STRUCTURAL SYSTEM FOR PRECAST CONCRETE SWIMMING POOL

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โครงสร้างคอนกรีตเสริมเหล็กเป็นระบบการก่อสร้างหลักของประเทศไทยมาอย่างยาวนาน และระยะหลังมีการใช้ระบบโครงสร้างคอนกรีตสำเร็จรูปกันอย่างแพร่หลายมามากกว่า 10 ปี อย่างไรก็ตาม ระบบคอนกรีตสำเร็จรูปที่ใช้กันอยู่มีข้อจำกัด คือ ไม่สามารถใช้งานได้ในสภาวะใต้น้ำ วิทยานิพนธ์ฉบับนี้มีจุดมุ่งหมายในการพัฒนาระบบคอนกรีตสำเร็จรูปสำหรับโครงสร้างสระว่ายน้ำ โดยประยุกต์ใช้ยางรองคอสะพานเพื่อเป็นยางกันซึม ซึ่งยางจะต้องรับแรงเฉือนระหว่างชิ้นส่วนคอนกรีตและป้องกันการรั่วซึมน้ำของโครงสร้างได้ วิธีการศึกษาประกอบไปด้วย 2 การทดสอบหลัก หลังจากการออกแบบต้นแบบสระว่ายน้ำคอนกรีตสำเร็จรูปและรอยต่อระหว่างชิ้นส่วนโครงสร้าง การทดสอบแรกเป็นการทดสอบความสามารถในการรับแรงเฉือนและแรงอัดในเวลาเดียวกันเพื่อที่จะศึกษาพฤติกรรมการรับแรงเฉือนของยางในสภาวะจริง ผลการทดสอบแสดงถึงความสามารถในการรับแรงเฉือนของยางภายใต้หน่วยแรงอัดที่ 1 และ 2 เมกะพาสคาล สำหรับยางที่มีค่าความแข็งเท่ากับ 60 และ 70 ค่าแรงเฉือนสุดท้ายพบว่ามีค่าสูงกว่าค่าแรงเฉือนที่ต้องการสำหรับต้นแบบโครงสร้างสระว่ายน้ำสำเร็จรูป การทดสอบที่ 2 เป็นการทดสอบการป้องกันการซึมผ่านของน้ำภายใต้แรงอัดและแรงเฉือนในเวลาเดียวกัน การทดสอบออกแบบให้จำลองสภาพความลึกจริงของสระว่ายน้ำต้นแบบ นอกจากนี้ยังมีการประยุกต์ใช้วิธีไฟไนต์เอลิเมนต์ 3 มิติเพื่อวิเคราะห์หาการกระจายของความเค้นอัดที่เกิดจากการอัดแรง ผลการทดสอบการป้องกันการซึมผ่านของน้ำพบว่า มีปัจจัยอื่นที่สำคัญในการป้องกันการซึมผ่านของน้ำภายใต้สภาวะการรับแรงอัดและเฉือนคือ การคืบของยาง และความสม่ำเสมอของผิวสัมผัสที่รอยต่อชิ้นส่วนคอนกรีต

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KEYWORD: IMMERSED PRECAST CONCRERTE STRUCTURE, COMPRESSION-SHEAR BEHAVIOUR OF JOINT, WATER IMPERMEABILITY, ELASTOMERIC BEARINGS

Waranyoo Prombandankul : STRUCTURAL SYSTEM FOR PRECAST CONCRETE SWIMMING POOL. Advisor: Asst. Prof. WATANACHAI SMITTAKORN, Ph. D. Co-advisor: Asst. Prof. TARTAT MOKKHAMAKKUL, Ph.D.

Reinforced concrete construction has long been the major construction system in Thailand, and recently, precast concrete has been widely used for more than 10 years. However, there are some limitation on the use of precast system in immersed condition. This thesis attempts to apply the precast construction system on concrete swimming pools. Elastomeric bearings are chosen to be used as rubber seals in order to provide both shear resistance between segments and leakage prevention to the structures. The methodology involves 2 main experiments, accordingly. To simulate the conditions of immersed structures, the prototype of precast swimming pool and the joint between segments are designed. The compression-shear tests of such joints are conducted subject to direct shear and confinement in order to investigate the shear resisting behaviour of the rubber seals. The test results show that the final shear stress under confinements of 1 and 2 MPa for rubber hardness levels of 60 and 70 are considerably higher than the required shear stress while the rubbers prevent slippery. The water impermeability test is conducted on the specimen made with full depth and thickness of the prototype. A three-dimensional finite element model is also created to determine the stresses caused by the post-tensioned BBR bars. Results from the numerical model exhibits non-uniformly distributed stresses in the rubber seals. From impermeability test, two other important factors are found to have influence on impermeability performance: the creep effect of rubber and the surface finishing of contacted precasts.

Moreover, business plan is conducted in this thesis including operations plan, marketing plan and financial plan to provide direction and feasibility of technology commercialization. Finally, universal theory of the application and use of technology (UTAUT) is employed to investigate the adoption of precast concrete swimming pool.

Field of Study:	Technopreneurship and Innovation Management	Student's Signature ....
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CHAPTER I

INTRODUCTION

1.1 Background

Construction industry in Thailand contributed THB 411.7 billion to the country's gross domestic product in 2018 which was 2.6 percent of national GDP. At the same time, it caused demand in products and services from other related industries such as construction materials and equipment. Moreover, it provided crucial impact on economic and social aspects of the country especially economic growth and unemployment rate.

In the last four decades reinforced concrete construction has been the major construction system in Thailand and precast concrete has been widely used in Thailand for more than 10 years. However, upon the use of precast concrete system, there are some limitation on the use of precast system which we explain in the following topics: precast concrete structure and immersed precast concrete structure.

1.1.1 Precast concrete structure: The trend and existing problems

Precast construction has several advantages over the traditional construction on many aspects which are less on-site construction time, less curing time, less energy and water consumption, fewer emissions and lower overall construction cost. Moreover, on quality aspect, cracks and leakages are still found in cast-in-situ system since the quality of work heavily relies on workmanship and the frequent problems are segregation, under-consolidation and improper curing process (Bilcik, 2013; Rahman, et al. 2013). Consequently, precast system is increasingly utilized and continuously replacing the use of cast-in-situ system (Jaillon & Poon (2009); Leger, 1985).

Jaillon & Poon (2009) provided evidence for increasing use of precast in Hong Kong. In the mid-1980s, prefabrication, combined with standard modular design, was introduced in public housing projects. Since then, the Hong Kong Housing Authority (HKHA) has recommended the usage of precast units and reusable formwork in all public housing contracts. In 2002, Chiang, Chan & Lok (2006) showed statistics that prefabricated elements accounted for about 17% of the concrete volume used in public housing projects. In the other continent like France, the adoption of precast building started since the end of 1960s responding to the public and state demand for houses. It was estimated in 1983 that 60% of the houses erected in France were built using precast construction method provided by Leger (1985).

Ganiron Jr, & Almarwae (2014) presented comparative evidence of construction sector in Philippines. They discovered that precast construction method has benefit over cast-in-situ construction in term of time. It is never delayed by curing time or missing materials. Furthermore, the modular house can be completed about half the time it takes using traditional mass construction which is 30 to 45 working days. Cao, Li, Zhu & Zhang (2015) also provided the samples from China. In term of environmental advantage, the precast system also has benefit over traditional construction. They showed that precast system is more efficient in energy use with a 20.49% reduction in total consumption including a 35.82% reduction in resource depletion, a 6.61% reduction in health damage and a 3.47% reduction in ecosystem damage compared to the traditional system. Wadel (2009) using evidence in Spain found that prefabricated buildings have a lower environmental impact for both the construction stage and the end-of-life stage. It consumes less energy and water and produces fewer emissions. Wadel then concluded that prefabricated systems are more sustainable than non-prefabricated ones. In UK, Wrap (2007), studied the potential for the waste minimization potential. They found that Modern Methods of Construction (MMC) offer significant potential to reduce the amount of waste generated onsite of volumetric building systems for 70 to 90 percent.

