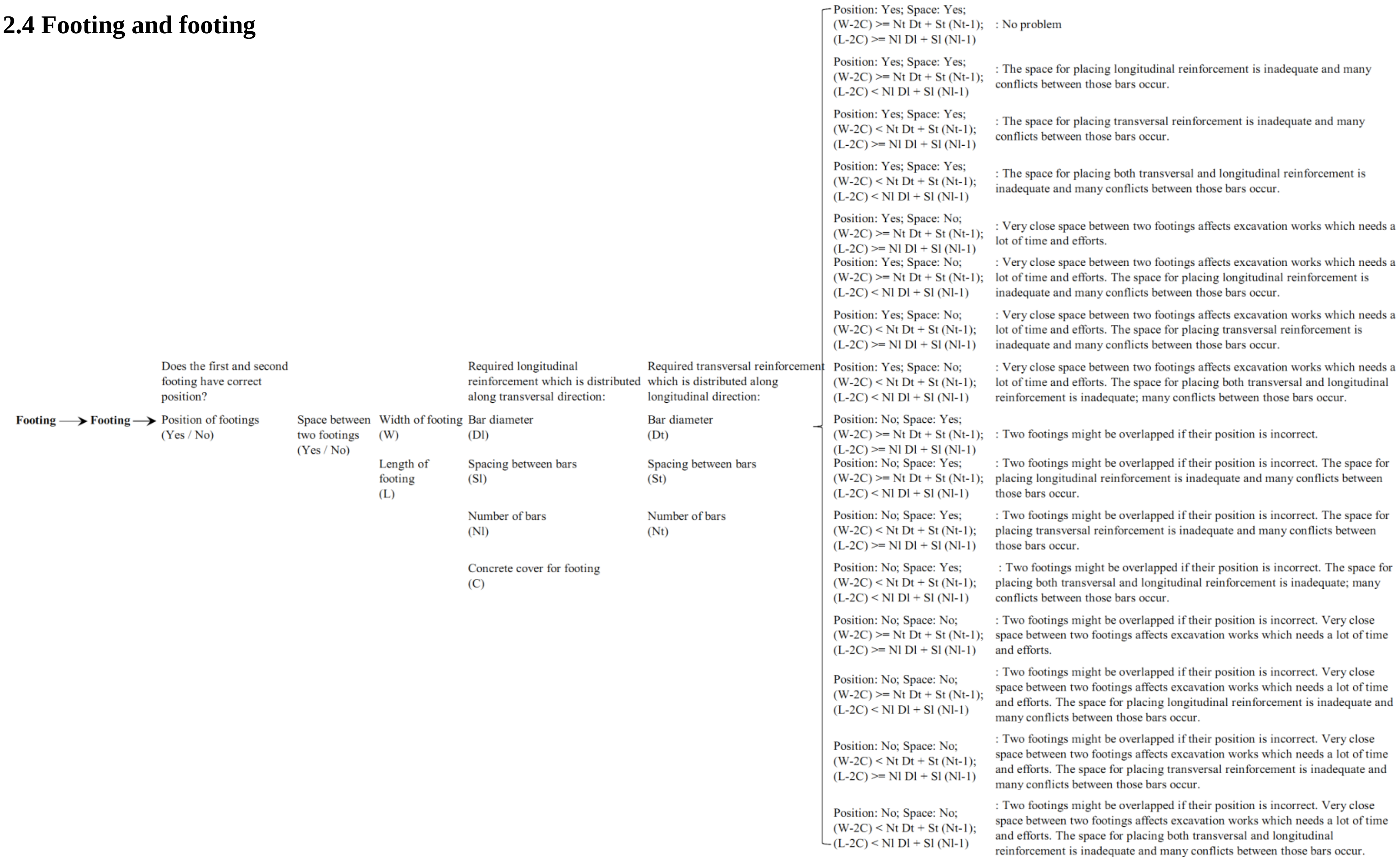
Is there any pipe of fire protection system nearby the footing in your structure?

(Yes / No)

(Pipe above the footing / Pipe across the footing section / Pipe under the footing)

Pipe: No	: No problem
Pipe: Yes; Position: Pipe above the footing	: No problem
Pipe: Yes; Position: Pipe across the footing	: The pipe has conflict with footing reinforcement and this pipe is impossible to be installed.
Pipe: Yes; Position: Pipe under the footing	: The pipe has to carry the loads from footing that makes the pipe broken and damaged. The water is then leaked from the broken pipe.

2.4 Footing and footing



Footing → **Footing** →

Does the first and second footing have correct position?
Position of footings (Yes / No)

Space between two footings (Yes / No)

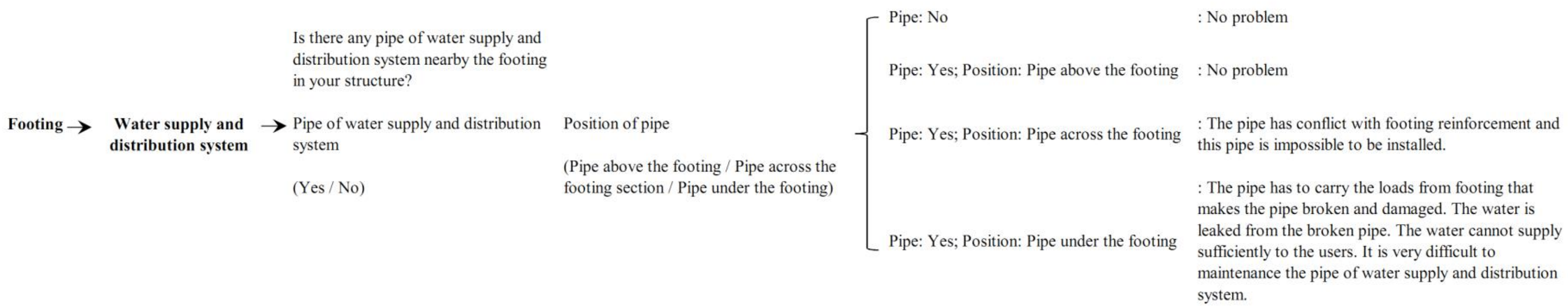
Width of footing (W)
Length of footing (L)

Required longitudinal reinforcement which is distributed along transversal direction:
Bar diameter (Dl)
Spacing between bars (Sl)
Number of bars (Nl)
Concrete cover for footing (C)

Required transversal reinforcement which is distributed along longitudinal direction:
Bar diameter (Dt)
Spacing between bars (St)
Number of bars (Nt)

Position: Yes; Space: Yes; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: No problem
Position: Yes; Space: Yes; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: The space for placing longitudinal reinforcement is inadequate and many conflicts between those bars occur.
Position: Yes; Space: Yes; (W-2C) < Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: The space for placing transversal reinforcement is inadequate and many conflicts between those bars occur.
Position: Yes; Space: Yes; (W-2C) < Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: The space for placing both transversal and longitudinal reinforcement is inadequate and many conflicts between those bars occur.
Position: Yes; Space: No; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Very close space between two footings affects excavation works which needs a lot of time and efforts.
Position: Yes; Space: No; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing longitudinal reinforcement is inadequate and many conflicts between those bars occur.
Position: Yes; Space: No; (W-2C) < Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing transversal reinforcement is inadequate and many conflicts between those bars occur.
Position: Yes; Space: No; (W-2C) < Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing both transversal and longitudinal reinforcement is inadequate; many conflicts between those bars occur.
Position: No; Space: Yes; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect.
Position: No; Space: Yes; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. The space for placing longitudinal reinforcement is inadequate and many conflicts between those bars occur.
Position: No; Space: Yes; (W-2C) < Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. The space for placing transversal reinforcement is inadequate and many conflicts between those bars occur.
Position: No; Space: Yes; (W-2C) < Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. The space for placing both transversal and longitudinal reinforcement is inadequate; many conflicts between those bars occur.
Position: No; Space: No; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. Very close space between two footings affects excavation works which needs a lot of time and efforts.
Position: No; Space: No; (W-2C) >= Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing longitudinal reinforcement is inadequate and many conflicts between those bars occur.
Position: No; Space: No; (W-2C) < Nt Dt + St (Nt-1); (L-2C) >= Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing transversal reinforcement is inadequate and many conflicts between those bars occur.
Position: No; Space: No; (W-2C) < Nt Dt + St (Nt-1); (L-2C) < Nl Dl + Sl (Nl-1)	: Two footings might be overlapped if their position is incorrect. Very close space between two footings affects excavation works which needs a lot of time and efforts. The space for placing both transversal and longitudinal reinforcement is inadequate and many conflicts between those bars occur.

2.5 Footing and water supply and distribution system



Footing → **Water supply and distribution system** → Pipe of water supply and distribution system

Is there any pipe of water supply and distribution system nearby the footing in your structure?

(Yes / No)

Position of pipe

(Pipe above the footing / Pipe across the footing section / Pipe under the footing)

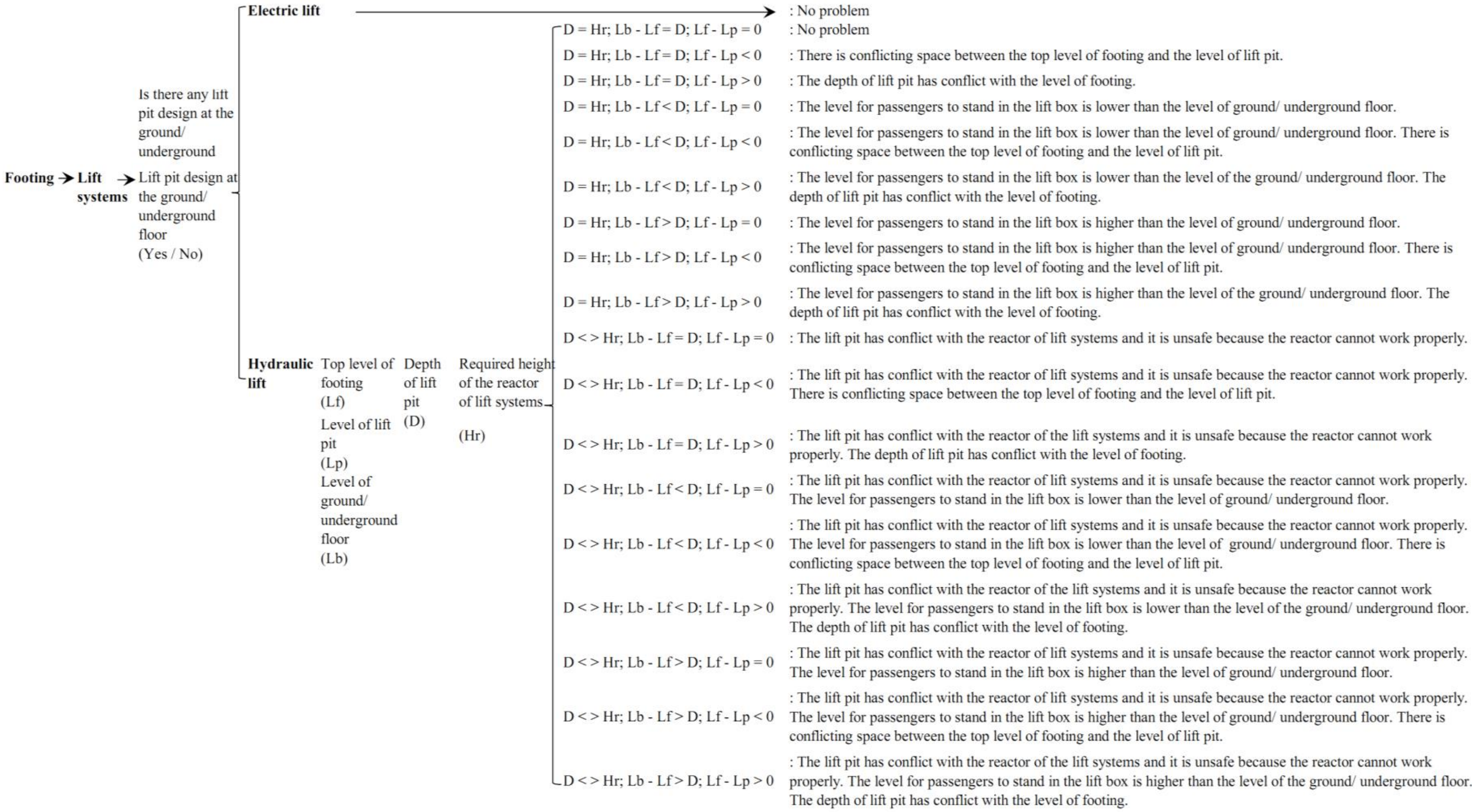
Pipe: No : No problem

Pipe: Yes; Position: Pipe above the footing : No problem

Pipe: Yes; Position: Pipe across the footing : The pipe has conflict with footing reinforcement and this pipe is impossible to be installed.

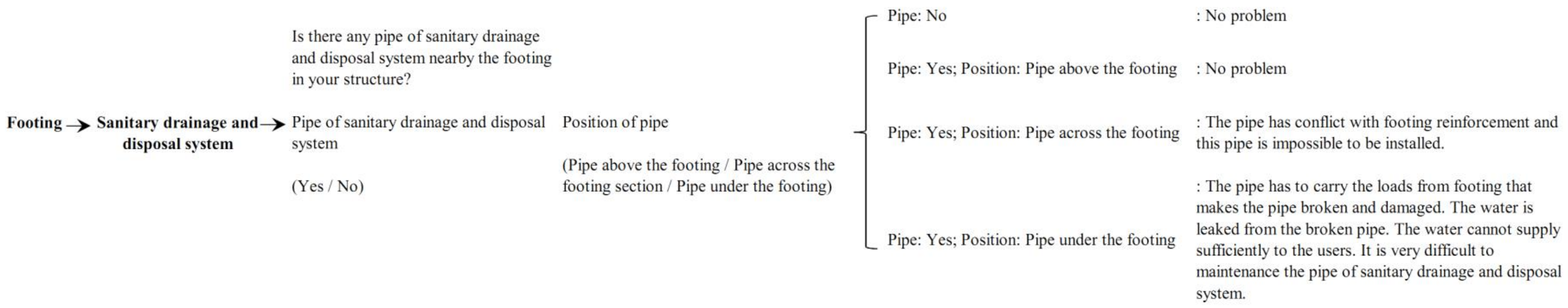
Pipe: Yes; Position: Pipe under the footing : The pipe has to carry the loads from footing that makes the pipe broken and damaged. The water is leaked from the broken pipe. The water cannot supply sufficiently to the users. It is very difficult to maintenance the pipe of water supply and distribution system.

2.6 Footing and lift systems



Electric lift	: No problem
D = Hr; Lb - Lf = D; Lf - Lp = 0	: No problem
D = Hr; Lb - Lf = D; Lf - Lp < 0	: There is conflicting space between the top level of footing and the level of lift pit.
D = Hr; Lb - Lf = D; Lf - Lp > 0	: The depth of lift pit has conflict with the level of footing.
D = Hr; Lb - Lf < D; Lf - Lp = 0	: The level for passengers to stand in the lift box is lower than the level of ground/ underground floor.
D = Hr; Lb - Lf < D; Lf - Lp < 0	: The level for passengers to stand in the lift box is lower than the level of ground/ underground floor. There is conflicting space between the top level of footing and the level of lift pit.
D = Hr; Lb - Lf < D; Lf - Lp > 0	: The level for passengers to stand in the lift box is lower than the level of the ground/ underground floor. The depth of lift pit has conflict with the level of footing.
D = Hr; Lb - Lf > D; Lf - Lp = 0	: The level for passengers to stand in the lift box is higher than the level of ground/ underground floor.
D = Hr; Lb - Lf > D; Lf - Lp < 0	: The level for passengers to stand in the lift box is higher than the level of ground/ underground floor. There is conflicting space between the top level of footing and the level of lift pit.
D = Hr; Lb - Lf > D; Lf - Lp > 0	: The level for passengers to stand in the lift box is higher than the level of the ground/ underground floor. The depth of lift pit has conflict with the level of footing.
D < > Hr; Lb - Lf = D; Lf - Lp = 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly.
D < > Hr; Lb - Lf = D; Lf - Lp < 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly. There is conflicting space between the top level of footing and the level of lift pit.
D < > Hr; Lb - Lf = D; Lf - Lp > 0	: The lift pit has conflict with the reactor of the lift systems and it is unsafe because the reactor cannot work properly. The depth of lift pit has conflict with the level of footing.
D < > Hr; Lb - Lf < D; Lf - Lp = 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is lower than the level of ground/ underground floor.
D < > Hr; Lb - Lf < D; Lf - Lp < 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is lower than the level of ground/ underground floor. There is conflicting space between the top level of footing and the level of lift pit.
D < > Hr; Lb - Lf < D; Lf - Lp > 0	: The lift pit has conflict with the reactor of the lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is lower than the level of the ground/ underground floor. The depth of lift pit has conflict with the level of footing.
D < > Hr; Lb - Lf > D; Lf - Lp = 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is higher than the level of ground/ underground floor.
D < > Hr; Lb - Lf > D; Lf - Lp < 0	: The lift pit has conflict with the reactor of lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is higher than the level of ground/ underground floor. There is conflicting space between the top level of footing and the level of lift pit.
D < > Hr; Lb - Lf > D; Lf - Lp > 0	: The lift pit has conflict with the reactor of the lift systems and it is unsafe because the reactor cannot work properly. The level for passengers to stand in the lift box is higher than the level of the ground/ underground floor. The depth of lift pit has conflict with the level of footing.

2.7 Footing and sanitary drainage and disposal system



Pipe: No : No problem

Pipe: Yes; Position: Pipe above the footing : No problem

Pipe: Yes; Position: Pipe across the footing : The pipe has conflict with footing reinforcement and this pipe is impossible to be installed.

Pipe: Yes; Position: Pipe under the footing : The pipe has to carry the loads from footing that makes the pipe broken and damaged. The water is leaked from the broken pipe. The water cannot supply sufficiently to the users. It is very difficult to maintenance the pipe of sanitary drainage and disposal system.

3.1 Beam and beam

Beam → Beam → Function of the first beam (Main beam / Secondary beam) → Function of the second beam (Main beam / Secondary beam)

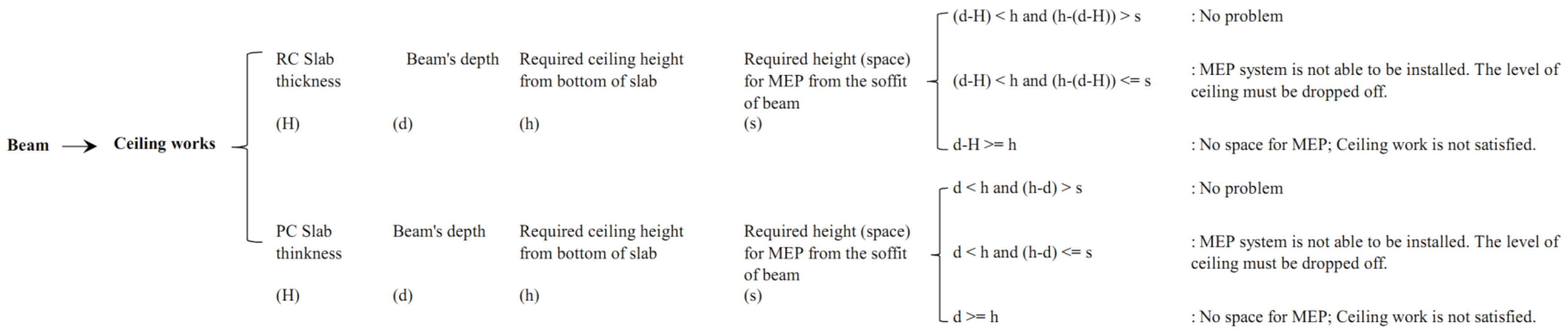
- **Main beam and secondary beam**
  - Depth of main beam (D1)
  - Depth of secondary beam (D2)
  - The depth of beam when the face fars (middle bars) are required based on the design standard (Dm)
  - - Middle bars in the main beam
  - - Middle bars in the secondary beam (Yes / No)
  - Beam reinforcement (Yes / No): Is the beam reinforcement at the connection of these two beams very complicated?
  - Strength of main beam (Yes / No): Does the main beam strong enough to carry the loads imposed on it by the secondary beam?

D1 < Dm; D2 < Dm; Middle bars in main beam or secondary beam: Yes/No;	: No problem because the face bars (middle bars) are not required.
D1 = D2; Beam reinforcement: Yes; Strength: Yes	: No problem
D1 < > D2	: The main bars in the bottom layer of the first and second beam has conflict with each other.
Beam reinforcement: No	: The concrete cover at the connection between these two beams may be lost.
Strength: No	: The main beam can be cracked.
D1 >= Dm or D2 >= Dm; Middle bars in main beam or secondary beam: Yes	: No problem
D1 >= Dm or D2 >= Dm; Middle bars in main beam or secondary beam: No	: The stirrup cannot be strengthen and torsion occurs.

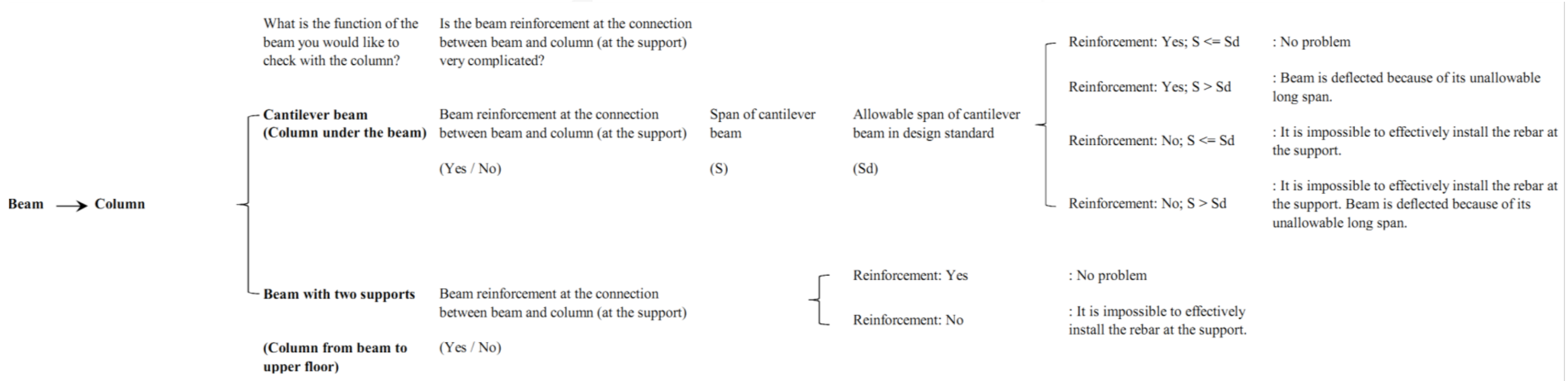
- **Main beam and main beam / Secondary beam and secondary beam**
  - Depth of first beam (D1)
  - Depth of second beam (D2)
  - The depth of beam when the face fars (middle bars) are required based on the design standard (Dm)
  - Middle bars in the first beam (Yes / No)
  - Middle bars in the second beam (Yes / No)
  - Beam reinforcement (Yes / No)

D1 < Dm; D2 < Dm; Middle bars in main beams or secondary beams: Yes/No;	: No problem because the face bars (middle bars) are not required.
D1 = D2; Beam reinforcement: Yes;	: No problem
D1 < > D2	: The main bars in the bottom layer of the first and second beam has conflict with each other.
Beam reinforcement: No	: The concrete cover at the connection between these two beams may be lost.
D1 >= Dm or D2 >= Dm; Middle bars in main beams or secondary beams: Yes	: No problem
D1 >= Dm or D2 >= Dm; Middle bars in main beams or secondary beams: No	: The stirrup cannot be strengthen and torsion occurs.

3.2 Beam and ceiling works



3.3 Beam and column



3.4 Beam and door/window

Beam → **Door/window**

- RC Slab thickness (H) | Beam's depth (d) | Required door/window height (h) | Required floor height (from the lower slab to the top level of upper slab) (F) | Lintel (beam) (Yes / No)
  - (F-d) = h, no lintel : No problem
  - (F-d) = h, lintel : No space to install lintel; however, door/window can be installed.
  - (F-d) < h, lintel or no lintel : Door/window is not able to be installed.
  - (F-d) > h, lintel : No problem
  - (F-d) > h, no lintel : Door/windlow can be installed; however, there might be cracks on the wall around that door/window since there is no lintel.
- PC Slab thickness (H) | Beam's depth (d) | Required door/window height (h) | Required floor height (from the lower slab to the top level of upper slab) (F) | Lintel (beam) (Yes / No)
  - (F-d-H) = h, no lintel : No problems
  - (F-d-H) = h, lintel : No space to install lintel; however, door/window can be installed.
  - (F-d-H) < h, lintel or no lintel : Door/window is not able to be installed.
  - (F-d-H) > h, lintel : No problems
  - (F-d-H) > h, no lintel : Door/windlow can be installed; however, there might be cracks on the wall around that door/window since there is no lintel.

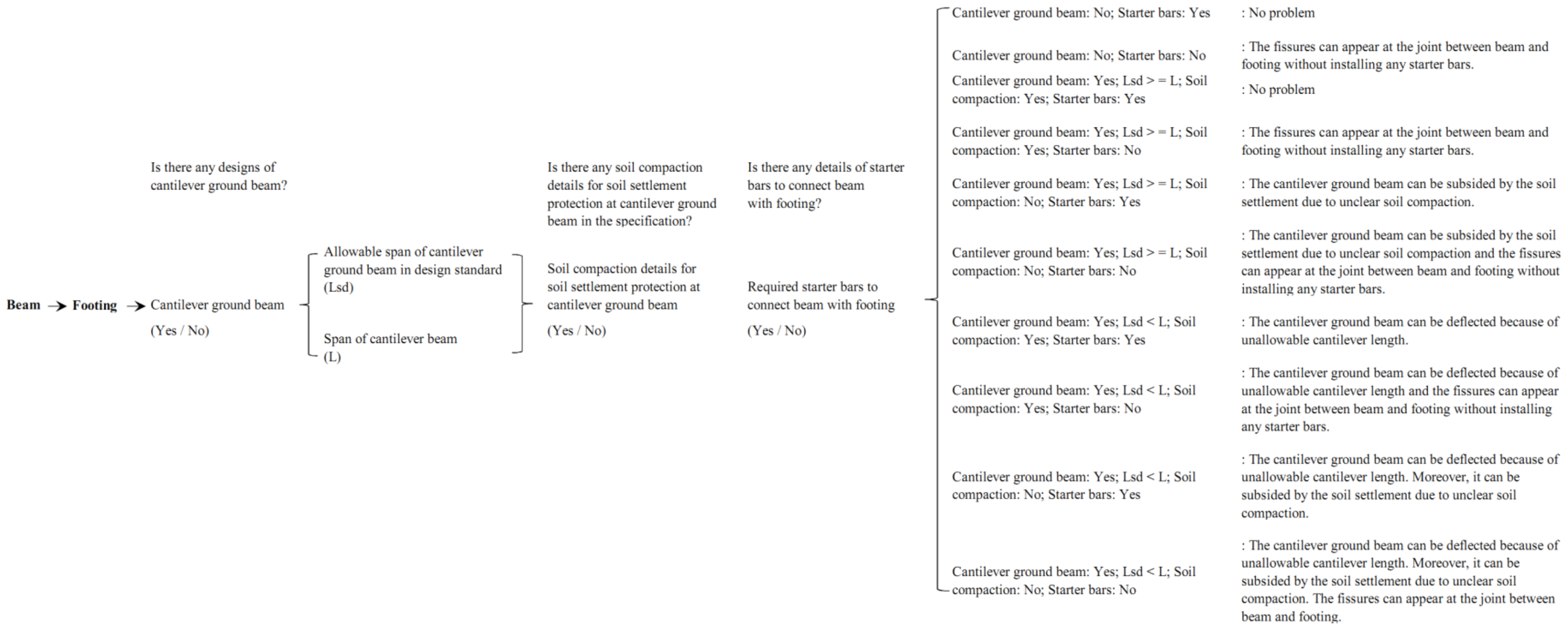
3.5 Beam and floor finish

Is there any gutter for carrying off the water in your structure?

Beam ⟶ **Floor finish** ⟶ Gutter for carrying off the water (Yes / No) | Required floor finish level at the gutter (Lg) | Required floor finish level at nearby areas (Ls) | Top level of beam for gutter (Lb) | Thickness of floor finish (hs)

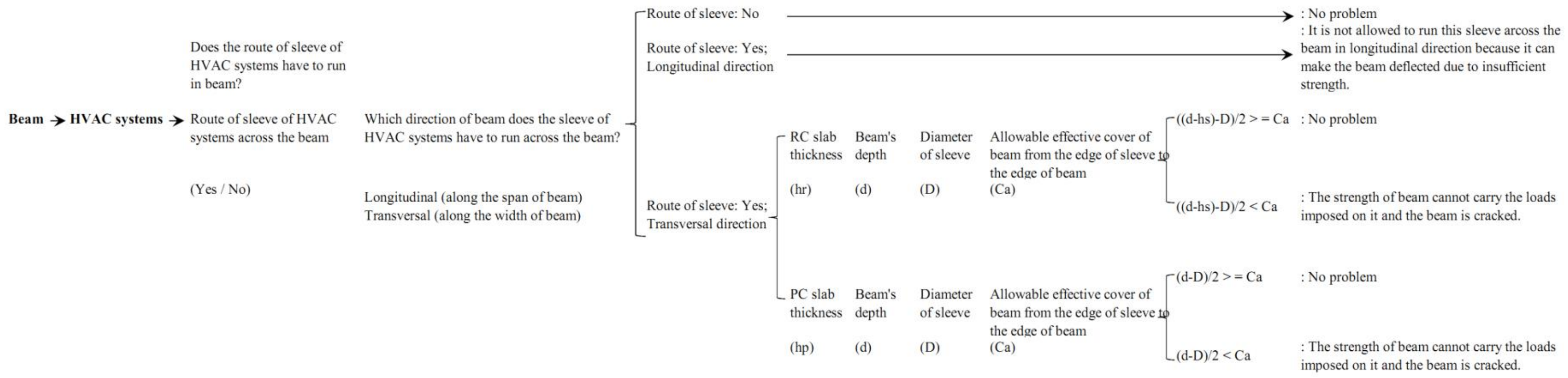
Gutter: No	: No problem
Gutter: Yes; Lg = Lb + hs; Lg < Ls	: No problem
Gutter: Yes; Lg = Lb + hs; Lg > Ls	: The water cannot flow off; so the top level of beam for gutter should be dropped.
Gutter: Yes; Lg = Lb + hs; Lg = Ls	: The water cannot flow off easily; the top level of beam for gutter should be dropped.
Gutter: Yes; Lg < Lb + hs; Lg < Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be dropped to fulfill the desired plan. However, the water can flow normally for this case.
Gutter: Yes; Lg < Lb + hs; Lg > Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be dropped to fulfill the desired plan. The water cannot flow off in this case.
Gutter: Yes; Lg < Lb + hs; Lg = Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be dropped to fulfill the desired plan. The water cannot flow off easily.
Gutter: Yes; Lg > Lb + hs; Lg < Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be raised up to fulfill the desired plan. However, the water can flow normally for this case.
Gutter: Yes; Lg > Lb + hs; Lg > Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be raised up to fulfill the desired plan. The water cannot flow off in this case.
Gutter: Yes; Lg > Lb + hs; Lg = Ls	: The required floor finish level for gutter is not satisfied; the level of beam for gutter should be raised up to fulfill the desired plan. The water cannot flow off easily.