On the economic basis, Chan (2011) compared the two case studies in Australia and Malaysia that have illustrated the technological trade-off between capital and labour in the production of concrete buildings. It is cheaper to develop precast system in Australia while, in Malaysia, it is the other way around. Construction firms in a developed country like Australia with high labour wage rates can easily opt to increase capital input and decrease labour input to minimize costs. On the other hand, construction firms in a developing economy like Malaysia with access to cheap migrant labour can choose to minimize construction costs by utilising greater labour inputs. The cost comparisons clearly indicated that the choice of construction method is based on overall construction cost. They further suggested that to increase the adoption of prefabricated construction in Malaysia the government must reduce the supply of cheap migrant labour coupled with the financial incentives. The labour policy in 2010 of engaging cheap migrant labour in Malaysia had the effect of keeping construction labour at an extremely low wage rate. The financial incentives offered by the government to the construction firms were not sufficient to overcome the higher investment cost of prefabrication systems.

In summary, evidences in many countries show similar increasing use of precast concrete structure replacing the use of traditional or cast-in-situ concrete structure system as we provide evidence in Hong Kong, Philippines and France. This trend stems from economic drives, environmental drives and efficiency drives as we provide more details in chapter 2. However, there are also problems in using precast system in many countries. We found that the most critical problem of using this system is water leakage through joints. Chiang & Tang (2003) had evidence from Hong Kong to reveal that, in 2000, during five consecutive months after the move-in, water leakage amounted to 10% of over 70,000 complaints filed in by the homebuyers. Moreover, in Malaysia, Rahman, Ahmad & Zainordin (2013) showed that leakage defects in pre-cast concrete structure has the highest percentage of occurrence at 11.2% compared to other defects which are in the range of 1.9% - 3.7%. According to the above evidence, we can conclude that there are still leakage problems on the existing joint designs for precast concrete structure. This is the reason why traditional system is still commonly used in immersed precast concrete structure.

One of the most used solutions for leakage problems is a joint design. Jindal & Bkisc (1975) provided the solution to eliminate the problems of leak-proof joint for external wall by their original joint designs for its easy-to-grout and irreversible drainage. The other alternative for leak-proof joint is sealants. Rahman, Zainordin, Ahmad & Mahat (2015) explained the mechanism of sealants that they are typically designed or applied to resist hydrostatic forces at PC joints to provide watertight seal. This solution has ranged from polymer modifiers for Portland cement based to pure polymers such as epoxy resins, polyesters and some polyurethane based systems (Morgan, 1995). Other non-Portland cement based materials, such as high alumina cements and magnesium phosphate based repair products have also found application. However the disadvantage of sealants is that the life span of sealant materials varies under different climatic conditions and it is often shorter for application under tropical climate. Even traditional system is commonly employed on small-and-medium-scale immersed structure, the leakage problem still remains and the current solution is found inappropriate in term of life span.

1.1.2 Immersed precast concrete structure: fabrication process and joints

In precast system, joints are important parts to the strength of the precast structures (Ghafur & Omar Aziz, 2019; Zhan, Zhang, Ye, Xi, & Wu, 2018). These joints must be capable to resist and transfer shear force between segments (Alcalde, Cifuentes & Medina, 2013; Zhou & Mickleborough, 2005). On the other hand, in immersed tunnel structures, joints with rubber seal are assumed to resist no shear force. All segments are laid mainly on aggregate just like pavement design as shown in Figure 1-1. Hence, no shear force occurs between segments. The rubber seal so called “Gina rubber gasket” as shown in figure 1-2 is installed only for leakage preventive purpose (Glerum, 1995). However, the recent study on immersion joints by Xiao, Yu, Yuan, Taerwe, & Xu (2017) showed that the rubber seals contribute substantial shear resistance to the joints of the precast structures and further study is needed.

(a)

(b)

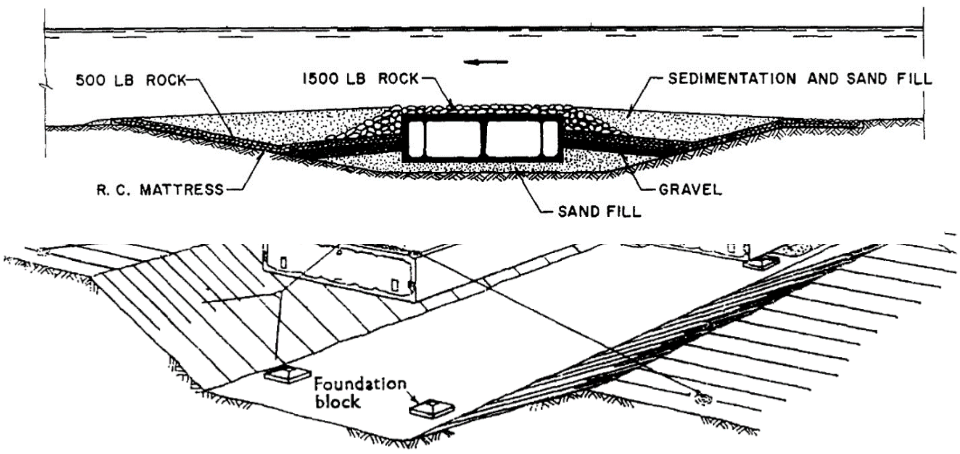


Figure 1-1 Precast tunnel construction; (a) Laying process of tunnel segment; (b) Cross-sectional tunnel

However, when foundation settlement and earthquake are concerned, it is important to study the shear resistance of rubber in joints. The recent study provided evidence that the rubber seal gives significant shear resistance to the structure (Xiao, et al., 2017).This paper therefore attempts to study the shear behavior of rubber seals. Here, we chose natural rubber bearing pads to be used as rubber seals because they are capable of supporting normal stress and facilitating horizontal shear movement to structures (Stanton & Roeder, 1982).

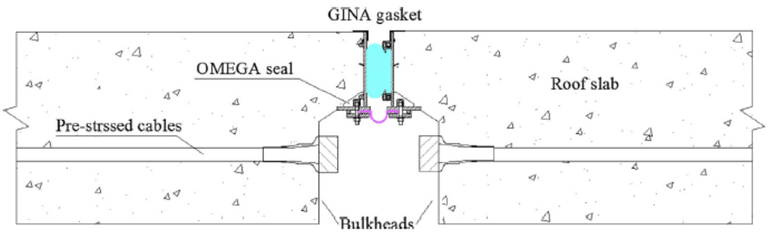


Figure 1-2 Detail of immersion joint and Gina gasket (Hu, Xie & Wang (2015))

Apart from the tunnel structure, the immersed concrete structure like swimming pools and water tanks are commonly constructed using traditional process. Concrete has to be cast in-place with the help of rubber water stops at the construction joints. This makes construction process complicated and takes such a long time, which may end up with a very high construction cost of the whole project, as a result. For a small pool structure, casting monolithically can be applied while large pool structures will require construction joints. Hence, the quality of work is mainly depending on workmanship. The frequent problems of casting large amount of concrete are segregation, under-compaction and improper curing process which may lead to permeability of the structure. Bilcik (2013) studied immersed concrete structure and suggested that there are a lot of failures occurring due to errors in the design and execution. The most common causes of failures of immersed structures are linear leakages through separating cracks and construction joints.

1.2 Problem statement

According to the review on existing precast concrete system and its limitation in chapter 1, we can conclude problems against our concept of immersed precast structure as follows:

1) Normal precast concrete structures are unable to prevent water leakage

2) Immersed precast concrete tunnels ignore the resistance to shear force between segments

3) Rubber seal is used only for leakage prevention but no evidence has been found on its shear capability

Hence, to apply the concept of precast construction method to swimming pool structures, the critical problem is the design of joints for strength and leakage preventive mechanism.