3.6 Beam and footing



Cantilever ground beam: No; Starter bars: Yes	: No problem
Cantilever ground beam: No; Starter bars: No	: The fissures can appear at the joint between beam and footing without installing any starter bars.
Cantilever ground beam: Yes; Lsd > = L; Soil compaction: Yes; Starter bars: Yes	: No problem
Cantilever ground beam: Yes; Lsd > = L; Soil compaction: Yes; Starter bars: No	: The fissures can appear at the joint between beam and footing without installing any starter bars.
Cantilever ground beam: Yes; Lsd > = L; Soil compaction: No; Starter bars: Yes	: The cantilever ground beam can be subsided by the soil settlement due to unclear soil compaction.
Cantilever ground beam: Yes; Lsd > = L; Soil compaction: No; Starter bars: No	: The cantilever ground beam can be subsided by the soil settlement due to unclear soil compaction and the fissures can appear at the joint between beam and footing without installing any starter bars.
Cantilever ground beam: Yes; Lsd < L; Soil compaction: Yes; Starter bars: Yes	: The cantilever ground beam can be deflected because of unallowable cantilever length.
Cantilever ground beam: Yes; Lsd < L; Soil compaction: Yes; Starter bars: No	: The cantilever ground beam can be deflected because of unallowable cantilever length and the fissures can appear at the joint between beam and footing without installing any starter bars.
Cantilever ground beam: Yes; Lsd < L; Soil compaction: No; Starter bars: Yes	: The cantilever ground beam can be deflected because of unallowable cantilever length. Moreover, it can be subsided by the soil settlement due to unclear soil compaction.
Cantilever ground beam: Yes; Lsd < L; Soil compaction: No; Starter bars: No	: The cantilever ground beam can be deflected because of unallowable cantilever length. Moreover, it can be subsided by the soil settlement due to unclear soil compaction. The fissures can appear at the joint between beam and footing.

3.7 Beam and HVAC systems



3.8 Beam and lift systems

Beam → **Lift systems** →

Is the position of beam for fixing lift railing system with the structure correctly placed?

(Yes / No)

Is the position of beam at the opening of lift correctly placed as required by the architecture?

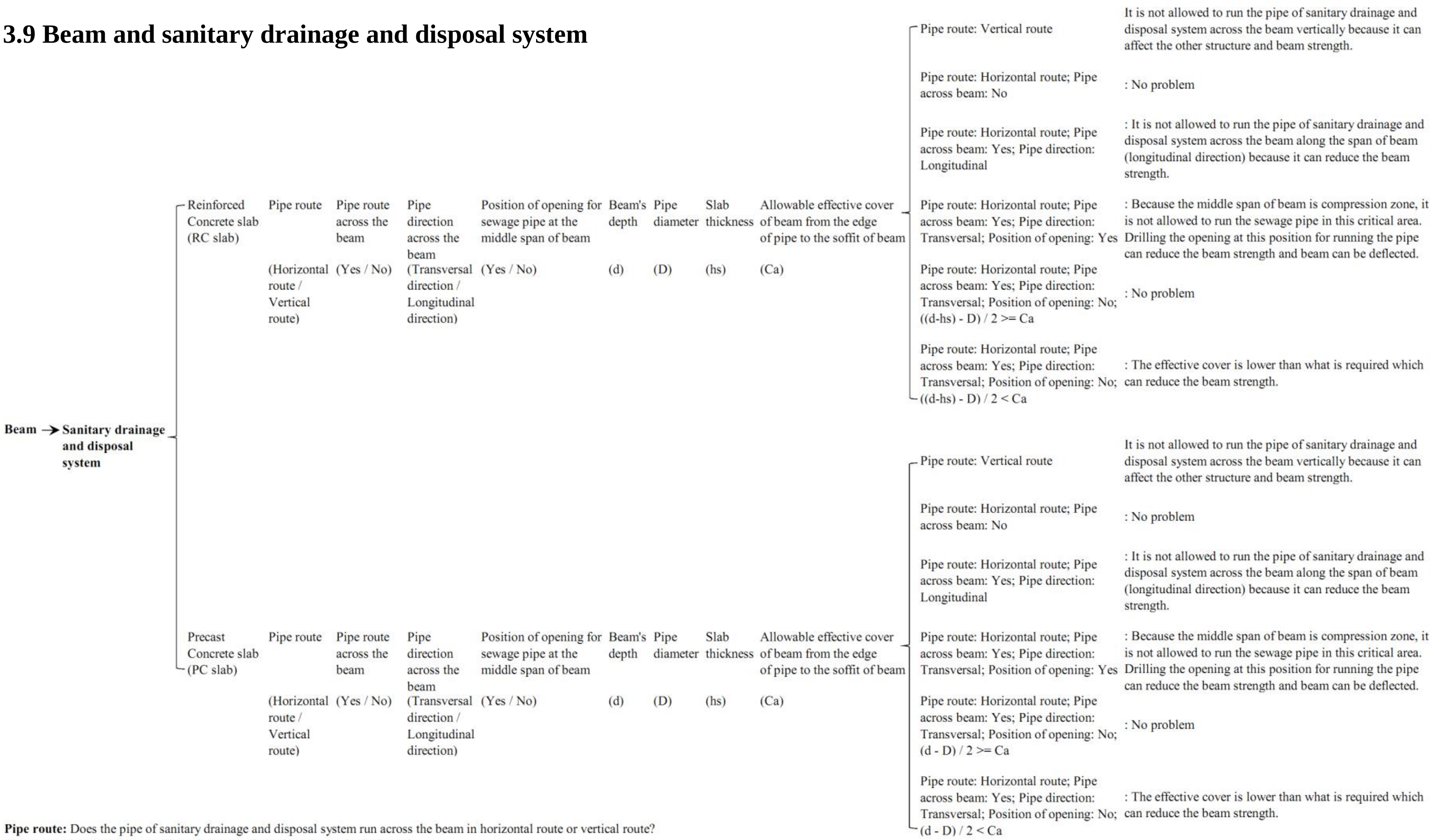
(Yes / No)

Opening for lift:
Width of opening for lift (W)
Length of opening for lift (L)

Required size of lift:
Width of lift (Wr)
Length of lift (Lr)

Beam for fixing: Yes; Beam at the opening: Yes; W = Wr; L = Lr	: No problem
Beam for fixing: Yes; Beam at the opening: Yes; W = Wr; L < > Lr	: It is not able to install the lift systems because the length of the reserved opening is different from the required length of lift box.
Beam for fixing: Yes; Beam at the opening: Yes; W < > Wr; L = Lr	: It is not able to install the lift systems because the width of the reserved opening is different from the required width of lift box.
Beam for fixing: Yes; Beam at the opening: Yes; W < > Wr; L < > Lr	: It is not able to install the lift systems because the size of the reserved opening is different from the required size of lift box.
Beam for fixing: Yes; Beam at the opening: No; W = Wr; L = Lr	: The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box.
Beam for fixing: Yes; Beam at the opening: No; W = Wr; L < > Lr	: The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the length of the reserved opening is different from the required length of lift box.
Beam for fixing: Yes; Beam at the opening: No; W < > Wr; L = Lr	: The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the width of the reserved opening is different from the required width of lift box.
Beam for fixing: Yes; Beam at the opening: No; W < > Wr; L < > Lr	: The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the size of the reserved opening is different from the required size of lift box.
Beam for fixing: No; Beam at the opening: Yes; W = Wr; L = Lr	: No any structure for fixing the lift railing systems with the building.
Beam for fixing: No; Beam at the opening: Yes; W = Wr; L < > Lr	: No any structure for fixing the lift railing systems with the building. It is not able to install the lift systems because the length of the reserved opening is different from the required length of lift box.
Beam for fixing: No; Beam at the opening: Yes; W < > Wr; L = Lr	: No any structure for fixing the lift railing systems with the building. It is not able to install the lift systems because the width of the reserved opening is different from the required width of lift box.
Beam for fixing: No; Beam at the opening: Yes; W < > Wr; L < > Lr	: No any structure for fixing the lift railing systems with the building. It is not able to install the lift systems because the size of the reserved opening is different from the required size of lift box.
Beam for fixing: No; Beam at the opening: No; W = Wr; L = Lr	: No any structure for fixing the lift railing systems with the building. The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box.
Beam for fixing: No; Beam at the opening: No; W = Wr; L < > Lr	: No any structure for fixing the lift railing systems with the building. The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the length of the reserved opening is different from the required length of lift box.
Beam for fixing: No; Beam at the opening: No; W < > Wr; L = Lr	: No any structure for fixing the lift railing systems with the building. The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the width of the reserved opening is different from the required width of lift box.
Beam for fixing: No; Beam at the opening: No; W < > Wr; L < > Lr	: No any structure for fixing the lift railing systems with the building. The incorrect position of beam at the opening of lift affects the required size of the reserved opening for lift box. It is not able to install the lift systems because the size of the reserved opening is different from the required size of lift box.

3.9 Beam and sanitary drainage and disposal system



Reinforced Concrete slab (RC slab)

Pipe route: Vertical route — It is not allowed to run the pipe of sanitary drainage and disposal system across the beam vertically because it can affect the other structure and beam strength.

Pipe route: Horizontal route; Pipe across beam: No : No problem

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Longitudinal : It is not allowed to run the pipe of sanitary drainage and disposal system across the beam along the span of beam (longitudinal direction) because it can reduce the beam strength.

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: Yes : Because the middle span of beam is compression zone, it is not allowed to run the sewage pipe in this critical area. Drilling the opening at this position for running the pipe can reduce the beam strength and beam can be deflected.

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: No; ((d-hs) - D) / 2 >= Ca : No problem

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: No; ((d-hs) - D) / 2 < Ca : The effective cover is lower than what is required which can reduce the beam strength.

Precast Concrete slab (PC slab)

Pipe route: Vertical route — It is not allowed to run the pipe of sanitary drainage and disposal system across the beam vertically because it can affect the other structure and beam strength.

Pipe route: Horizontal route; Pipe across beam: No : No problem

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Longitudinal : It is not allowed to run the pipe of sanitary drainage and disposal system across the beam along the span of beam (longitudinal direction) because it can reduce the beam strength.

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: Yes : Because the middle span of beam is compression zone, it is not allowed to run the sewage pipe in this critical area. Drilling the opening at this position for running the pipe can reduce the beam strength and beam can be deflected.

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: No; (d - D) / 2 >= Ca : No problem

Pipe route: Horizontal route; Pipe across beam: Yes; Pipe direction: Transversal; Position of opening: No; (d - D) / 2 < Ca : The effective cover is lower than what is required which can reduce the beam strength.

Pipe route: Does the pipe of sanitary drainage and disposal system run across the beam in horizontal route or vertical route?
Pipe route across the beam: Does the route of pipe have to run in the beam?
Pipe direction across the beam: Which direction does the sewage pipe have to run across the beam?
Position of opening for sewage pipe in the middle span of beam: Is the opening for sewage pipe in the middle span of beam?

3.10 Beam and wall finish

Beam → Wall finish

- **Beam supports the wall finish**
  - Alignment of beam: (At the side of wall finish / In the same alignment of wall finish / In different alignment of wall finish)
  - Can the moment inertia resist with the loads from the wall finish? (Yes / No)
    - Alignment: At the side of wall; Moment inertia: Yes : The wall may have no beam to support it and beam.
    - Alignment: At the side of wall; Moment inertia: No : The wall may have no beam to support it and beam may be deflected due to lack of moment inertia.
    - Alignment: In the same alignment; Moment inertia: Yes : The wall may have no beam to support it and beam.
    - Alignment: In the same alignment; Moment inertia: No : Beam may be deflected due to lack of moment inertia.
    - Alignment: In different alignment; Moment inertia: Yes : The wall is only partly supported by beam.
    - Alignment: In different alignment; Moment inertia: No : The wall is only partly supported by beam. Beam may be deflected due to lack of moment inertia.
- **Beam at the upper floor**
  - Alignment of beam (At the side of wall finish / In the same alignment of wall finish / In different alignment of wall finish)
  - Beam's depth (Dw)
  - Height of wall (Hw)
  - Required wall height in architecture (Hr)
    - Alignment: At the side of wall; Dw + Hw = Hr : No problem; however, please check the case between beam supporting the wall and wall finish.
    - Alignment: At the side of wall; Dw + Hw < Hr : The wall height is not satisfied since it is lower than what is required.
    - Alignment: At the side of wall; Dw + Hw > Hr : The wall height is not satisfied since it is greater than what is required.
    - Alignment: In the same alignment; Dw + Hw = Hr : No problem
    - Alignment: In the same alignment; Dw + Hw < Hr : The wall height is not satisfied since it is lower than what is required.
    - Alignment: In the same alignment; Dw + Hw > Hr : The wall height is not satisfied since it is greater than what is required.
    - Alignment: In different alignment; Dw + Hw = Hr : The wall is only partly supported by beam.
    - Alignment: In different alignment; Dw + Hw < Hr : The wall is only partly supported by beam. The wall height is not satisfied since it is lower than what is required.
    - Alignment: In different alignment; Dw + Hw > Hr : The wall is only partly supported by beam. The wall height is not satisfied since it is greater than what is required.

4.1 Column and beam (1)

What is the function of beam you would like to check with the column?

Is the column reinforcement at the connection between column and beam (at the support) very complicated?

Is the column strong enough to carry the loads imposed on it?

Column → Beam → Cantilever beam

(Column under the beam)

Column reinforcement (Yes / No)

Column strength (Yes / No)

Width of column (Wc)

Width of cantilever beam (Wb)

Span of cantilever beam (S)

Allowable span of cantilever beam in design standard

(Sd)

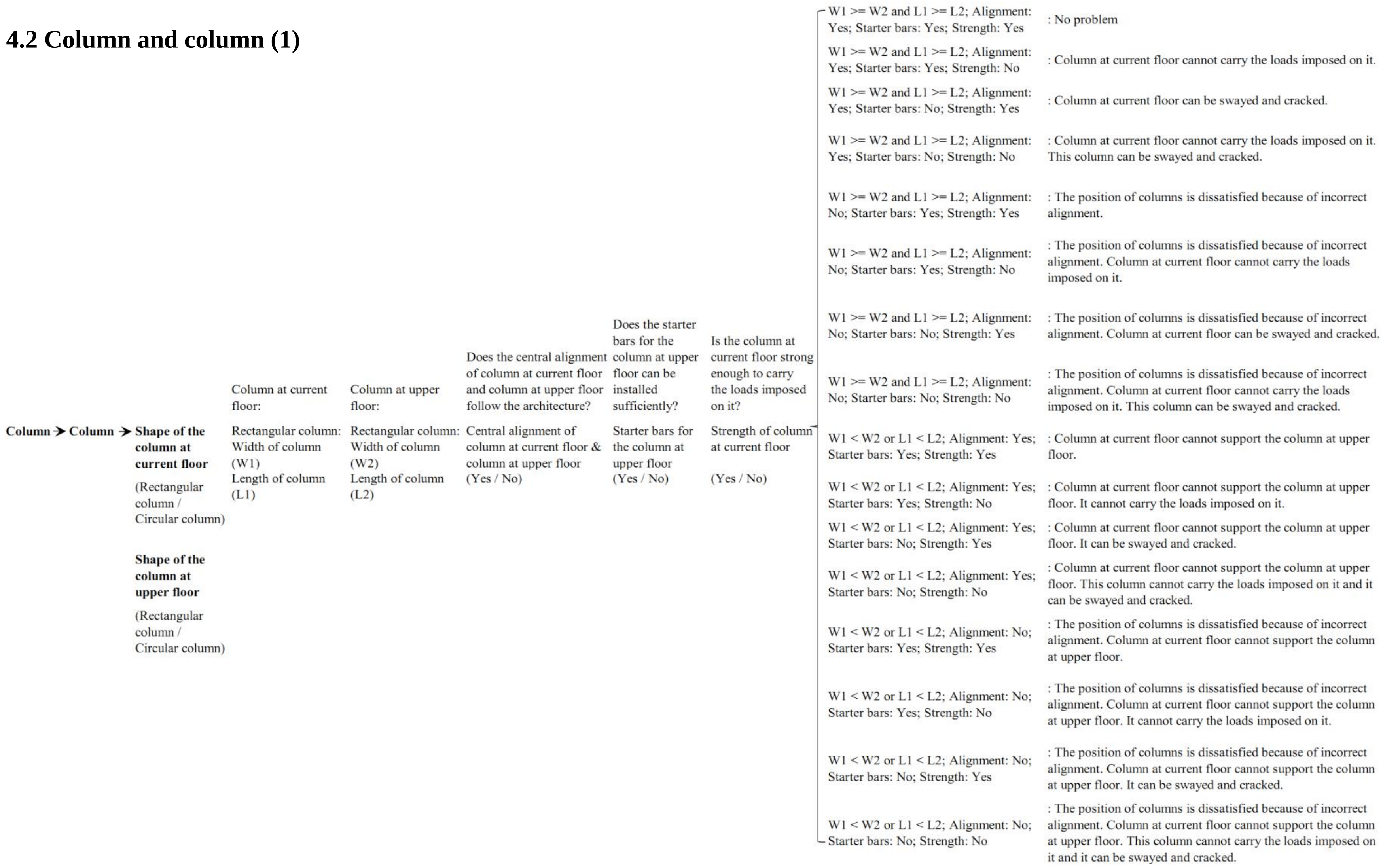
Reinforcement: Yes; Strength: Yes; Wc >= Wb; S <= Sd	: No problem
Reinforcement: Yes; Strength: Yes; Wc >= Wb; S > Sd	: Cantilever beam is deflected and cracked.
Reinforcement: Yes; Strength: Yes; Wc < Wb; S <= Sd	: Column is swayed and cracked because its strength is insufficient to carry the eccentric loads imposed by cantilever beam.
Reinforcement: Yes; Strength: Yes; Wc < Wb; S > Sd	: Column is swayed and cracked because its strength is insufficient to carry the eccentric loads imposed by cantilever beam. Cantilever beam is deflected and cracked.
Reinforcement: Yes; Strength: No; Wc >= Wb; S <= Sd	: Column strength is insufficient to carry the loads imposed on it.
Reinforcement: Yes; Strength: No; Wc >= Wb; S > Sd	: Column strength is insufficient to carry the loads imposed on it. Cantilever beam is deflected and cracked.
Reinforcement: Yes; Strength: No; Wc < Wb; S <= Sd	: Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.
Reinforcement: Yes; Strength: No; Wc < Wb; S > Sd	: Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it. Cantilever beam is deflected and cracked.
Reinforcement: No; Strength: Yes; Wc >= Wb; S <= Sd	: Column reinforcement cannot be installed properly.
Reinforcement: No; Strength: Yes; Wc >= Wb; S > Sd	: Column reinforcement cannot be installed properly. Cantilever beam is deflected and cracked.
Reinforcement: No; Strength: Yes; Wc < Wb; S <= Sd	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the eccentric loads imposed by cantilever beam.
Reinforcement: No; Strength: Yes; Wc < Wb; S > Sd	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the eccentric loads imposed by cantilever beam. Cantilever beam is deflected and cracked.
Reinforcement: No; Strength: No; Wc >= Wb; S <= Sd	: Column reinforcement cannot be installed properly. Column strength is insufficient to carry the loads imposed on it.
Reinforcement: No; Strength: No; Wc >= Wb; S > Sd	: Column reinforcement cannot be installed properly. Column strength is insufficient to carry the loads imposed on it. Cantilever beam is deflected and cracked.
Reinforcement: No; Strength: No; Wc < Wb; S <= Sd	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.
Reinforcement: No; Strength: No; Wc < Wb; S > Sd	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it. Cantilever beam is deflected and cracked.