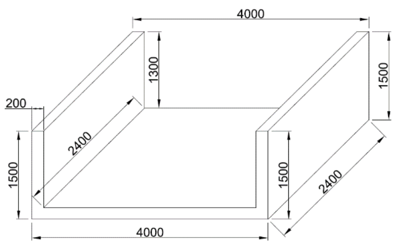
1.3 Research objectives and scope of the study

This research attempts to apply the precast construction to swimming pools and ensure the water impermeability and shear capacity of joints. In such case, the behavior of rubber sealed joints for both shear resistance and impermeability needs to be investigated. The research objectives can be summarized as listed below:

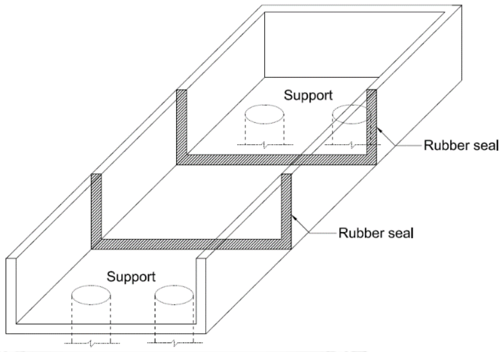
1) To develop joint design for precast structures which is capable of shear resistance and leakage prevention.

2) To study compression-shear behavior and impermeability of rubber seals by developing new test setups for both experiments.

3) To develop precast swimming pool structures for commercialization by conducting business environment analysis and business plan. By applying the new joint design, the prototype design is shown in figure 1-3.



(a)



(b)

Figure 1-3 Prototype of a precast swimming pool; (a) Dimensions in mm of the precast concrete segment; (b) The connections of precast segments and rubber seal

The scope of the study is described as follows:

1. Only elastomeric bearings are chosen to be used as rubber seals since they are widely used to support vertical loading and allow horizontal shear movement of the super-structures (Stanton & Roeder (1982); Cook, Allen, & Ansley (2009)). Other types of rubber and materials are not included in this study.

2. The thicknesses of chosen rubbers are 10 mm and 20 mm with the hardness levels of 60 and 70. Their properties are according to Thai Industrial Standard 951-2533 (1995).

3. We conduct experiments on dry flat joint and do not consider keyed-joints nor epoxied joints.

4. In the compression-shear test, the loading is applied at strain rate of 0.04 per second until the final shear strain is equal to 1. The selected loading rate is half of the lowest rate of Wei, Yuan, Igarashi, Tan, Iemura, & Zhu (2016)

5. Shear modulus is calculated by taking the secant modulus from the point of 2% maximum stress to the point at 25% shear strain according to ASTM D 4014 (1995).

1.4 Contribution of the study

This paper develop 2 new knowledge on shear capacity and water impermeability of elastomeric bearings and apply them to the joints of precast swimming pool structures. As a result, this new system remarkably reduces construction time and overall cost.

The contributions of this research is described below:

1.4.1 Academic contribution

1.4.1.1 The new understanding of compression-shear behavior of rubber seal is founded. Elastomeric bearing is capable to resist shear force from precast structure.

1.4.1.2 The impermeability behavior and limitation of elastomeric bearings are founded. They are capable to prevent water leakage in immersed precast structure.

1.4.2 Social contribution

1.4.2.1 The application of rubber seals in this study increases the value of natural rubber and it is an opportunity to apply natural rubber to construction industry.

1.4.2.2 The precast swimming pool increase productivity of construction industry.

The immersed precast structures remarkably reduce construction time and overall cost from cast-in-situ system.

1.4.2.3 Our business plan is easily adaptable to other types of precast structure production. Entrepreneurs in construction industry can adapt our business plan to their production.

CHAPTER II
LITERATURE REVIEW

The study of "structural system for precast concrete swimming pool" relates to researches and knowledge in many domains. To develop and commercialize such system, we need to understand existing system and its limitation, existing & potential material behavior and limitation, related engineering experiments, business environment, project roadmap and adoption potential. Prior researches in 9 domains have been reviewed and we use three main theories to support our research objective as they are listed below:

1) The use of post-tension and the behavior of joints in precast concrete segmental bridge structures.
2) The advantage of Gina gasket which provides the water impermeability to immersed tunnel structures.
3) We employ elastomeric bearing as rubber seals. The behavior of rubber sealed joints for both shear resistance and impermeability needs to be investigated.

2.1 Existing joints in precast concrete segmental bridge

Rahman, Ahmad & Zainordin (2013) provided a definition for joints in precast concrete structure as follow; " Joints between pre-cast concrete (PC) components provide physical separation between each panel which is necessary because PC components have to be of manageable size so that they can be manufactured in factory, transported on public road and erected on site." When more than two large concrete panels are connected, joints are the highly important part of this integration. The serviceability and ultimate strength capacity of precast concrete structure is depending on the behavior of joints between panels. The actual segmental bridge joint is as shown in figure 2-1.

American Association of State Highway and Transportation Officials or AASHTO, proposed the shear design formulas for series of full-scale joints, flat and keyed, dry and epoxied, single keyed and multiple-keyed. However, Zhou &

Mickleborough (2005) argued that the AASHTO and Rombach and Specker's design formulas always underestimate the shear capacity of single-keyed joints but greatly overestimate the shear capacity of multiple-keyed dry joints. Hence, they could lead to unsafe designs when applied to multiple-keyed joints. He further suggested that the shear strength reduction factor should be introduced to those formulas derived from single-keyed joints to estimate the shear capacity of multiple-keyed joints. His experiment details are shown in figure 2-2. Moreover, the evidences from Alcalde, Cifuentes & Medina (2013) supported Zhou & Mickleborough (2005) that AASHTO formula overestimates the nominal shear capacity of multiple-keyed dry joints. However, the numerical value of single keyed dry joint was found slightly above value of AASHTO formula. Hence, we use the validity of flat dry joints and compares the behavior of shear capacity of them to our newly developed joint.

For our local standard on precast concrete system in Thailand, there are many regulators that administer the product quality and the fabrication quality of precast concrete system. However, they only concentrate on the ultimate load capacity and the superficial fabrication quality. For instance, the engineering institute of Thailand specifies the live load capacity, carrying point, ultimate strength of concrete, temporary bracing and minimum reinforcement of the topping. Thai industrial standard institute 576-2546 and 828-2546 focuses on precast casting specification and strength test specification. Hence there is no local standard which identifies the joint specification.

Figure 2-1 Construction of concrete segmental bridge fabrication from Airport Road to Tampines Avenue 10, Singapore

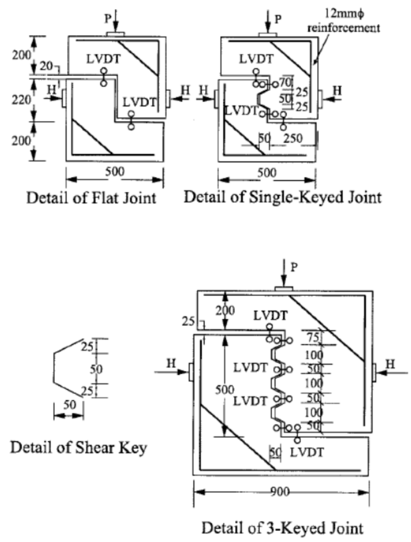


Figure 2-1

Figure 2-2 Specimens of joints of concrete segmental bridge by Zhou & Mickleborough (2005)

2.2 Study on immersed tunnel structures and GINA gasket

Hu, Xie & Wang (2015) studied A 6 km immersed tunnel of the Hong Kong–Zhuhai–Macao Bridge (HZMB). Some joints, for instance the 0.72 m long terminal joint, will be constructed using underwater cast concrete and gasketed steel plates installed by divers. The water tightness of joints is extremely important, since it is almost impossible to replace or reinforce the joint devices from the outside during the service life. The immersion joints are flexible joints, each consisting of a GINA gasket, an Omega seal, eight shear keys, and 60 pre-stressed cables as shown in the figure 2-3. For the flexible joint, GINA gasket and Omega seal serve as the primary and secondary waterproof materials, respectively, with specially designed rubber material to adapt the 120 year service life.