4.1 Column and beam (2)

	What is the function of the beam you would like to check with the column?	Is the column reinforcement at the connection between column and beam (at the support) very complicated?	Is the column strong enough to carry the loads imposed on it?		
Column → Beam →	**Beam with two supports**	Column reinforcement (Yes / No)	Column strength (Yes / No)	Width of column (Wc)	Width of beam (Wb)

Reinforcement: Yes; Strength: Yes; Wc >= Wb	: No problem
Reinforcement: Yes; Strength: Yes; Wc < Wb	: Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.
Reinforcement: Yes; Strength: No; Wc >= Wb	: Column strength is insufficient to carry the loads imposed on it.
Reinforcement: Yes; Strength: No; Wc < Wb	: Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.
Reinforcement: No; Strength: Yes; Wc >= Wb	: Column reinforcement cannot be installed properly.
Reinforcement: No; Strength: Yes; Wc < Wb	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.
Reinforcement: No; Strength: No; Wc >= Wb	: Column reinforcement cannot be installed properly. Column strength is insufficient to carry the loads imposed on it.
Reinforcement: No; Strength: No; Wc < Wb	: Column reinforcement cannot be installed properly. Column is swayed and cracked because its strength is insufficient to carry the loads imposed on it.

4.2 Column and column (1)



Column ➔ **Column** ➔ **Shape of the column at current floor**

(Rectangular column / Circular column)

Shape of the column at upper floor

(Rectangular column / Circular column)

Column at current floor: Rectangular column: Width of column (W1) Length of column (L1)

Column at upper floor: Rectangular column: Width of column (W2) Length of column (L2)

Does the central alignment of column at current floor and column at upper floor follow the architecture? Central alignment of column at current floor & column at upper floor (Yes / No)

Does the starter bars for the column at upper floor can be installed sufficiently? Starter bars for the column at upper floor (Yes / No)

Is the column at current floor strong enough to carry the loads imposed on it? Strength of column at current floor (Yes / No)

W1 >= W2 and L1 >= L2; Alignment: Yes; Starter bars: Yes; Strength: Yes : No problem

W1 >= W2 and L1 >= L2; Alignment: Yes; Starter bars: Yes; Strength: No : Column at current floor cannot carry the loads imposed on it.

W1 >= W2 and L1 >= L2; Alignment: Yes; Starter bars: No; Strength: Yes : Column at current floor can be swayed and cracked.

W1 >= W2 and L1 >= L2; Alignment: Yes; Starter bars: No; Strength: No : Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.

W1 >= W2 and L1 >= L2; Alignment: No; Starter bars: Yes; Strength: Yes : The position of columns is dissatisfied because of incorrect alignment.

W1 >= W2 and L1 >= L2; Alignment: No; Starter bars: Yes; Strength: No : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it.

W1 >= W2 and L1 >= L2; Alignment: No; Starter bars: No; Strength: Yes : The position of columns is dissatisfied because of incorrect alignment. Column at current floor can be swayed and cracked.

W1 >= W2 and L1 >= L2; Alignment: No; Starter bars: No; Strength: No : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.

W1 < W2 or L1 < L2; Alignment: Yes; Starter bars: Yes; Strength: Yes : Column at current floor cannot support the column at upper floor.

W1 < W2 or L1 < L2; Alignment: Yes; Starter bars: Yes; Strength: No : Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.

W1 < W2 or L1 < L2; Alignment: Yes; Starter bars: No; Strength: Yes : Column at current floor cannot support the column at upper floor. It can be swayed and cracked.

W1 < W2 or L1 < L2; Alignment: Yes; Starter bars: No; Strength: No : Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.

W1 < W2 or L1 < L2; Alignment: No; Starter bars: Yes; Strength: Yes : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor.

W1 < W2 or L1 < L2; Alignment: No; Starter bars: Yes; Strength: No : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.

W1 < W2 or L1 < L2; Alignment: No; Starter bars: No; Strength: Yes : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It can be swayed and cracked.

W1 < W2 or L1 < L2; Alignment: No; Starter bars: No; Strength: No : The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.

4.2 Column and column (2)

Column ➔ **Column** ➔ **Shape of the column at current floor** (Rectangular column / Circular column)

Shape of the column at upper floor (Rectangular column / Circular column)

Rectangular column: Width of column (W1) Length of column (L1)

Circular column: Diameter of column (D2)

Central alignment of column at current floor & column at upper floor (Yes / No)

Starter bars for the column at upper floor (Yes / No)

Strength of column at current floor (Yes / No)

W1 >= D2 or L1 >= D2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: No problem
W1 >= D2 or L1 >= D2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot carry the loads imposed on it.
W1 >= D2 or L1 >= D2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor can be swayed and cracked.
W1 >= D2 or L1 >= D2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
W1 >= D2 or L1 >= D2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment.
W1 >= D2 or L1 >= D2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it.
W1 >= D2 or L1 >= D2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor can be swayed and cracked.
W1 >= D2 or L1 >= D2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
W1 < D2 and L1 < D2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: Column at current floor cannot support the column at upper floor.
W1 < D2 and L1 < D2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
W1 < D2 and L1 < D2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
W1 < D2 and L1 < D2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.
W1 < D2 and L1 < D2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor.
W1 < D2 and L1 < D2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
W1 < D2 and L1 < D2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
W1 < D2 and L1 < D2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.

4.2 Column and column (3)

Column ➔ Column ➔	**Shape of the column at current floor**	Circular column: Diameter of column	Rectangular column: Width of column (W2)	Central alignment of column at current floor and column at upper floor	Starter bars for the column at upper floor	Strength of column at current floor
	(Rectangular column / Circular column)	(D1)	Length of column (L2)	(Yes / No)	(Yes / No)	(Yes / No)
	Shape of the column at upper floor					
	(Rectangular column / Circular column)					

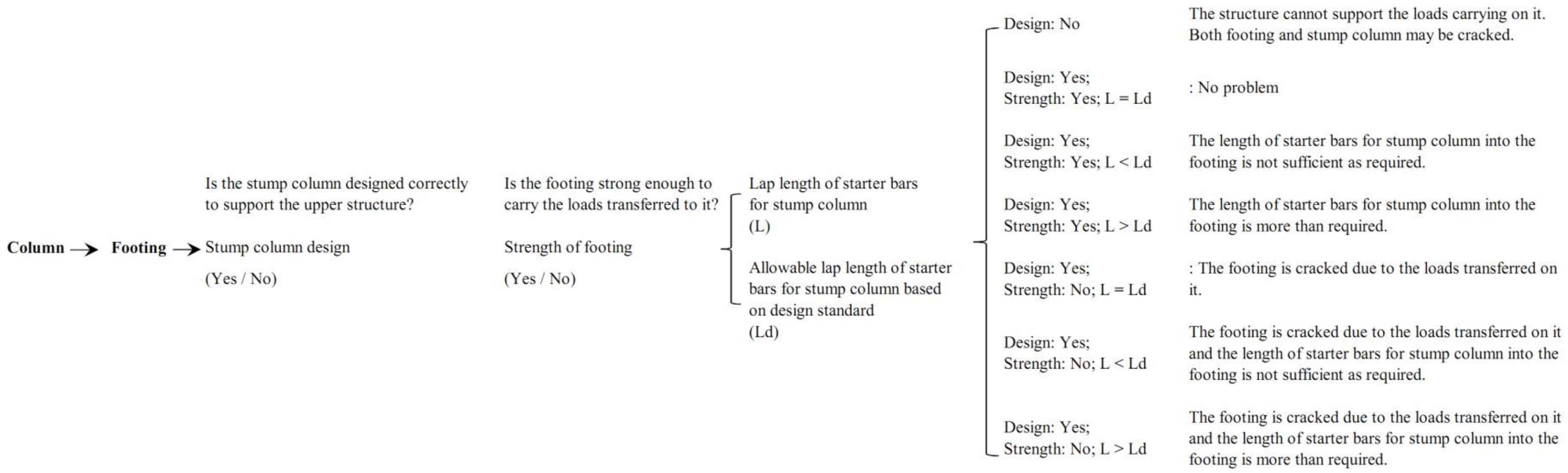
D1 >= W2 or D1 >= W2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: No problem
D1 >= W2 or D1 >= W2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot carry the loads imposed on it.
D1 >= W2 or D1 >= W2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor can be swayed and cracked.
D1 >= W2 or D1 >= W2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
D1 >= W2 or D1 >= W2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment.
D1 >= W2 or D1 >= W2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it.
D1 >= W2 or D1 >= W2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor can be swayed and cracked.
D1 >= W2 or D1 >= W2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
D1 < W2 and D1 < L2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: Column at current floor cannot support the column at upper floor.
D1 < W2 and D1 < L2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
D1 < W2 and D1 < L2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
D1 < W2 and D1 < L2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.
D1 < W2 and D1 < L2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor.
D1 < W2 and D1 < L2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
D1 < W2 and D1 < L2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
D1 < W2 and D1 < L2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.

4.2 Column and column (4)

Column ➔ Column ➔	**Shape of the column at current floor**	Circular column: Diameter of column	Circular column: Diameter of column	Central alignment of column at current floor and column at upper floor	Starter bars for the column at upper floor	Strength of column at current floor
	(Rectangular column / Circular column)	(D1)	(D2)	(Yes / No)	(Yes / No)	(Yes / No)
	Shape of the column at upper floor					
	(Rectangular column / Circular column)					

D1 >= D2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: No problem
D1 >= D2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot carry the loads imposed on it.
D1 >= D2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor can be swayed and cracked.
D1 >= D2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
D1 >= D2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment.
D1 >= D2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it.
D1 >= D2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor can be swayed and cracked.
D1 >= D2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot carry the loads imposed on it. This column can be swayed and cracked.
D1 < D2; Alignment: Yes; Starter bars: Yes; Strength: Yes	: Column at current floor cannot support the column at upper floor.
D1 < D2; Alignment: Yes; Starter bars: Yes; Strength: No	: Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
D1 < D2; Alignment: Yes; Starter bars: No; Strength: Yes	: Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
D1 < D2; Alignment: Yes; Starter bars: No; Strength: No	: Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.
D1 < D2; Alignment: No; Starter bars: Yes; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor.
D1 < D2; Alignment: No; Starter bars: Yes; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It cannot carry the loads imposed on it.
D1 < D2; Alignment: No; Starter bars: No; Strength: Yes	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. It can be swayed and cracked.
D1 < D2; Alignment: No; Starter bars: No; Strength: No	: The position of columns is dissatisfied because of incorrect alignment. Column at current floor cannot support the column at upper floor. This column cannot carry the loads imposed on it and it can be swayed and cracked.

4.3 Column and footing



Design: No	The structure cannot support the loads carrying on it. Both footing and stump column may be cracked.
Design: Yes; Strength: Yes; L = Ld	: No problem
Design: Yes; Strength: Yes; L < Ld	The length of starter bars for stump column into the footing is not sufficient as required.
Design: Yes; Strength: Yes; L > Ld	The length of starter bars for stump column into the footing is more than required.
Design: Yes; Strength: No; L = Ld	: The footing is cracked due to the loads transferred on it.
Design: Yes; Strength: No; L < Ld	The footing is cracked due to the loads transferred on it and the length of starter bars for stump column into the footing is not sufficient as required.
Design: Yes; Strength: No; L > Ld	The footing is cracked due to the loads transferred on it and the length of starter bars for stump column into the footing is more than required.

4.4 Column and sanitary ware

Column → **Sanitary ware** →

Is the size of column in structure the same as the one as required in architecture?	Is the position of sanitary ware correct and able to link to the main sanitary drainage and disposal system?	Is the space for fixing the sanitary ware with the column correctly reserved as the requirement?	Is the route for running the pipe of sanitary ware to the public sewer system correctly reserved at the surface of the column?
Size of column in structure and in architecture	Position of sanitary ware	Reserved space for fixing the sanitary ware with the column	Reserved route for running the pipe of sanitary ware to the main sanitary drainage and disposal system
(Yes / No)	(Yes / No)	(Yes / No)	(Yes / No)

Size of column: Yes; Position of sanitary ware: Yes; Reserved space: Yes; Reserved route: Yes	: No problem
Size of column: Yes; Position of sanitary ware: Yes; Reserved space: Yes; Reserved route: No	: The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe, which can affect the architectural design.
Size of column: Yes; Position of sanitary ware: Yes; Reserved space: No; Reserved route: Yes	: There is no space for fixing the sanitary ware with the column. More space is required for installing this sanitary ware, which can affect the architectural design.
Sizee of column: Yes; Position of sanitary ware: Yes; Reserved space: No; Reserved route: No	: The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe and also for installing this sanitary ware, which can affect the architectural design.
Sizee of column: Yes; Position of sanitary ware: No; Reserved space: Yes; Reserved route: Yes	: The position of sanitary ware may have conflict with the required space in the room.
Sizee of column: Yes; Position of sanitary ware: No; Reserved space: Yes; Reserved route: No	: The position of sanitary ware may have conflict with the required space in the room. The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe, which can affect the architectural design.
Sizee of column: Yes; Position of sanitary ware: No; Reserved space: No; Reserved route: Yes	: The position of sanitary ware may have conflict with the required space in the room. There is no space for fixing the sanitary ware with the column. More space is required for installing this sanitary ware, which can affect the architectural design.
Sizee of column: Yes; Position of sanitary ware: No; Reserved space: No; Reserved route: No	: The position of sanitary ware may have conflict with the required space in the room. The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe and also for installing this sanitary ware, which can affect the architectural design.
Size of column: No; Position of sanitary ware: Yes/No; Reserved space: Yes; Reserved route: Yes	: The size of column in structure and architecture is different which make the position of sanitary ware incorrect from what is required by the architecture.
Size of column: No; Position of sanitary ware: Yes/No; Reserved space: Yes; Reserved route: No	: The size of column in structure and architecture is different which make the position of sanitary ware incorrect from what is required by the architecture. The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe, which can affect the architectural design.
Size of column: No; Position of sanitary ware: Yes/No; Reserved space: No; Reserved route: Yes	: The size of column in structure and architecture is different which make the position of sanitary ware incorrect from what is required by the architecture. There is no space for fixing the sanitary ware with the column. More space is required for installing this sanitary ware, which can affect the architectural design.
Size of column: No; Position of sanitary ware: Yes/No; Reserved space: No; Reserved route: No	: The size of column in structure and architecture is different which make the position of sanitary ware incorrect from what is required by the architecture. The position of sanitary ware may have conflict with the required space in the room. The pipe of sanitary ware cannot link with the main sanitary drainage and disposal system. Since it is not allowed to drill the column, more space is required to make the route for this pipe and also for installing this sanitary ware, which can affect the architectural design.

4.5 Column and wall finish

Column → Wall finish →

Is the alignment of column correct comparing to the alignment of masonry wall in architecture?	Is there any starter bars to connect the column with the masonry wall?			
Alignment of column and masonry wall (Yes / No)	Starter bars to connect the column with the masonry wall (Yes / No)	Size of column in structure: Width of column (Ws) Length of column (Ls)	Required size of column based on architecture: Width of column (Wa) Length of column (La)	Masonry wall thickness (Hm) Column dimension opposite to the masonry wall thickness (Hc)

Alignment: Yes; Starter bars: Yes; Ws = Wa; Ls = La; Hm = Hc	: No problem
Alignment: Yes; Starter bars: Yes; Ws = Wa; Ls = La; Hm < > Hc	: The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: Yes; Ws = Wa; Ls < > La; Hm = Hc	: The length of column in structure and architecture is different.
Alignment: Yes; Starter bars: Yes; Ws = Wa; Ls < > La; Hm < > Hc	: The length of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: Yes; Ws < > Wa; Ls = La; Hm = Hc	: The width of column in structure and architecture is different.
Alignment: Yes; Starter bars: Yes; Ws < > Wa; Ls = La; Hm < > Hc	: The width of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: Yes; Ws < > Wa; Ls < > La; Hm = Hc	: The size of column in structure and architecture is different.
Alignment: Yes; Starter bars: Yes; Ws < > Wa; Ls < > La; Hm < > Hc	: The size of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: No; Ws = Wa; Ls = La; Hm = Hc	: The fissures on the wall may appear at the joint between the column and the masonry wall.
Alignment: Yes; Starter bars: No; Ws = Wa; Ls = La; Hm < > Hc	: The fissures on the wall may appear at the joint between column and wall. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: No; Ws = Wa; Ls < > La; Hm = Hc	: The fissures on the wall may appear at the joint between the column and the masonry wall. The length of column in structure and architecture is different.
Alignment: Yes; Starter bars: No; Ws = Wa; Ls < > La; Hm < > Hc	: The fissures may appear at the joint between column and wall. The length of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: No; Ws < > Wa; Ls = La; Hm = Hc	: The fissures on the wall may appear at the joint between the column and the masonry wall. The width of column in structure and architecture is different.
Alignment: Yes; Starter bars: No; Ws < > Wa; Ls = La; Hm < > Hc	: The fissures may appear at the joint between column and wall. The width of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: Yes; Starter bars: No; Ws < > Wa; Ls < > La; Hm = Hc	: The fissures on the wall may appear at the joint between the column and the wall. The size of column in structure and architecture is different.
Alignment: Yes; Starter bars: No; Ws < > Wa; Ls < > La; Hm < > Hc	: The fissures may appear at the joint between column and wall. The size of column in structure and architecture is different. The corners of this column are projected outside the wall which affects the architectural design.
Alignment: No; Starter bars: No	: The corners of column may be projected outside the wall due to different alignment of column and masonry wall. The fissures may appear at the joint between column and wall.

5.1 Slab and ceiling works

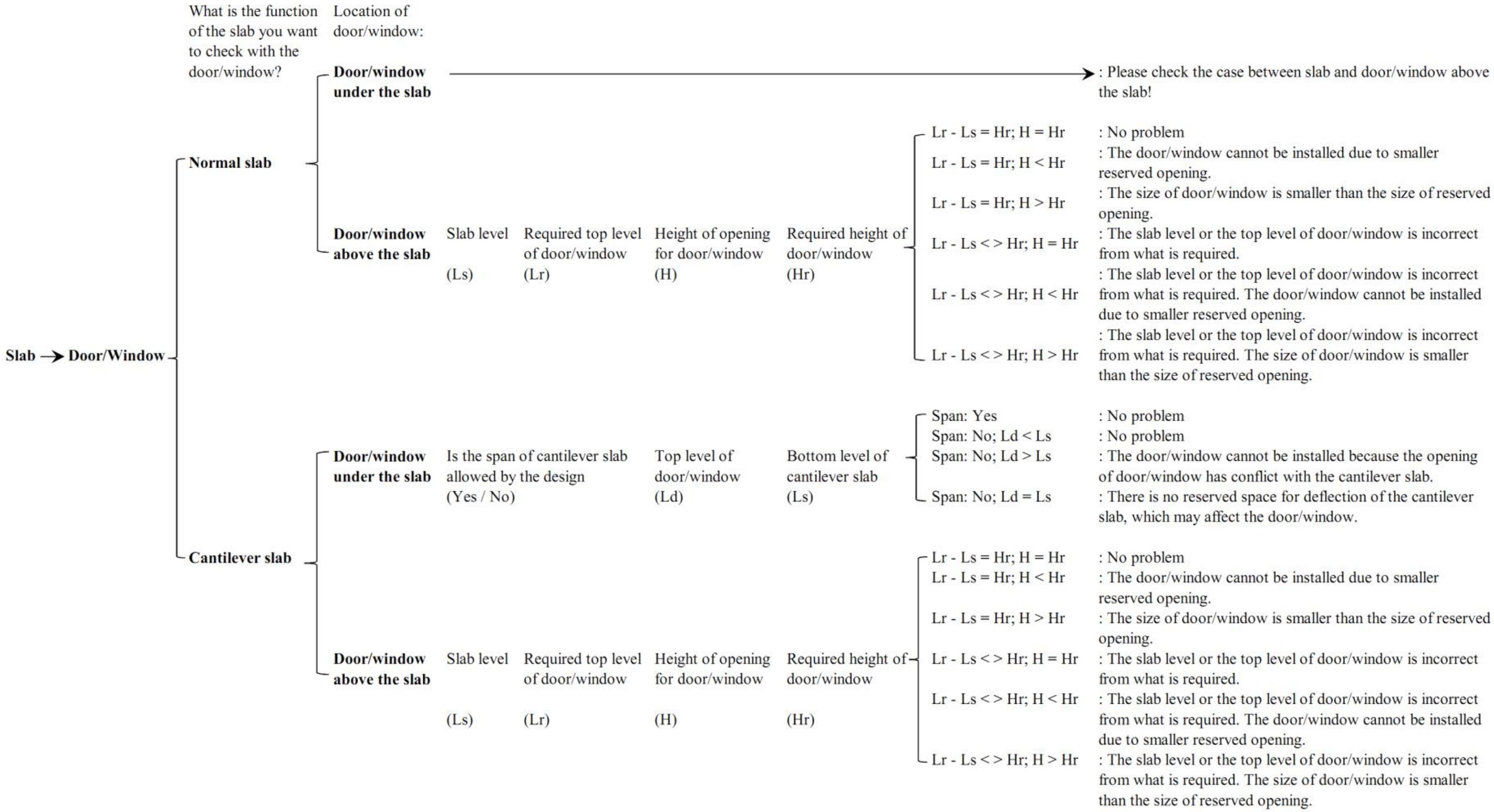
Slab → **Ceiling works** → Required height (space) for MEP from the soffit of slab (S) — Required ceiling height from the soffit of slab (h)

$S > h$: No problem

$S < h$: There is no space for installing MEP systems. Ceiling works is not satified.

$S = h$: It is difficult to install MEP systems.

5.2 Slab and door/window



Slab → Door/Window

What is the function of the slab you want to check with the door/window?

Location of door/window:

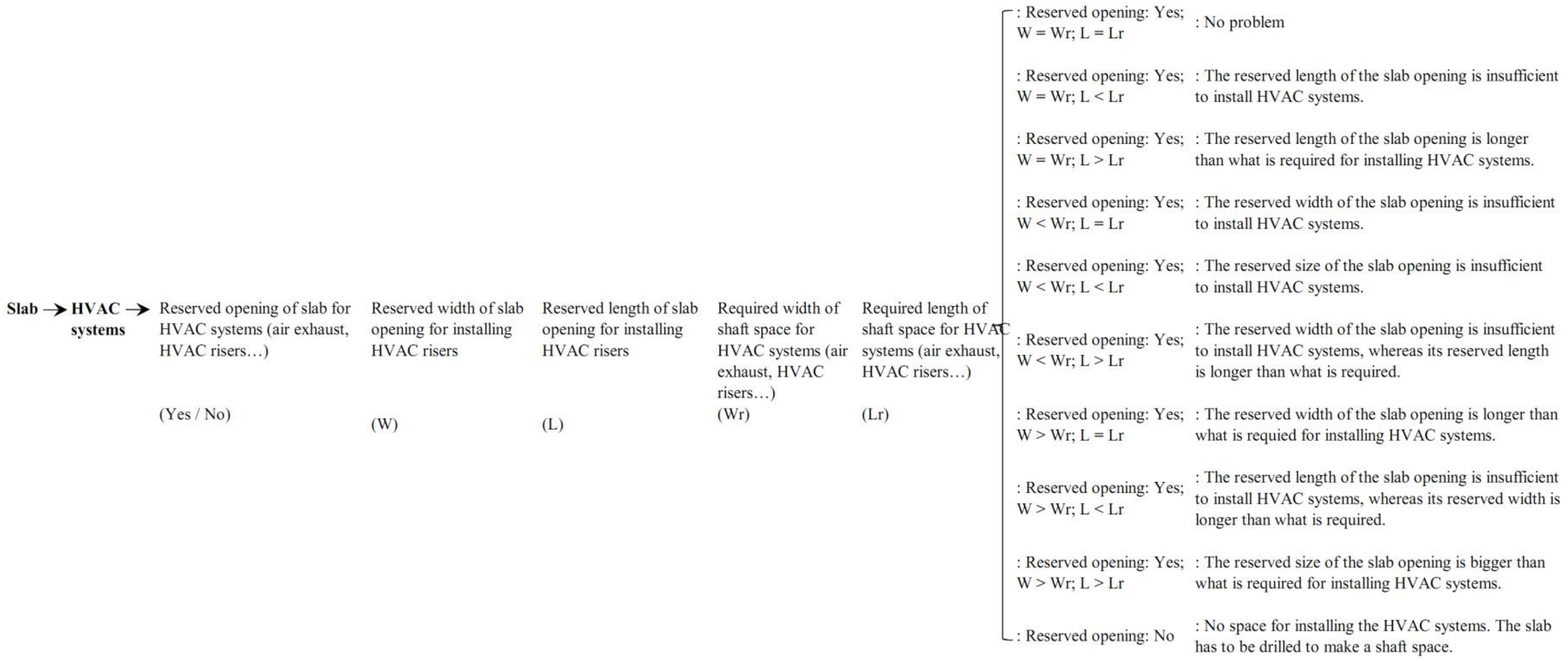
- **Normal slab**
  - **Door/window under the slab** → : Please check the case between slab and door/window above the slab!
  - **Door/window above the slab**
    - Slab level (Ls); Required top level of door/window (Lr); Height of opening for door/window (H); Required height of door/window (Hr)
      - Lr - Ls = Hr; H = Hr : No problem
      - Lr - Ls = Hr; H < Hr : The door/window cannot be installed due to smaller reserved opening.
      - Lr - Ls = Hr; H > Hr : The size of door/window is smaller than the size of reserved opening.
      - Lr - Ls < > Hr; H = Hr : The slab level or the top level of door/window is incorrect from what is required.
      - Lr - Ls < > Hr; H < Hr : The slab level or the top level of door/window is incorrect from what is required. The door/window cannot be installed due to smaller reserved opening.
      - Lr - Ls < > Hr; H > Hr : The slab level or the top level of door/window is incorrect from what is required. The size of door/window is smaller than the size of reserved opening.
- **Cantilever slab**
  - **Door/window under the slab**
    - Is the span of cantilever slab allowed by the design (Yes / No); Top level of door/window (Ld); Bottom level of cantilever slab (Ls)
      - Span: Yes : No problem
      - Span: No; Ld < Ls : No problem
      - Span: No; Ld > Ls : The door/window cannot be installed because the opening of door/window has conflict with the cantilever slab.
      - Span: No; Ld = Ls : There is no reserved space for deflection of the cantilever slab, which may affect the door/window.
  - **Door/window above the slab**
    - Slab level (Ls); Required top level of door/window (Lr); Height of opening for door/window (H); Required height of door/window (Hr)
      - Lr - Ls = Hr; H = Hr : No problem
      - Lr - Ls = Hr; H < Hr : The door/window cannot be installed due to smaller reserved opening.
      - Lr - Ls = Hr; H > Hr : The size of door/window is smaller than the size of reserved opening.
      - Lr - Ls < > Hr; H = Hr : The slab level or the top level of door/window is incorrect from what is required.
      - Lr - Ls < > Hr; H < Hr : The slab level or the top level of door/window is incorrect from what is required. The door/window cannot be installed due to smaller reserved opening.
      - Lr - Ls < > Hr; H > Hr : The slab level or the top level of door/window is incorrect from what is required. The size of door/window is smaller than the size of reserved opening.

5.3 Slab and floor finish

Slab → Floor finish

- **Structural slab at normal areas**
  - Required structural slab level (Ls)
  - Floor finish level (Lf)
  - Floor finish thickness (h)
    - Lf - Ls = h : No problem
    - Lf - Ls < > h : The slab level is not satisfied because it is different from the architecture.
- **Structural slab at bathroom/ kitchen room**
  - Required level of structural slab at normal areas (L1)
  - Level of structural slab at bathroom/kitchen room (L2)
  - Required dropped height (H)
  - Floor finish level (Lf)
  - Floor finish thickness (h)
  - Is the slab at bathroom designed as the slope? Slope requirement for slab at bathroom /kitchen room (Yes / No)
    - (L1 - L2) = H; (Lf - L2) = h; Slope: Yes : No problem
    - (L1 - L2) = H; (Lf - L2) = h; Slope: No : The water cannot flow easily to the drain in the bathroom.
    - (L1 - L2) = H; (Lf - L2) < > h; Slope: Yes : The slab level at bathroom is not satisfied because it is different from the architecture.
    - (L1 - L2) = H; (Lf - L2) < > h; Slope: No : The slab level at bathroom is not satisfied because it is different from the architecture. Moreover, the water cannot flow easily to the drain in the bathroom.
    - (L1 - L2) < H; (Lf - L2) = h; Slope: Yes : The water might flow outside the bathroom to other areas.
    - (L1 - L2) < H; (Lf - L2) = h; Slope: No : The water might flow outside the bathroom to other areas and it cannot flow easily to the drain in the bathroom.
    - (L1 - L2) < H; (Lf - L2) < > h; Slope: Yes : The water might flow outside the bathroom to other areas. The slab level at bathroom is not satisfied because it is different from the architecture.
    - (L1 - L2) < H; (Lf - L2) < > h; Slope: No : The water might flow outside the bathroom to other areas. The slab level at bathroom is not satisfied because it is different from the architecture. Moreover, the water cannot flow easily to the drain in the bathroom.
    - (L1 - L2) > H; (Lf - L2) = h; Slope: Yes : The dropped height is more than required.
    - (L1 - L2) > H; (Lf - L2) = h; Slope: No : The dropped height is more than required. The water cannot flow easily to the drain in the bathroom.
    - (L1 - L2) > H; (Lf - L2) < > h; Slope: Yes : The dropped height is more than required. The slab level at bathroom is not satisfied because it is different from the architecture.
    - (L1 - L2) > H; (Lf - L2) < > h; Slope: No : The dropped height is more than required. The slab level at bathroom is not satisfied because it is different from the architecture. Moreover, the water cannot flow easily to the drain in the bathroom.