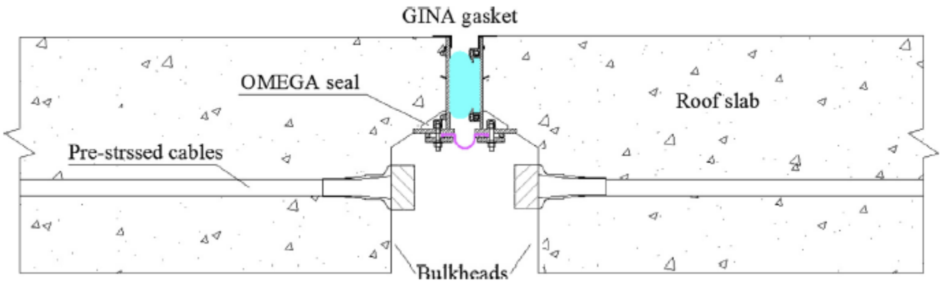


Figure 2-3 Detail of immersion joint by Hu, Z., Xie Y., & Wang

Glerum (1995) studied developments in immersed tunnelling in Holland and stated that the development of the Gina gasket was a major step forward in immersed tunnel construction. These coupling problems were eliminated when the Gina rubber gasket was applied at the Rotterdam North-South Metroline in the early 1960s. This new method reduced the time required for actual watertight coupling of two elements from many months to less than an hour, although installing the second seal (the Omega gasket) and finishing the connection inside the Gina still takes many weeks.

Figure 2-4 shows a cross-section of such an expansion joint. The keyed shape of the joint allows the joints small movements and rotations in the longitudinal direction, but prevents unequal displacements in the transverse direction. Cast-in rubber-metal waterstops provide watertightness to the elements to ensure that the waterstops work properly, foam rubber stripe are fixed to the metal strips. When the concrete has hardened, epoxy resin is injected into the compressible strip, forming a continuous barrier that prevents any leakage around the waterstop. The resin is injected through cast-in tubes.

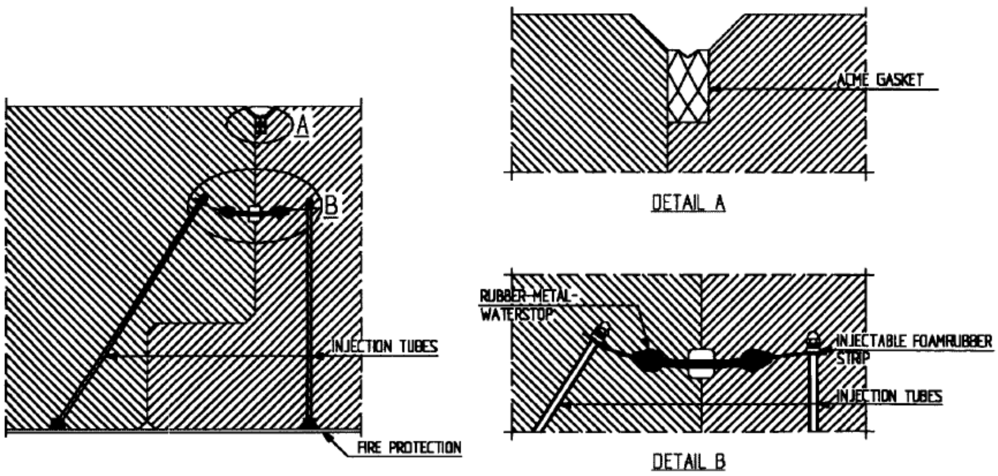


Figure 2-4 Expansion joints of immersed tunnel by Glerum (1995)

Each precast tunnel segment is placed on top of gravel layers and connected to the next segment presuming that no shear force transfers between them Ganiron Jr, & Almarwae (2014)[1]. Immersion joints are therefore designed for water tightness only. The rubber seal is thus designed solely to prevent water leakage which does not match the criteria of our joint design mechanism. We, then decided to use intermediate of bearing pad rubber which can transfer the shear force through joints and evaluate the shear capability of this new joint design.

2.3 Specifications and shear capacity of elastomeric bearings

According to the Thai Industrial Standard 951-2533, we found bearing pad rubbers used in construction sector which are neoprene rubber and natural rubber with 3 levels of hardness. Their properties are gradually different as shown on the table 2-1 below. The content of this standard mostly covers quality assessment and testing criteria. Stanton & Roeder (1982) explained that natural rubber produces larger elongations than neoprene rubber of the same hardness. For all practical purposes bridge bearings are designed by the assumption of linear elastic, simple shear deformation. For the compressive deformation as shown in figure 2-5, Stanton & Roeder (1982) illustrated that, from the normal shape (a), if the surfaces are perfectly lubricated it will deform to shape (b). However, if the contact surfaces are bonded to the rubber, it will deform to shape (c). For the laminated type with bonded surfaces, it will deform to shape (d).

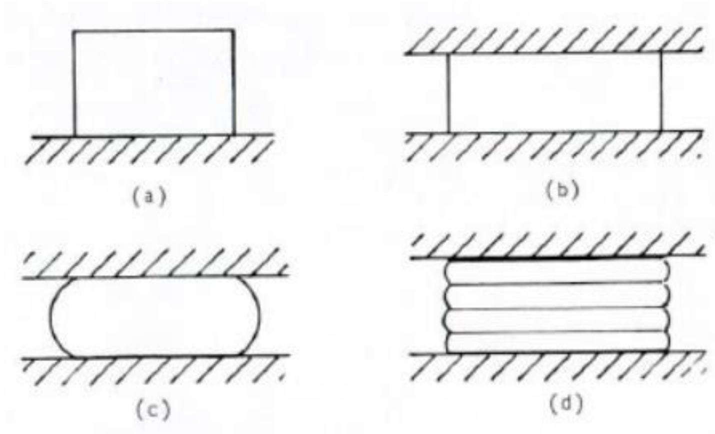


Figure 2-5 Compressive behavior of bearing pads by Stanton & Roeder (1982)

For the shear capacity test on bearing pad rubber, Cook, Allen, & Ansley (2009) reviewed the shear modulus test AASHTO designation: M251-06 as shown in figure 2-6. It use an inclined compression test to calculate shear modulus with the surface slope between 1:10 to 1:20. Another method in this code is “A test method for creep and shear bond in elastomeric bearings” as shown in figure 2-7. The sample of 51 mm by 51 mm is bonded to the steel plates. The sample is strained in shear 10 times at the rate of 1 percent per second to 50% and loaded at 50% strain for minimum of 6 hours. The records are taken at the first 30 minutes and every 5 minutes.

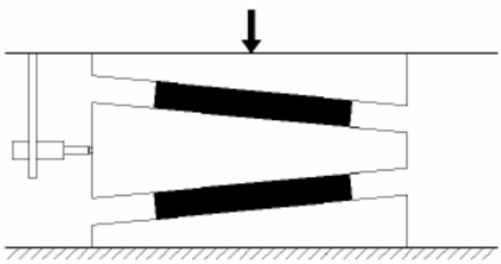


Figure 2-6 The inclined shear test AASHTO designation: M251-06

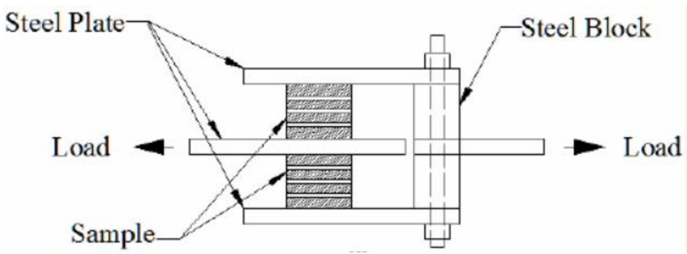


Figure 2-7 The shear creep test AASHTO designation: M251-06

Table 2-1 AASHTO bearing pad specification and test results for neoprene rubber and natural rubber