5.4 Slab and HVAC systems

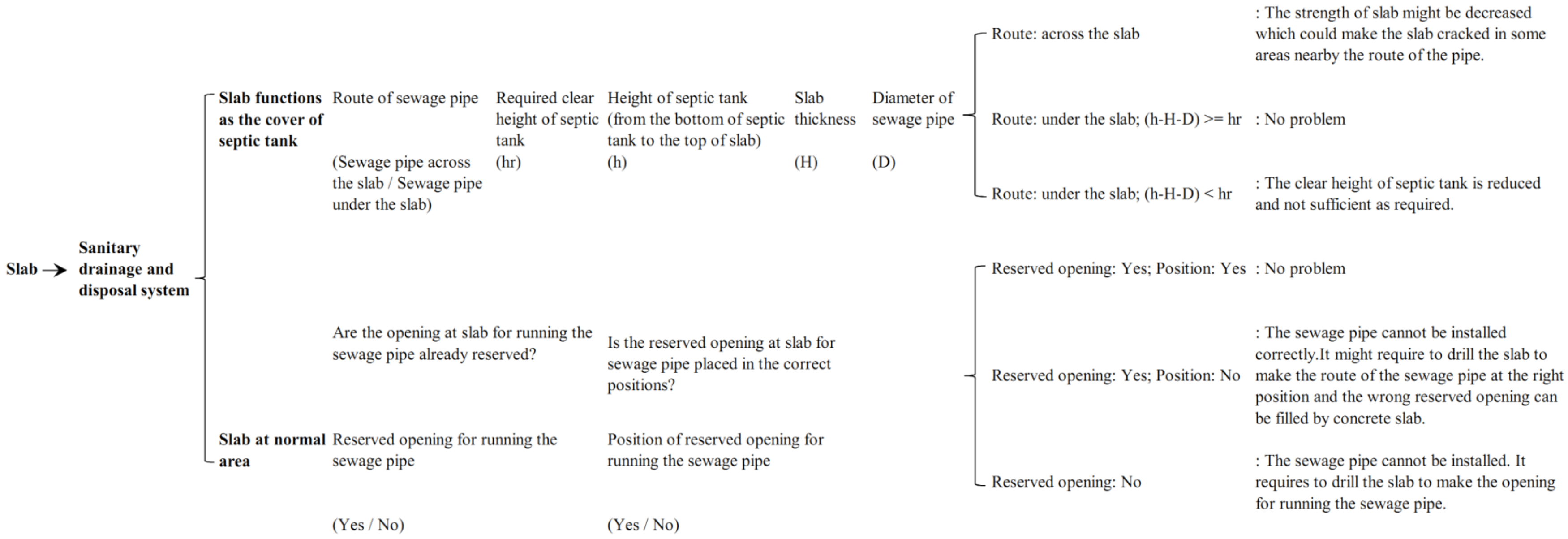


Slab → HVAC → systems

Reserved opening of slab for HVAC systems (air exhaust, HVAC risers…)	Reserved width of slab opening for installing HVAC risers	Reserved length of slab opening for installing HVAC risers	Required width of shaft space for HVAC systems (air exhaust, HVAC risers…)	Required length of shaft space for HVAC systems (air exhaust, HVAC risers…)
(Yes / No)	(W)	(L)	(Wr)	(Lr)

: Reserved opening: Yes; W = Wr; L = Lr	: No problem
: Reserved opening: Yes; W = Wr; L < Lr	: The reserved length of the slab opening is insufficient to install HVAC systems.
: Reserved opening: Yes; W = Wr; L > Lr	: The reserved length of the slab opening is longer than what is required for installing HVAC systems.
: Reserved opening: Yes; W < Wr; L = Lr	: The reserved width of the slab opening is insufficient to install HVAC systems.
: Reserved opening: Yes; W < Wr; L < Lr	: The reserved size of the slab opening is insufficient to install HVAC systems.
: Reserved opening: Yes; W < Wr; L > Lr	: The reserved width of the slab opening is insufficient to install HVAC systems, whereas its reserved length is longer than what is required.
: Reserved opening: Yes; W > Wr; L = Lr	: The reserved width of the slab opening is longer than what is requied for installing HVAC systems.
: Reserved opening: Yes; W > Wr; L < Lr	: The reserved length of the slab opening is insufficient to install HVAC systems, whereas its reserved width is longer than what is required.
: Reserved opening: Yes; W > Wr; L > Lr	: The reserved size of the slab opening is bigger than what is required for installing HVAC systems.
: Reserved opening: No	: No space for installing the HVAC systems. The slab has to be drilled to make a shaft space.

5.5 Slab and sanitary drainage and disposal system



Slab → **Sanitary drainage and disposal system**

- **Slab functions as the cover of septic tank**
  - Route of sewage pipe (Sewage pipe across the slab / Sewage pipe under the slab)
  - Required clear height of septic tank (hr)
  - Height of septic tank (from the bottom of septic tank to the top of slab) (h)
  - Slab thickness (H)
  - Diameter of sewage pipe (D)
    - Route: across the slab : The strength of slab might be decreased which could make the slab cracked in some areas nearby the route of the pipe.
    - Route: under the slab; (h-H-D) >= hr : No problem
    - Route: under the slab; (h-H-D) < hr : The clear height of septic tank is reduced and not sufficient as required.
- **Slab at normal area**
  - Are the opening at slab for running the sewage pipe already reserved? Reserved opening for running the sewage pipe (Yes / No)
  - Is the reserved opening at slab for sewage pipe placed in the correct positions? Position of reserved opening for running the sewage pipe (Yes / No)
    - Reserved opening: Yes; Position: Yes : No problem
    - Reserved opening: Yes; Position: No : The sewage pipe cannot be installed correctly.It might require to drill the slab to make the route of the sewage pipe at the right position and the wrong reserved opening can be filled by concrete slab.
    - Reserved opening: No : The sewage pipe cannot be installed. It requires to drill the slab to make the opening for running the sewage pipe.

5.6 Slab and sanitary ware

Slab → **Sanitary ware** → Reserved opening of slab for toilet sleeve (Yes / No) | Reserved diameter of opening at slab for toilet sleeve (D) | Diameter of toilet sleeve (Ds)

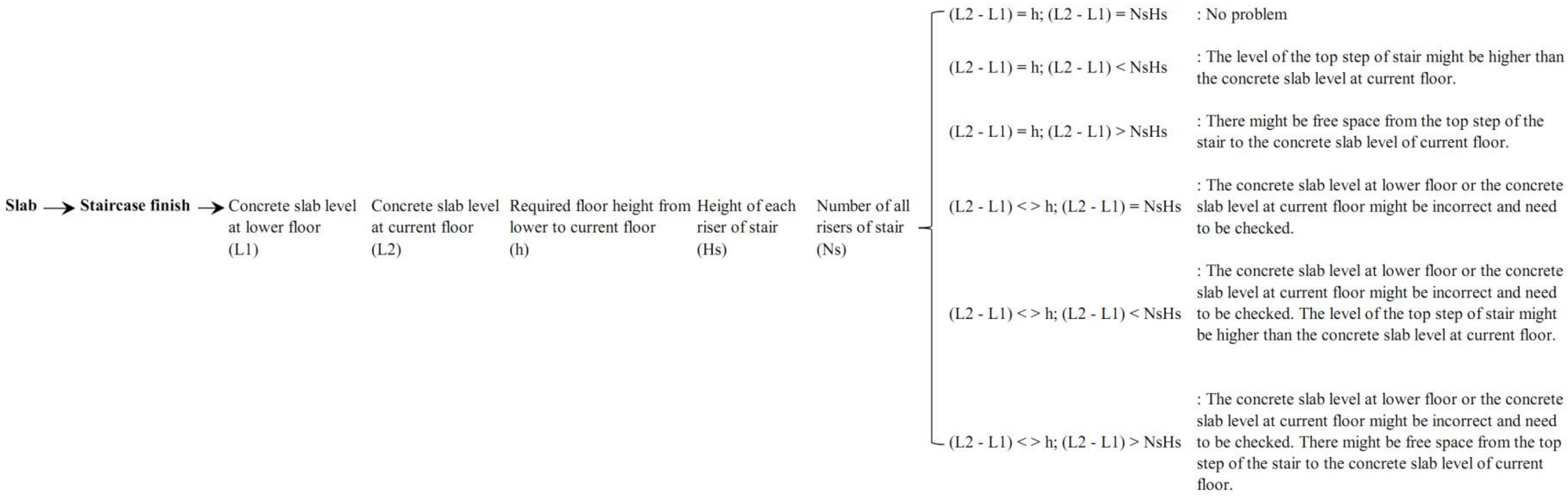
Reserved opening: Yes; D = Ds	: No problem
Reserved opening: Yes; D < Ds	: The reserved size of opening at slab for toilet sleeve is insufficient.
Reserved opening: Yes; D > Ds	: The reserved size of opening at slab for toilet sleeve is bigger than what is required.
Reserved opening: No	: No opening for linking the toilet sleeve with the main sanitary drainage and disposal system. The slab has to be drilled to make a hole for putting the toilet sleeve.

5.7 Slab and slab

	When the slab level is dropped, are the typical details of rebar installation clearly provided?	Is it the last version of architectural plan of slab that design used?	Are all structural slab level in each floor correctly designed?
Slab → **Slab** →	Typical details of rebar installation when the slab level is dropped	Last version of architectural design of slab	Actual levels of slab that designer designed
	(Yes / No)	(Yes / No)	(Yes / No)

Typical details: Yes; Last version: Yes; Actual slab level: Yes	: No problem
Typical details: Yes; Last version: Yes; Actual slab level: No	: The incorrect slab level might affect the function of the room.
Typical details: Yes; Last version: No; Actual slab level: Yes	: There might be more slabs or less slabs than what is needed as speficied in architectural plan of slab.
Typical details: Yes; Last version: No; Actual slab level: No	: There might be more slabs or less slabs than what is needed as speficied in architectural plan of slab. The incorrect slab level might affect the function of the room.
Typical details: No; Last version: Yes; Actual slab level: Yes	: Without typical details of rebar installation when the slab is dropped, the concrete cover of the slab in higher lever might be over the allowable concrete cover.
Typical details: No; Last version: Yes; Actual slab level: No	: Without typical details of rebar installation when the slab is dropped, the concrete cover of the slab in higher lever might be over the allowable concrete cover. The incorrect slab level might affect the function of the room.
Typical details: No; Last version: No; Actual slab level: Yes	: Without typical details of rebar installation when the slab is dropped, the concrete cover of the slab in higher lever might be over the allowable concrete cover. There might be more slabs or less slabs than what is needed as speficied in architectural plan of slab.
Typical details: No; Last version: No; Actual slab level: No	: Without typical details of rebar installation when the slab is dropped, the concrete cover of the slab in higher lever might be over the allowable concrete cover. There might be more slabs or less slabs than what is needed as speficied in architectural plan of slab. The incorrect slab level might affect the function of the room.

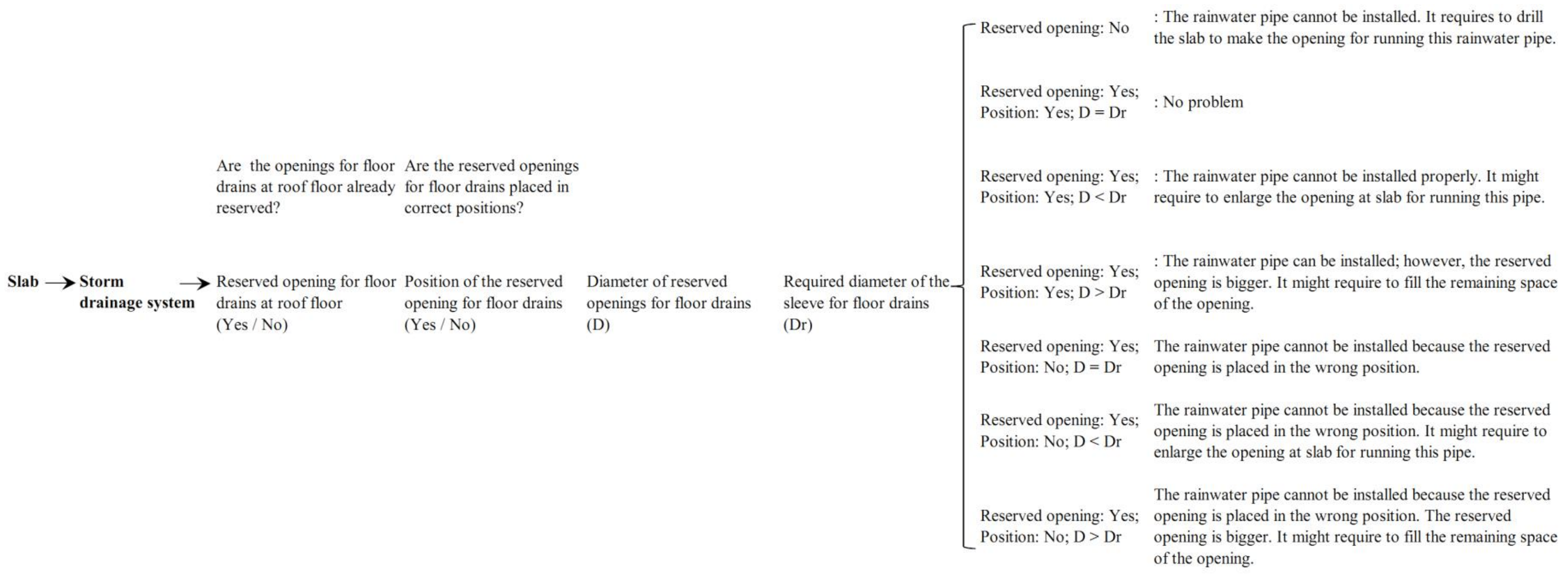
5.8 Slab and staircase finish



Slab → **Staircase finish** → Concrete slab level at lower floor (L1) | Concrete slab level at current floor (L2) | Required floor height from lower to current floor (h) | Height of each riser of stair (Hs) | Number of all risers of stair (Ns)

(L2 - L1) = h; (L2 - L1) = NsHs	: No problem
(L2 - L1) = h; (L2 - L1) < NsHs	: The level of the top step of stair might be higher than the concrete slab level at current floor.
(L2 - L1) = h; (L2 - L1) > NsHs	: There might be free space from the top step of the stair to the concrete slab level of current floor.
(L2 - L1) < > h; (L2 - L1) = NsHs	: The concrete slab level at lower floor or the concrete slab level at current floor might be incorrect and need to be checked.
(L2 - L1) < > h; (L2 - L1) < NsHs	: The concrete slab level at lower floor or the concrete slab level at current floor might be incorrect and need to be checked. The level of the top step of stair might be higher than the concrete slab level at current floor.
(L2 - L1) < > h; (L2 - L1) > NsHs	: The concrete slab level at lower floor or the concrete slab level at current floor might be incorrect and need to be checked. There might be free space from the top step of the stair to the concrete slab level of current floor.

5.9 Slab and storm drainage system



Slab → **Storm drainage system** → Reserved opening for floor drains at roof floor (Yes / No) · Position of the reserved opening for floor drains (Yes / No) · Diameter of reserved openings for floor drains (D) · Required diameter of the sleeve for floor drains (Dr)

Are the openings for floor drains at roof floor already reserved?

Are the reserved openings for floor drains placed in correct positions?

Reserved opening: No	: The rainwater pipe cannot be installed. It requires to drill the slab to make the opening for running this rainwater pipe.
Reserved opening: Yes; Position: Yes; D = Dr	: No problem
Reserved opening: Yes; Position: Yes; D < Dr	: The rainwater pipe cannot be installed properly. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: Yes; D > Dr	: The rainwater pipe can be installed; however, the reserved opening is bigger. It might require to fill the remaining space of the opening.
Reserved opening: Yes; Position: No; D = Dr	The rainwater pipe cannot be installed because the reserved opening is placed in the wrong position.
Reserved opening: Yes; Position: No; D < Dr	The rainwater pipe cannot be installed because the reserved opening is placed in the wrong position. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: No; D > Dr	The rainwater pipe cannot be installed because the reserved opening is placed in the wrong position. The reserved opening is bigger. It might require to fill the remaining space of the opening.

5.10 Slab and telephone/Datacom system

Is there any reserved penetration at the slab for installing the telephone/datacom system (cable conduits…)?

Slab → **Telephone/ Datacom system** → Penetration at the slab for installing the telephone/datacom system (cable conduits…) (Yes / No)

Reserved penetration diameter for installing the telephone/datacom system (cable conduits…) (D)

Required opening diameter for installing the telephone/datacom system (cable conduits…) (Dr)

- Penetration at slab: No : There is no opening for installing the telephone/datacom system. Slab might be required to be drilled.
- Penetration at slab: Yes; D = Dr : No problem
- Penetration at slab: Yes; D < Dr : The reserved penetration at slab is not sufficient for installing the telephone/datacom system.
- Penetration at slab: Yes; D > Dr : The reserved penetration at slab is bigger than what is required for installing the telephone/datacom

5.11 Slab and wall finish

Does the structural layout plan of slab follow the architectural design?

Does the masonry wall has the slab to support it?

Slab → **Wall finish**

- **Cantilever slab**
  - Architectural and structural layout plan of slab (Yes / No)
  - Slab to support the masonry wall (Yes / No)
  - Span of cantilever slab (Ls)
  - Allowable span of cantilever slab (La)

Layout plans: Yes; Support: Yes; Ls > = La : No problem
Layout plans: Yes; Support: Yes; Ls < La : Cantilever slab can be deflected after laying the masonry wall.
Layout plans: Yes; Support: No; Ls > = La : The masonry wall cannot be laid without any structure to support it.
Layout plans: Yes; Support: No; Ls < La : The masonry wall cannot be laid without any structure to support it. Cantilever slab can be deflected after laying the masonry wall.
Layout plans: No; Support: Yes; Ls > = La : The structural design may affect the architectural design of the room.
Layout plans: No; Support: Yes; Ls < La : The structural design may affect the architectural design of the room. Cantilever slab can be deflected after laying the masonry wall.
Layout plans: No; Support: No; Ls > = La : The structural design may affect the architectural design of the room. The masonry wall cannot be laid without any structure to support it.
Layout plans: No; Support: No; Ls < La : The structural design may affect the architectural design of the room. The masonry wall cannot be laid without any structure to support it. Cantilever slab can be deflected after laying the masonry wall.

- **Normal slab**
  - Architectural and structural layout plan of slab (Yes / No)
  - Slab to support the masonry wall (Yes / No)

Layout plans: Yes; Support: Yes : No problem
Layout plans: Yes; Support: No : The masonry wall cannot be laid without any structure to support it.
Layout plans: No; Support: Yes : The structural design may affect the architectural design of the room.
Layout plans: No; Support: No : The structural design may affect the architectural design of the room. The masonry wall cannot be laid without any structure to support it.

5.12 Slab and water supply and distribution system

Slab → **Water supply and distribution system** →

Is the opening at slab for running the water pipe already reserved?	Is the reserved opening at slab for water pipe placed in correct position?	Due to slope requirement, is it required to run the water pipe across the section of structural slab?				
Reserved opening at slab for water pipe	Position of the reserved opening at slab for water pipe	Route of water pipe across the section of structural slab due to slope requirement	Diameter of reserved opening for water pipe	Required diameter of water pipe	Slab thickness	Concrete cover of slab
(Yes / No)	(Yes / No)	(Yes / No)	(D)	(Dr)	(H)	(C)

Reserved opening: Yes; Position: Yes; D = Dr; Route: No	: No problem
Reserved opening: Yes; Position: Yes; D < Dr; Route: No	: The water pipe cannot be installed properly. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: Yes; D > Dr; Route: No	: The water pipe can be installed; however, the reserved opening is bigger. It might require to fill the remaining space of the opening.
Reserved opening: Yes; Position: No; D = Dr; Route: No	: The water pipe cannot be installed because the reserved opening is placed in the wrong position.
Reserved opening: Yes; Position: No; D < Dr; Route: No	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: No; D > Dr; Route: No	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. The reserved opening is bigger. It might require to fill the remaining space of the opening.
Reserved opening: Yes; Position: Yes; D = Dr; Route: Yes; (H - D) / 2 > C	: No problem
Reserved opening: Yes; Position: Yes; D = Dr; Route: Yes; (H - D) / 2 < C	: The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: Yes; D = Dr; Route: Yes; (H - D) / 2 = C	: It might not be able to install the slab reinforcement properly.
Reserved opening: Yes; Position: Yes; D < Dr; Route: Yes; (H - D) / 2 > C	: The water pipe cannot be installed properly. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: Yes; D < Dr; Route: Yes; (H - D) / 2 < C	: The water pipe cannot be installed properly. It might require to enlarge the opening at slab for running this pipe. The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: Yes; D < Dr; Route: Yes; (H - D) / 2 = C	: The water pipe cannot be installed properly. It might require to enlarge the opening at slab for running this pipe. It might not be able to install the slab reinforcement properly.
Reserved opening: Yes; Position: Yes; D > Dr; Route: Yes; (H - D) / 2 > C	: The water pipe can be installed; however, the reserved opening is bigger. It might require to fill the remaining space of the opening.
Reserved opening: Yes; Position: Yes; D > Dr; Route: Yes; (H - D) / 2 < C	: The water pipe can be installed; however, the reserved opening is bigger. It might require to fill the remaining space of the opening. The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: Yes; D > Dr; Route: Yes; (H - D) / 2 = C	: The water pipe can be installed; however, the reserved opening is bigger. It might require to fill the remaining space of the opening. It might not be able to install the slab reinforcement properly.
Reserved opening: Yes; Position: No; D = Dr; Route: Yes; (H - D) / 2 > C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position.
Reserved opening: Yes; Position: No; D = Dr; Route: Yes; (H - D) / 2 < C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: No; D = Dr; Route: Yes; (H - D) / 2 = C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. It might not be able to install the slab reinforcement properly.
Reserved opening: Yes; Position: No; D < Dr; Route: Yes; (H - D) / 2 > C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. It might require to enlarge the opening at slab for running this pipe.
Reserved opening: Yes; Position: No; D < Dr; Route: Yes; (H - D) / 2 < C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. It might require to enlarge the opening at slab for running this pipe. The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: No; D < Dr; Route: Yes; (H - D) / 2 = C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. It might require to enlarge the opening at slab for running this pipe. It might not be able to install the slab reinforcement properly.
Reserved opening: Yes; Position: No; D > Dr; Route: Yes; (H - D) / 2 > C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. The reserved opening is bigger. It might requires to fill the remaining space of the opening.
Reserved opening: Yes; Position: No; D > Dr; Route: Yes; (H - D) / 2 < C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. The reserved opening is bigger. It might requires to fill the remaining space of the opening. The concrete cover of slab is not sufficient when the pipe runs across the slab.
Reserved opening: Yes; Position: No; D > Dr; Route: Yes; (H - D) / 2 = C	: The water pipe cannot be installed because the reserved opening is placed in the wrong position. The reserved opening is bigger. It might requires to fill the remaining space of the opening. It might not be able to install the slab reinforcement properly.

6.1 Stair and beam

Stair → **Beam** → Starter bars to connect beam with the stair

Are there any details of starter bars to connect beam with the stair in the design drawing?

(Yes / No)

Required width of stair opening (Ws)

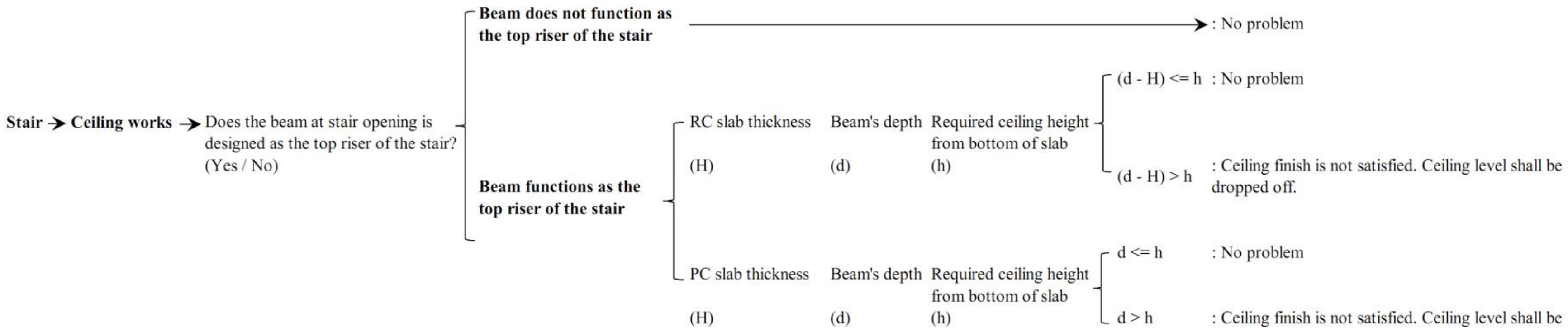
Span of short beam (Wb)

Required length of stair opening (Ls)

Span of long beam (Lb)

Starter bars: Yes; Ws = Wb; Ls = Lb	: No problem
Starter bars: Yes; Ws = Wb; Ls < Lb	: The reserved length for stair opening is shorter than what is required in architecture.
Starter bars: Yes; Ws = Wb; Ls > Lb	: The reserved length for stair opening is longer than what is required in architecture.
Starter bars: Yes; Ws < Wb; Ls = Lb	: The reserved width for stair opening is shorter than what is required in architecture.
Starter bars: Yes; Ws < Wb; Ls < Lb	: The reserved size for stair opening is smaller than what is required in architecture.
Starter bars: Yes; Ws < Wb; Ls > Lb	: The reserved width for stair opening is shorter than what is required in architecture, whereas the its reserved length is longer.
Starter bars: Yes; Ws > Wb; Ls = Lb	: The reserved width for stair opening is longer than what is required in architecture.
Starter bars: Yes; Ws > Wb; Ls < Lb	: The reserved width for stair opening is longer than what is required in architecture, whereas the its reserved length is shorter.
Starter bars: Yes; Ws > Wb; Ls > Lb	: The reserved size for stair opening is bigger than what is required in architecture.
Starter bars: No; Ws = Wb; Ls = Lb	: The concrete at the connection between stair and beam is cracked.
Starter bars: No; Ws = Wb; Ls < Lb	: The concrete at the connection between stair and beam is cracked. The reserved length for stair opening is shorter than what is required in architecture.
Starter bars: No; Ws = Wb; Ls > Lb	: The concrete at the connection between stair and beam is cracked. The reserved length for stair opening is longer than what is required in architecture.
Starter bars: No; Ws < Wb; Ls = Lb	: The concrete at the connection between stair and beam is cracked. The reserved width for stair opening is shorter than what is required in architecture.
Starter bars: No; Ws < Wb; Ls < Lb	: The concrete at the connection between stair and beam is cracked. The reserved size for stair opening is smaller than what is required in architecture.
Starter bars: No; Ws < Wb; Ls > Lb	: The concrete at the connection between stair and beam is cracked. The reserved width for stair opening is shorter than what is required in architecture, whereas the its reserved length is longer.
Starter bars: No; Ws > Wb; Ls = Lb	: The concrete at the connection between stair and beam is cracked. The reserved width for stair opening is longer than what is required in architecture.
Starter bars: No; Ws > Wb; Ls < Lb	: The concrete at the connection between stair and beam is cracked. The reserved width for stair opening is longer than what is required in architecture, whereas the its reserved length is shorter.
Starter bars: No; Ws > Wb; Ls > Lb	: The concrete at the connection between stair and beam is cracked. The reserved size for stair opening is bigger than what is required in architecture.

6.2 Stair and ceiling works



6.3 Stair and slab

Is there additional bars at the corners of the slab opening for stair?

Stair → **Slab** → Additional bars at the corners of the slab opening for stair (Yes / No) — Required height of floor (H) — Height of each riser (Hs) — Number of risers (Ns)

Additional bars: Yes; HsNs = H	: No problem
Additional bars: Yes; HsNs < H	: Level of slab is lower than the required level due to the total height of risers of the stair.
Additional bars: Yes; HsNs > H	: Level of slab is higher than the required level due to the total height of risers of the stair.
Additional bars: No; HsNs = H	: Slab might be cracked at the corners of the slab opening.
Additional bars: No; HsNs < H	: Slab might be cracked at the corners of the slab opening. Level of slab is lower than the required level due to the total height of risers of the stair.
Additional bars: No; HsNs > H	: Slab might be cracked at the corners of the slab opening. Level of slab is higher than the required level due to the total height of risers of the stair.

6.4 Stair and staircase finish

Stair → **Staircase finish** →

Required plastering thickness of the material used	Reserved plastering thickness for staircase finish	Required width of stair landing	Required length of stair	Tread's width	Number of treads (number of steps)
(h)	(hr)	(W)	(Ls)	(Wt)	(Nt)

$h = hr$; $(Ls - NtWt) = W$: No problem

$h = hr$; $(Ls - NtWt) < W$: The reserved width for landing is insufficient and it is shorter than what is required.

$h = hr$; $(Ls - NtWt) > W$: The reserved width for stair landing is longer than what is required.

$h < hr$; $(Ls - NtWt) = W$: The level of each step of stair might be lower than the required level after staircase finish.

$h < hr$; $(Ls - NtWt) < W$: The level of each step of stair might be lower than the required level after staircase finish. The reserved width for landing is insufficient and it is shorter than what is required.

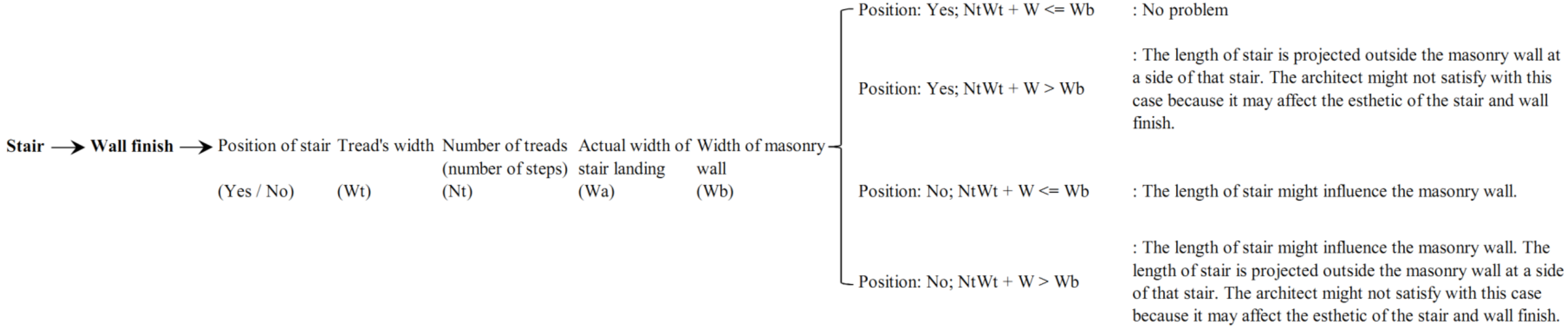
$h < hr$; $(Ls - NtWt) > W$: The level of each step of stair might be lower than the required level after staircase finish. The reserved width for stair landing is longer than what is required.

$h > hr$; $(Ls - NtWt) = W$: The level of each step of stair might be thicker than the required level of staircase finish.

$h > hr$; $(Ls - NtWt) < W$: The level of each step of stair might be thicker than the required level of staircase finish. The reserved width for landing is insufficient and it is shorter than what is required.

$h > hr$; $(Ls - NtWt) > W$: The level of each step of stair might be thicker than the required level of staircase finish. The reserved width for stair landing is longer than what is required.