AASHTO DESIGNATION: M251-90									
Neoprene rubber					Natural rubber				
D 2240	Hardness	50 ± 5	60 ± 5	70 ± 5	D 2240	Hardness	50 ± 5	60 ± 5	70 ± 5
D 412	Tensile Streng. min. psi	2500	2500	2500	D 412	Tensile Streng. min. psi	2500	2500	2500
	MPa	(17.237)	(17.237)	(17.237)					
	Ultimate elongation, min., %	400	350	350		Ultimate elongation, min., %	450	400	400
D 573	Heat resistance 70 hr. 212°F				D 573	Heat resistance 70 hr. 158°F			
	(100°C)					(69.9°C)			
	Change in durometer hardness,					Change in durometer hardness,			
	max., point	+15	+15	+15		max., point	+10	+10	+10
	Change in tensile strength,					Change in tensile strength,			
	max, %	-15	-15	-15		max, %	-25	-25	-25
	Change in Ultimate elongation,					Change in Ultimate elongation,			
	max, %	-40	-40	-40		max, %	-25	-25	-25
D 395	Compression set				D 395	Compression set			
Method B	22 hr. 212°F (100°C) max, %	35	35	35	Method B	22 hr. 158°F (69.9°C) max, %	25	25	25
D 1149	Ozone				D 1149	Ozone			
	100 pphm ozone in air by					25 pphm ozone in air by			
	volume, 20% strain 100°±2°F					volume, 20% strain 100°±2°F			
	(37.7°C ± 1°C) 100 hr No.	No	No	No		(37.7°C ± 1°C)	No	No	No
	mounting procedure E 518,					mounting procedure D 518,			
	procedure A	Cracks	Cracks	Cracks		procedure A	Cracks	Cracks	Cracks
D 429	Adhesion				D 429, B	Adhesion			
	Bond made during vulcanization					Bond made during vulcanization			
	lb per Inch	40	40	40		lb per Inch	40	40	40
	(Kg/m)	714	714	714		(Kg/m)	714	714	714
D 746	Low temperature test				D 746	Low temperature test	No	No	No
	Procedure B Brittleness at					Procedure B Brittleness at			
	-40°F (-40°C)	Failure	Failure	Failure		-40°F (-40°C)	Failure	Failure	Failure

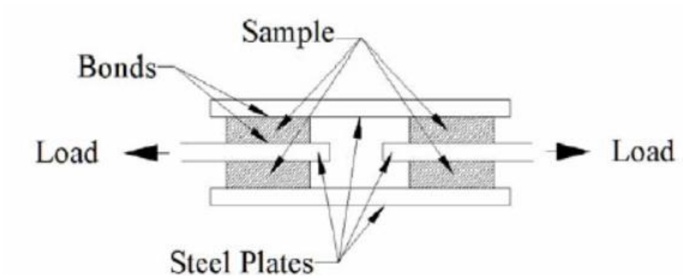


Figure 2-8 The shear modulus test ASTM D 4014 ANNEX-A

For shear modulus test ASTM D 4014 ANNEX-A as shown in figure 2-8, the sample is strained from 0 to 50 percent for 6 times while taking from 30 seconds to 60 seconds to reach 50% shear strain each cycle. It is noted that there is no compressive stress in the test setup.

Arditzoglou, Yura, & Haines (1995) also classified bearing pads into 3 levels of hardness. They explained that there are two types of bearing pad rubber which are plain pad and reinforced pad. A plain pad behaves differently from a reinforced bearing when subjected to a compressive force while it behaves similar to reinforced pads in term of shear deformation. Hence, our scope of study covers only plain bearing pad as it is commonly used in Thailand. They explained further that the shear deformations are as large as the rubber thickness. The test was conducted as shown in figure 2-9. Elastomers have a linear stress-strain relationship up to strains of l00%. Even though such strains are possible without causing any rubber deterioration, it is a widely accepted design practice to limit the shear strain of elastomeric bearings to 50% of the total elastomer thickness. He also combines the shear modulus, creep deflection and tensile stress-strain curve of rubber from different sources as shown in figure 2-10.

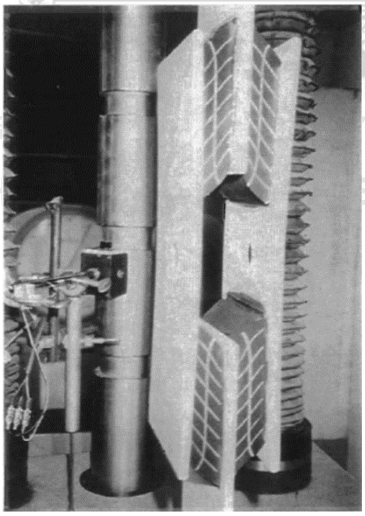


Figure 2-9 The test setup at 100% strain by Arditzoglou, Yura, & Haines (1995)

	Mechanical Properties E and G Obtained from the Following References								
	Ref. 6	Ref. 12	Ref. 7	Ref. 3	Ref. 22	Ref. 24	Ref. 35	Ref. 10	Ref 11
Hardness (Degrees)	**SHEAR MODULUS G (psi)**								
50	87	93	93	90-115	85-110	95-130	71	91	110
60	145	154	154	135-165	120-155	130-200	114	129	160
70	203	254	251	200-260	160-260	200-300	157	177	215
Hardness (Degrees)	**YOUNG'S MODULUS E (psi)**								
50	334	319	319	320-400	-	-	-	-	-
60	537	645	645	500-600	-	-	-	-	-
70	900	1088	1066	780-900	-	-	-	-	-

Note: 145psi = 1MPa

Hardness (Shore"A")	50	60	70
Shear Modulus at 73F (23C) psi (MPa)	95-130 (0.68-0.93)	130-200 (0.93-1.43)	200-300 (1.43-2.14)
creep deflection instantaneous deflection at 25 years	25%	45%	45%

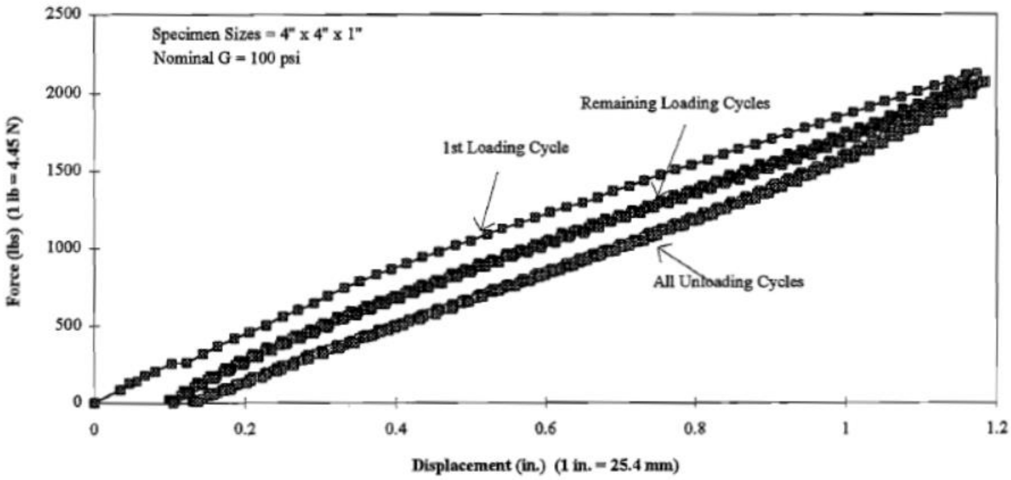


Figure 2-10 Shear modulus, Young modulus, Creep deflection and Load-displacement of shear test of rubber by Arditzoglou, Yura, & Haines (1995)

2.4 Degradation of rubber

Samsuri (2010) explained the classification of rubber in accordance with international organization for standardization with 3 major properties which are heat resistance, oil resistance and low temperature resistance. On the other hand, if it is classified by the usage purpose, there are 2 main categories which are general purpose rubbers and specialty rubbers. The latter are tailor made to meet certain specific requirements, for instance, highly resistance to heat and oxidation. It includes silicone rubber, fluoroleastomers, epicholorohydrin, cholorosulfonated rubber, etc. The technical properties of each type of rubber is provided in table 2-2.

Table 2-2 The technical properties of each type of rubber by Samsuri, A. (2010)

Elastomer	*T_g (°C)*	*O_3 resistance*	*Swelling resistance (%)[a]*	*Heat resistant up to (°C)[b]*
NR	−72	L	200 (120 °C)	100
SBR	−63	L	130 (120 °C)	100
BR	−112	L	>140 (70 °C)	100
EPDM	−55	H	>140 (70 °C)	150
IIR	−66	M	120 (120 °C)	150
CIIR	−66	M	>140 (150 °C)	150
ACM	−22 to −40	H	25 (150 °C)	175
CO	−26	H	5 (150 °C)	150
CR	−45	M	65 (120 °C)	125
NBR (med ACN)	−34	L	10 (100 °C)	125
MVQ	−120	VH	50 (150 °C)	225
CSM	−25	H	50 (150 °C)	150
H-NBR	−30	H	15 (150 °C)	150
FKM	−18 to −50	VH	2 (150 °C)	250
EU	−55	H	40 (100 °C)	100

[a]Swelling after 70 h in ASTM oil 3.[5,9]
[b]Classification after ISO/TR 8461, aerobic condition, Method ISO 4632/1 3 days, (Retention properties).[9]
L = low resistance M = medium resistance H = high resistance.[5,9]

The properties of rubber are determined by its ingredients. The common additives can be classified into six major categories which are vulcanization agents which is chemical process for converting natural rubber or related polymers into more durable materials by the addition of sulfur, accelerators, age-resistors or antioxidants, fillers used to reinforce or modify physical properties, softeners and miscellaneous ingredients such as color.