6.5 Stair and wall finish



Stair → **Wall finish** → Position of stair (Yes / No) | Tread's width (Wt) | Number of treads (number of steps) (Nt) | Actual width of stair landing (Wa) | Width of masonry wall (Wb)

Position: Yes; NtWt + W <= Wb : No problem

Position: Yes; NtWt + W > Wb : The length of stair is projected outside the masonry wall at a side of that stair. The architect might not satisfy with this case because it may affect the esthetic of the stair and wall finish.

Position: No; NtWt + W <= Wb : The length of stair might influence the masonry wall.

Position: No; NtWt + W > Wb : The length of stair might influence the masonry wall. The length of stair is projected outside the masonry wall at a side of that stair. The architect might not satisfy with this case because it may affect the esthetic of the stair and wall finish.

7.1 RC wall and door/window

RC wall → **Door/window** →

Is there any reserved window opening for lift maintenance at the RC wall?

window opening for lift maintenance

(Yes / No)

Size of opening for lift door:

Width of opening for lift door at RC wall (W)

Height of opening for lift door at RC wall (H)

Size of lift door:

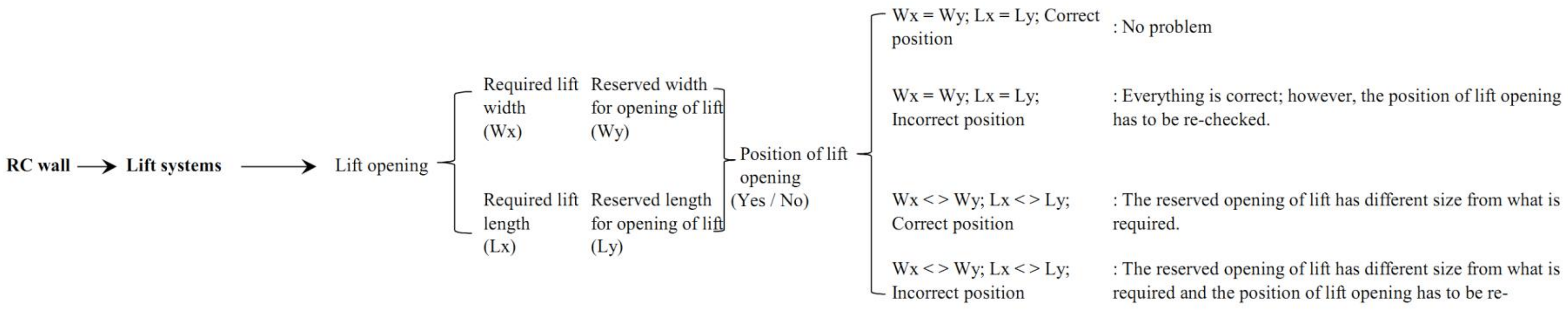
Width of lift door (Wd)

Height of lift door (Hd)

Frame thickness (h)

Opening for lift maintenance: Yes; $(Wd + h) = W; (Hd + h) = H$	: No problem
Opening for lift maintenance: Yes; $(Wd + h) = W; (Hd + h) > H$	: The height of reserved opening is greater than the height of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) = W; (Hd + h) < H$	: The height of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) > W; (Hd + h) = H$	: The width of reserved opening is greater than the width of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) > W; (Hd + h) > H$	: The size of reserved opening is greater than the size of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) > W; (Hd + h) < H$	: The width of reserved opening is greater than the width of lfit door, whereas its height is not sufficient. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) < W; (Hd + h) = H$	: The width of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) < W; (Hd + h) > H$	: The height of reserved opening is greater than the height of lfit door, whereas its width is not sufficient. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: Yes; $(Wd + h) < W; (Hd + h) < H$	: The size of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) = W; (Hd + h) = H$	: There is no entrance to reach the lift systems for maintenance.
Opening for lift maintenance: No; $(Wd + h) = W; (Hd + h) > H$	: There is no entrance to reach the lift systems for maintenance. The height of reserved opening is greater than the height of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) = W; (Hd + h) < H$	: There is no entrance to reach the lift systems for maintenance. The height of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) > W; (Hd + h) = H$	: There is no entrance to reach the lift systems for maintenance. The width of reserved opening is greater than the width of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) > W; (Hd + h) > H$	: There is no entrance to reach the lift systems for maintenance. The size of reserved opening is greater than the size of lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) > W; (Hd + h) < H$	: There is no entrance to reach the lift systems for maintenance. The width of reserved opening is greater than the width of lfit door, whereas its height is not sufficient. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) < W; (Hd + h) = H$	: There is no entrance to reach the lift systems for maintenance. The width of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) < W; (Hd + h) > H$	: There is no entrance to reach the lift systems for maintenance. The height of reserved opening is greater than the height of lfit door, whereas its width is not sufficient. This case affects the architectural design which might need to change the size of lift door.
Opening for lift maintenance: No; $(Wd + h) < W; (Hd + h) < H$	: There is no entrance to reach the lift systems for maintenance. The size of reserved opening is not sufficient to install the lfit door. This case affects the architectural design which might need to change the size of lift door.

7.2 RC wall and lift systems (1)



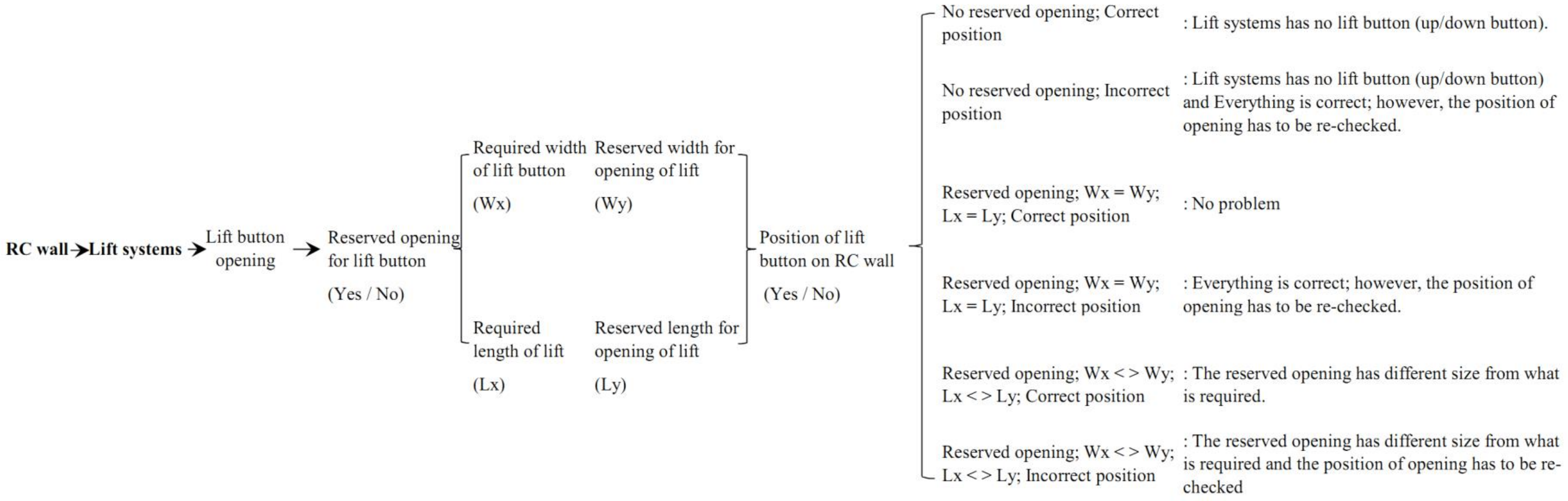
Wx = Wy; Lx = Ly; Correct position : No problem

Wx = Wy; Lx = Ly; Incorrect position : Everything is correct; however, the position of lift opening has to be re-checked.

Wx < > Wy; Lx < > Ly; Correct position : The reserved opening of lift has different size from what is required.

Wx < > Wy; Lx < > Ly; Incorrect position : The reserved opening of lift has different size from what is required and the position of lift opening has to be re-

7.2 RC wall and lift systems (2)

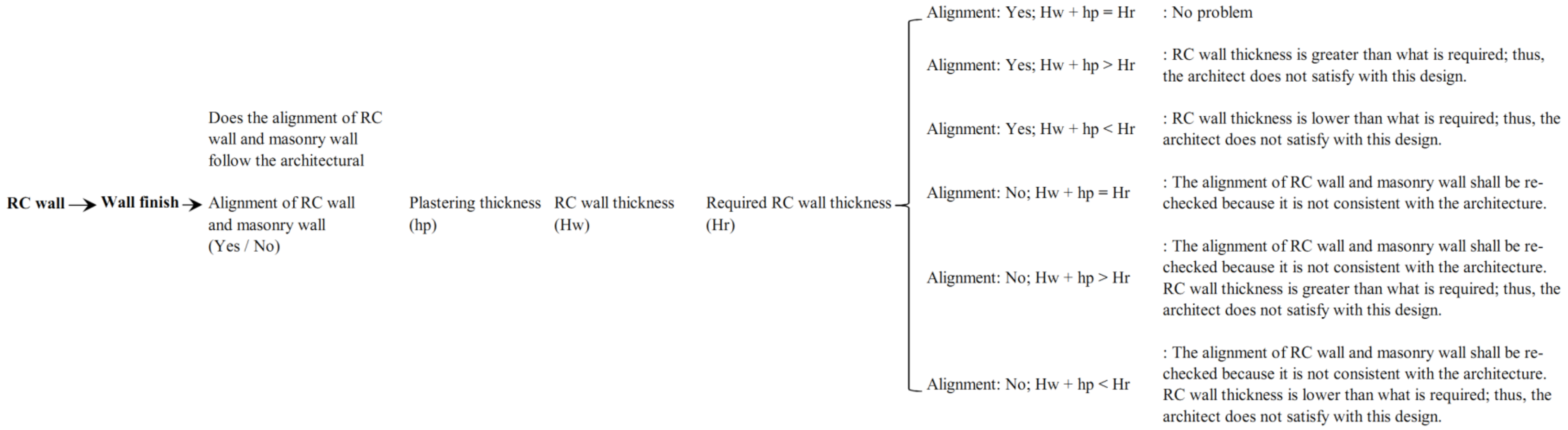


7.3 RC wall and storm drainage system

	Does the route of rainwater pipe have to run across the RC wall?	Is the rainwater pipe penetrated into RC wall before pouring the concrete?	Does the rainwater pipe run across the RC wall in horizontal route or vertical route?		Is the RC wall reinforcement very complicated?	
RC wall ➔ Storm ➔ drainage system	Route of rainwater pipe	Penetrated pipe into RC wall	Route of rainwater pipe across the RC wall	Position of sleeve penentrated into RC wall for rainwater pipe	RC wall reinforcement	Diameter of rainwater pipe (D)
	(Yes / No)	(Yes / No)	(Horizontal route / Vertical route)	(Yes / No)	(Yes / No)	RC wall thickness (h)
						Allowable effective concrete cover of RC wall (Ca)

Route: No	: No problem
Route: Yes; Penetrated pipe: No	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Horizontal; Position: Yes	: No problem
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Horizontal; Position: No	: It is not able to connect the sleeve of rainwater pipe with the storm drainage system when the reserved position is incorrect.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: Yes; Reinforcement: No; (h - D) >= Ca	: No problem
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: Yes; Reinforcement: No; (h - D) < Ca	: The strength of RC wall might be reduced because the effective concrete cover of RC wall is insufficient.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: Yes; Reinforcement: Yes; (h - D) >= Ca	: It might not be able to install the RC wall reinforcement properly or it might not be able to pre-installed the pipe into the RC wall.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: Yes; Reinforcement: Yes; (h - D) < Ca	: It might not be able to install the RC wall reinforcement properly or it might not be able to pre-installed the pipe into the RC wall. The strength of RC wall might be reduced because the effective concrete cover of RC wall is insufficient.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: No; Reinforcement: No; (h - D) >= Ca	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: No; Reinforcement: No; (h - D) < Ca	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised. The strength of RC wall might be reduced because the effective concrete cover of RC wall is insufficient.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: No; Reinforcement: Yes; (h - D) >= Ca	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised. It might not be able to install the RC wall reinforcement properly or it might not be able to pre-installed the pipe into the RC wall.
Route: Yes; Penetrated pipe: Yes; Route across RC wall: Vertical; Position: No; Reinforcement: Yes; (h - D) < Ca	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised. It might not be able to install the RC wall reinforcement properly or it might not be able to pre-installed the pipe into the RC wall. The strength of RC wall might be reduced because the effective concrete cover of RC wall is insufficient.

7.4 RC wall and wall finish



RC wall → **Wall finish** → Alignment of RC wall and masonry wall (Yes / No)

Does the alignment of RC wall and masonry wall follow the architectural

Plastering thickness (hp)

RC wall thickness (Hw)

Required RC wall thickness (Hr)

Alignment: Yes; Hw + hp = Hr : No problem

Alignment: Yes; Hw + hp > Hr : RC wall thickness is greater than what is required; thus, the architect does not satisfy with this design.

Alignment: Yes; Hw + hp < Hr : RC wall thickness is lower than what is required; thus, the architect does not satisfy with this design.

Alignment: No; Hw + hp = Hr : The alignment of RC wall and masonry wall shall be re-checked because it is not consistent with the architecture.

Alignment: No; Hw + hp > Hr : The alignment of RC wall and masonry wall shall be re-checked because it is not consistent with the architecture. RC wall thickness is greater than what is required; thus, the architect does not satisfy with this design.

Alignment: No; Hw + hp < Hr : The alignment of RC wall and masonry wall shall be re-checked because it is not consistent with the architecture. RC wall thickness is lower than what is required; thus, the architect does not satisfy with this design.

7.5 RC wall and water supply and distribution system

	Does the route of rainwater pipe have to run across the RC wall?	Is the opening of water pipe at the RC wall penetrated before pouring the concrete?	Does the rainwater pipe run across the RC wall in horizontal route or vertical route?			
RC wall → Water supply and distribution system	Route of rainwater pipe	Reserved opening of water pipe at the RC wall	Route of water pipe across the RC wall	Position of sleeve penentrated into RC wall for rainwater pipe	Diameter of water pipe	Required diameter of water pipe
	(Yes / No)	(Yes / No)	(Horizontal route / Vertical route)	(Yes / No)	(D)	(Dr)

Route: No	: No problem
Route: Yes; Opening: No	: It dissatifies the engineers of MEP systems because the design of rainwater pipe has to be revised.
Route: Yes; Opening: Yes; Route across the RC wall: Vertical	: It is not allowed to run the water pipes of water supply and distribution system into the RC wall vertically because it would be very difficult for maintenance when the water pipe was damaged. The water might be leaked out.
Route: Yes; Opening: Yes; Route across the RC wall: Horizontal; Position: Yes; D = Dr	: No problem
Route: Yes; Opening: Yes; Route across the RC wall: Horizontal; Position: No; D = Dr	: It is not able to connect the sleeve of water pipe with the main water supply and distribution system when the reserved position is incorrect.
Route: Yes; Opening: Yes; Route across the RC wall: Horizontal; Position: Yes; D < > Dr	: It might not be able to install the water pipe into the penetrated sleeve at the RC wall because their size are different.
Route: Yes; Opening: Yes; Route across the RC wall: Horizontal; Position: No; D < > Dr	: It is not able to connect the sleeve of water pipe with the main water supply and distribution system when the reserved position is incorrect. It might not be able to install the water pipe into the penetrated sleeve at the RC wall because their size are different.

VITA

Rothmony Ly was born on 6th June 1989, in Kompong Thom province, Cambodia. She finished her secondary school at Hun Sen Balaing High School in 2004 and high school at the same school in 2007. After that, she got a scholarship from the government to pursue her Bachelor Degree in Engineering at Institute of Technology of Cambodia (ITC). At the same time, she also studied another Bachelor Degree in Teaching English as a Second Language at Institute of Foreign Language, Royal University of Phnom Penh. She obtained her Bachelor of Civil Engineering and Bachelor of Education in the same year of 2012. Before her graduation, she had participated in some training related to civil engineering and done internships in several construction companies. She then went to work for an international company, LBL international, for at least ten months after graduation. Within this experience, she was awarded a scholarship from Chulalongkorn University via the programme of CU – ASEAN Scholarship in 2013 to continue her Master’s Degree in Construction Engineering and Management at Chulalongkorn University.