Degradation is known as corrosion of rubbers which is associated with the aging process. The aging factors are summarized as follow:

1) All unsaturated rubbers are subject to degradation due to the attack of heat, ultraviolet (UV) light, oxygen, ozone.
2) Aging process of rubber cannot be stopped but just slowed down. The mechanical property of rubbers changes during aging process.

3) Oxygen reacts with rubber only after the rubber has been energized. This is usually from UV light, heat or mechanical energy.

Samsuri (2010) further suggested that the most effective solution against aging is to select the correct elastomers to meet the maximum service temperature and environment. These include specialty elastomers such as acrylic (ACM), chloro-sulfonyl-polyethylene (CSM), ethylene propylene copolymer (EPM), fluoroelastomers (FKM), silicones (MQ , VMQ), polyester urethanes (AU), etc. The other solution is to use chemical antioxidants Two main types of chemical antioxidants are amines and phenolics. Amine types are more effective and powerful antioxidants than phenolic types. However, the former is staining and the latter is not. Thus, this limits applications of amine types to black and dark colored elastomeric products. Phenolic types are exclusively used for white and bright colored products.

For the tunnel structure which is assumed to have lifespan of 100 years, the rubber seal Gina gasket is designed to have life span of 100 years accordingly with correct functioning and incorporation of the effect of relaxation. Consequently, we decide to select appropriate elastomer with at least 50-year life span and pursue shear capacity and impermeability test in the next step.

The ageing test or rubber deterioration test for bearing pad rubber commonly use ASTM D1149. It is to increase the rate of oxidation using ozone. The test specimens are rectangular strips 10.00 ± 0.03 mm (0.40 ± 0.01 in.) wide by 100 ± 25 mm (4 ± 1 in.) long. The standard ozone partial pressure shall be 50 ± 5 mPa (equivalent to 50 pphm at 100 kPa atmospheric pressure). The test conducted in Thailand use temperature at 37.7°C ± 1 over 100 hours with 20% strain. The neoprene rubber cracks with the ozone concentration of 100 pphm and the natural rubber cracks with the ozone concentration of 25 pphm in air by volume.

2.5 Types of swimming pool structure

There 3 types of swimming pool structures which are commonly used in the world. They are concrete structure, vinyl liner and fiberglass. Each type of structure has different superior properties. Hence, we conducted in-depth interview with composite material and swimming pool expert who is the engineering instructor of

Chulalongkorn University, Ajarn Vicha Mektrakarn, and let him compare major attributes and limitations between 3 types of structure as shown in table 2-3. The first traditional type, the cast-in-situ concrete structure uses its material as both water leakage prevention and bearing capacity as shown in figure 2-11. On the other hand, for vinyl liner type, its concrete structure is not accountable for leakage prevention but just load bearing capacity while the PVC sheet is accountable for water leakage prevention instead. The vinyl liner is a PVC (Polyvinyl chloride) sheet which is fabricated by heat ironing over the finished concrete structure. This type of concrete structure has considerably less load bearing capacity than the traditional concrete structure according to less dead load of finishing work as shown in figure 2-12 and 2-13. The weakness of vinyl liner type is the shorter life span compared to the other types at 10 years of PVC usage which means the users need to change the vinyl surface every 10 years. The other limitation of vinyl liner type is its less flexibility and less preferable choice for architects since every angle of its structure has to be in arch shape and unchangeable finishing type which is less appealing in term of aesthetic value.

The minimum construction time of traditional concrete structure is at least 15 days consisting of 3 days for floor casting, steel work and formwork plus 4 days of wall casting, steel work and formwork. The additional 7 days for concrete curing and formwork removal. Hence, it is in total of minimum 14 days of traditional swimming pool structure.

Figure 2-11 traditional concrete swimming pool structure

Figure 2-12 Vinyl liner installation

Figure 2-13 Vinyl liner structure

Fiberglass structure has the shortest installation time, as its advantage over the other two approaches, since it has a single panel, water proof and load bearing in its own structure and does not need any fabrication process as shown in figure 2-14 and 2-15. However, it also has crucial limitation on the fixed size, shape and depth which importantly constraints the user customization and is less appealing to architects. On commercial basis, the most selected structure by architects is concrete structure since it offers the superior aesthetic and wider range of pool finishing.

Figure 2-14 Fiberglass swimming pool

Figure 2-15 Production process of fiberglass by spraying

Table 2-3 Properties comparison between 3 types of swimming pool structure by in-depth interview with composite material and swimming pool structure expert

	Concrete structure	Vinyl liner structure	Fiberglass (composite structure)	Precast structure
Cost of structure size 4meter x 10meter	THB 286k	THB 200-300k	THB 126k	THB 190k
	Plus finishing THB 82-246k	plus liner THB 328k		plus finishing THB 82-246k
Cost of pile work	THB 300k	THB 300k	THB 300k	THB 150k
Total cost	THB 668-832k	THB 828-928k	THB 426k	THB 422-586k
Construction time (not include pile or supports)	15-30 days	7 days	1 day	1-3 days
Factory controlled quality	Low	Medium	High	High
Customized shape	Flexible	Partially flexible	Fixed size, only arch angle and maximum length of 10 meters	Flexible
Architect preference	Most frequent use	Least preferable	Least preferable	Most frequent use
Load bearing	Concrete structure	Concrete structure	Fiberglass (composite structure)	Concrete structure
Leakage prevention material	Concrete	PVC	Fiberglass	Concrete
Material life time	50 years	10 years	30 years	50 years
Other benefit	-	-	Waste reduction	Waste reduction

2.6 Shear strength experimental setup and test procedure

Mattock & Hawkins (1972) proposed the test of monolithically cast "push-off" specimens to study the characteristics of the shear plane and the reinforcement and the concrete as shown in figure 2-16. The length and width of the shear planes were 10 x 5 in., 12 x 4.75 in., and 12 x 6 in. (approx. 25 x 13 cm, 30x12 cm, and 30x15 cm). Later, Zhou & Mickleborough (2005) adopted the similar test setup to investigate the shear strength and behavior of joints in precast concrete segmental bridges as shown in figure 2-17. All of the specimens had a thickness of 250 mm. Confining stress, simulating the effect of prestress force in segmental bridges, was applied to the joint surfaces through a framework driven by a hydraulic pump. The test setup, simulating hinged joint, enabled the shear plane to be subjected to pure shear without moment. We found the test of Zhou extremely useful for the adaptation to our test as we redesigned from Zhou & Mickleborough (2005) test which is also previously tested on double components. However, the dissimilarities are on the scale assumption of swimming pool structures and the intermediate between double components.

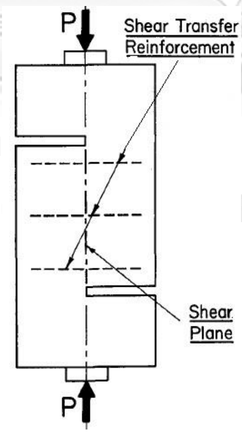


Figure 2-16 Push-off shear transfer test by Mattock & Hawkins (1972)

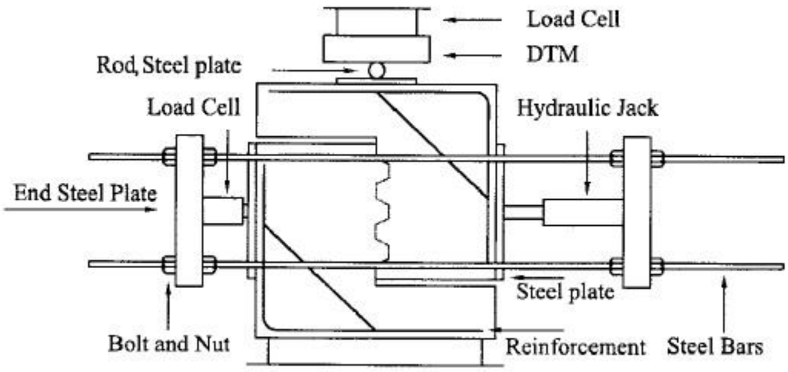


Figure 2-17 Shear strength test setup for precast concrete segmental bridge by Zhou & Mickleborough (2005)

2.7 Impermeability test for joints in precast concrete components

We found several permeability test setups which are differently conducted regarding the objectives of those particular researches. Lopez, Masters, & Bolton (2010) studied water penetration resistance of residential window and wall systems subjected to steady and unsteady wind loading. Finished residential wall specimens with windows were subjected to uniform static and rapid pulsed pressure sequences and uniform wetting as shown in figure 2-18. Window variables included size, material, and operator type. Wall construction and finish was varied, as well as the wall-window interface. Windows from four different manufacturers were subjected to static and time-varying pressure loads computed from wind tunnel model data. Water passing the innermost plane of the window assembly was collected and continuously weighed to determine the rate of ingress. We found that this method drives water pressure with wind which is not the water pressure mechanism of immersed structure. We, then, find this kind of method inappropriate to our test.

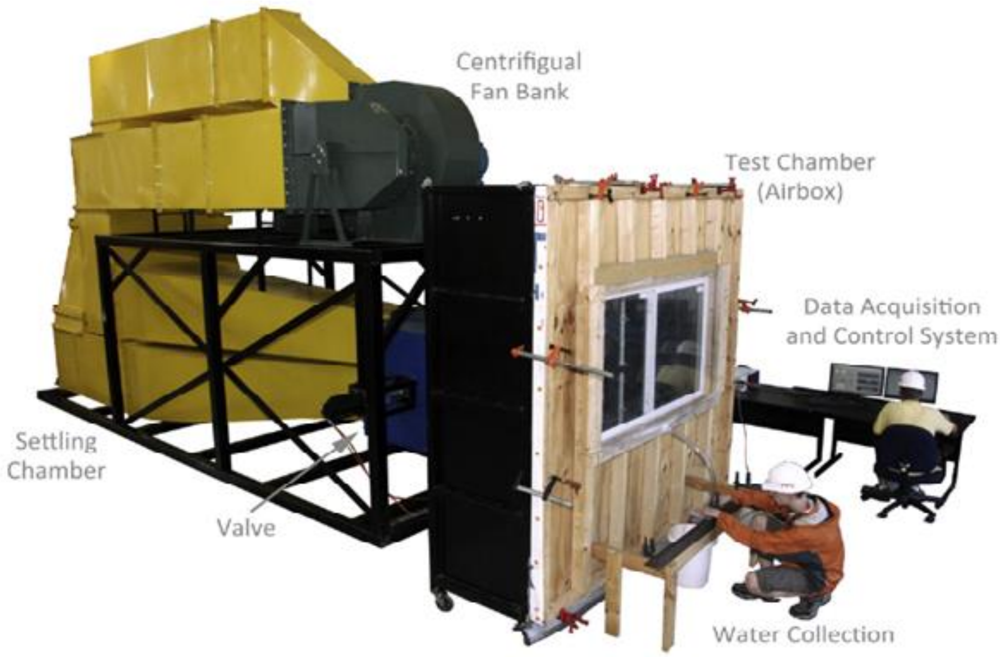


Figure 2-18 Water penetration test by Lopez, Masters, & Bolton (2010)

According to German water permeability standard, as shown in figure 2-19, DIN 1048, this permeability test gives a measure of concrete's resistance against the penetration of water at 28 days after casting specimens. The test is carried out on concrete specimens of size 150x150x150 mm, at an age of 28 days. The test cell assembly being used had the provision for testing six cubes at a time. Once the specimens were assembled in the test cells, a water pressure of 500 KPa (5 bar) was applied for 72 hours. Water pressure is applied by means of an arrangement consisting of a water tank connected to an air compressor through a valve, to adjust the pressure.

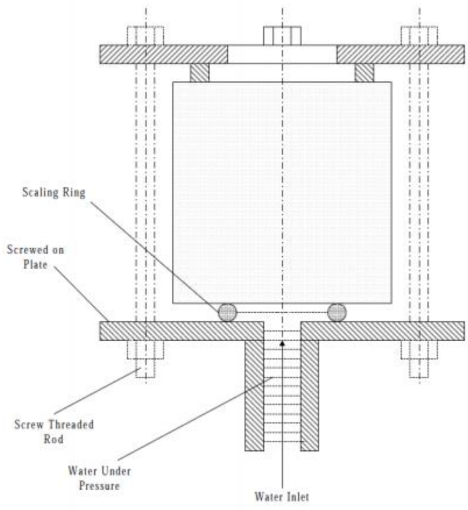


Figure 2-19 German standard water permeability test, DIN 1048

2.8 New product development (NPD) models

The objective of the review on NPD is to find appropriate roadmap for our project. In the last few decades, NPD process are developed following the increased competition for new and better products. Krishnan & Ulrich (2001) gave critical review on NPDs from the marketing domain. They explained that the strength of marketing models are complete and integral methods for consumer preferences while their weakness is the ignorance on the constraints of the design procedure and production technologies. In other words, to use NPD process for industrial or engineering product by using process from marketing domain is not compatible. From this suggestion, we continue to explore the NPD process in engineering context. Pugh (1983) proposed the design activity model which is viewed as highly inter-disciplinary in engineering domain. The major steps of this model are Market, Specification, Concept design, Detail design, Manufacture and Sell. We also compare NPD process from 5 authors with our newly developed model as shown in table 2-4.

Booz, Allen & Hamilton, 1982; Cooper (1990) suggested that the business analysis stage is considered as an indispensably relevant stage since it generates critical business information and possible economic value in the context of firms. However, we found that Pugh's model ignores some important business information prior to the design stage. Hence, business environment analysis and strategy are found relevant and should be included prior to the front-end process.

Meanwhile, we found some stages redundant and repetitive to our project. For instance, Ulrich & Eppinger model (2011), we found no use of market testing stage since the system of precast structure has been used and understood by users for many decades. In essence, our work is the change of only the component within the system and it could be classified as modular innovation according to Henderson & Clark (1990). On the other way around, for architectural and radical innovation, we believe this stage is extremely important to the product development since it brings and rechecks the comfortable and compatible use of customers which can be drawn back for the improvement of products. For the NPD model of Cooper (1990), we found that idea screening stage is irrelevant to our product development since we already review research gap and found that to apply precast system in immersed structures, the only critical problems is at joint design. Hence, we directly focus on the solution and test for the appropriate joint design.

Table 2-4 The comparison between 7 NPD models classified by the output of each stage

Output	Booz, Allen & Hamilton, 1982	Cooper, 1990	Ulrich & Eppinger, 2011	Pugh, 1983	Natcha, 2012	Prombandankul, 2017
Innovation topic, mission statement, business target, key assumptions and constraints, product plan	new product strategy	X	planning	X	discover	Business environment analysis & strategy
Market needs and problems, customer requirements, existing comparable products	X	preliminary market assessment	X	market	define	market
Many raw ideas	idea generation	idea generation	concept development	X	design	X
The best ideas from previous stage	idea screening	initial screening				
Design concept, practical function, aesthetic function, sketching, prototype, concept screening	concept testing and development	detailed market study		specification		specification
		X	system level design	concept design		design
Production process design, product design	design and development	product development	detail design	detail design	develop	development
Marketing plan, operation plan, financial plan, risk management plan	business analysis	business analysis	X	X	deploy	business plan
improvement from customer's feedback	testing	market testing	testing and refinement	X		X
Product launch and post-launch review	commercialization	commercialization	production ramp-up	manufacture		manufacture
				sell		sell

2.9 Technology adoption model

TRA (Theory of Reasonable Action) is one of the most common theories utilized for determining relationship between human's attitudes on human's behavior. To perform behavior, this theory point out 2 important factors which are his/her own attitudes and subjective norms as shown in Figure 2-20. Attitudes come from positive, negative or neutral belief towards behavior and personal evaluation of consequences. For example, it is cheaper to use precast construction method for building a condominium. Subjective norms are social perception that may affect individual's behavior. For example, all other construction companies employ precast construction method on their current projects. Hence, it is time to study and use this new method.

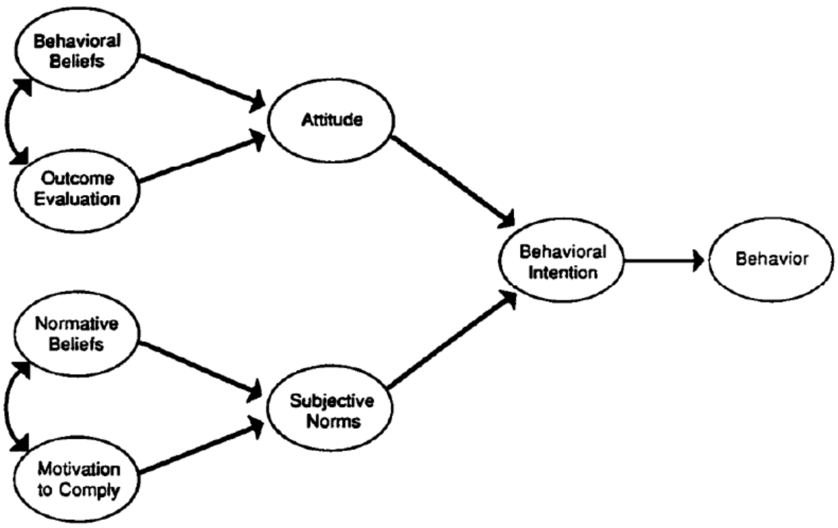


Figure 2-20 Fishbein & Ajzen (1975)'s Theory of Reasonable Action

The development from Reasonable Action Theory, Fred Davis introduced Technology acceptance model (TAM) in 1986. TAM is designed primarily to framework the adoption of information systems or technologies. Two different factors were included and evaluated in the simple TAM model which are Perceived Usefulness (PU) and Perceived Ease of Use (PEU) as shown in figure 2-21. Perceived Usefulness is subjective possibility of the potential user that using a specific would enhance his/her job performance. For example, using precast construction method will help decrease the total time of the whole project. Perceived Ease of Use relates to the effort the user need to put on if they employ this new system. For example, we do not need to change our procedure of work to employ precast construction system. The final version of TAM is shown in figure 2-22 in which Perceived Usefulness and Perceived Ease of Use have direct effect on behavioral intention.

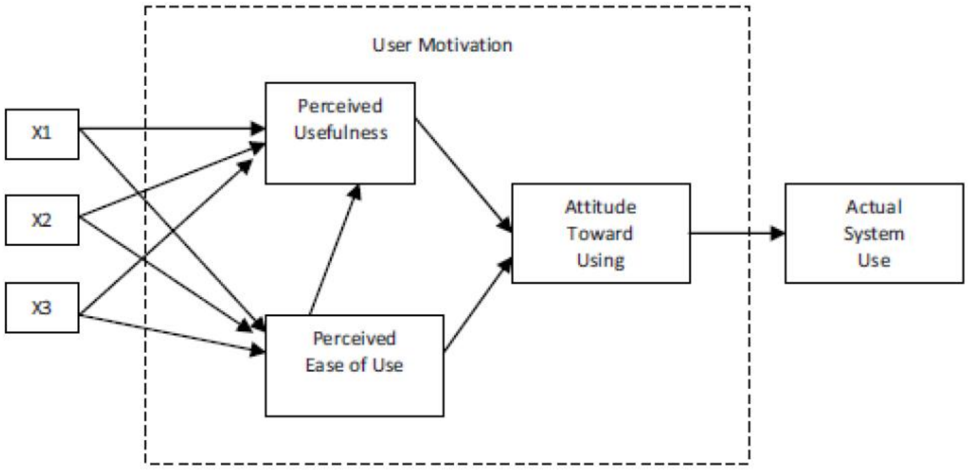


Figure 2-21 Fred Davis's Technology Acceptance Model (1986)

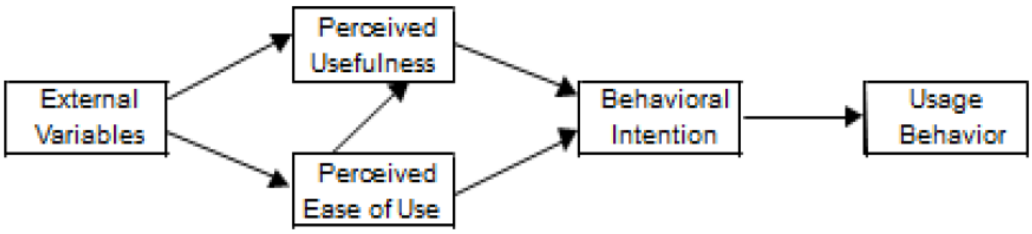


Figure 2-22 The final version of TAM by Venkatesh & Davis (1996)

Venkatesh, Morris, Davis & Davis (2003) developed the Unified Theory of Acceptance and Use of Technology (UTAUT) as shown in Figure 2-23 from prior theories. The UTAUT includes four determinants of the behavioral intention of the users: performance expectancy, effort expectancy, social influence and facilitating conditions. Meanwhile, they include age, gender, experience and voluntariness of use having impact on 4 main factors. According to Venkatesh, et al. (2003), as for the societal meaning, the validity experiments showed that social influence has less impact when it is individual voluntariness.

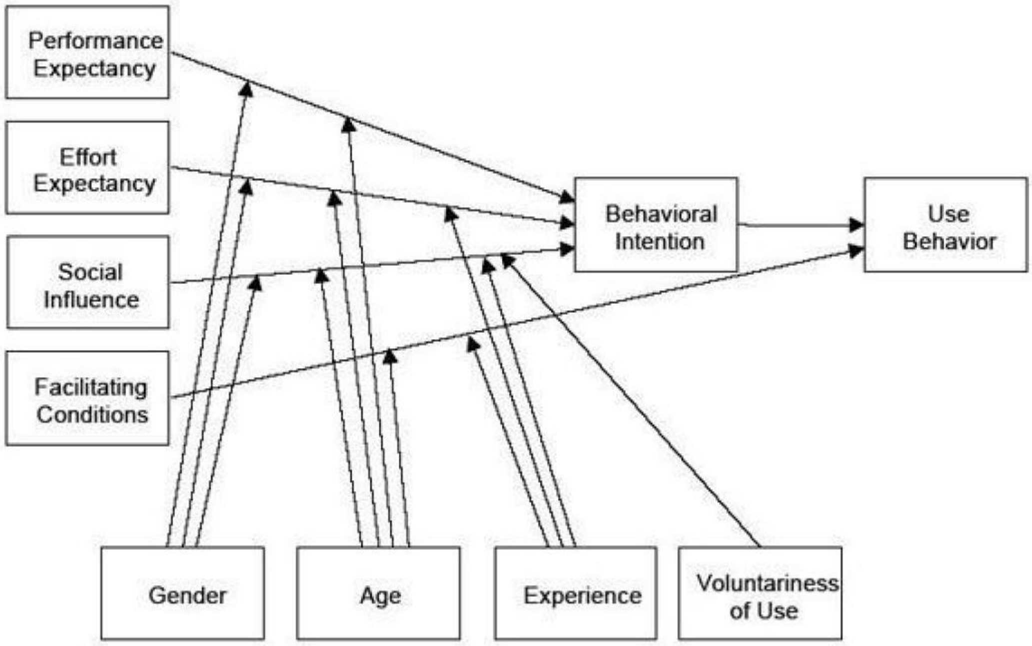


Figure 2-23 Unified Theory of Acceptance and Use of Technology (UTAUT)

Chapter III

Research methodology

This study aims to develop precast swimming pool structures for commercialization. Therefore, we need to explore business environment situations and product differentiation prior to the engineering development. According to our study on NPD process in Section 2.8, we design our research methodology procedure accordingly. The table 3-1 shows the research phases including the tools of each stage.

Table 3-1 7 research phases and research tools

Phase	Research process	Tools
1	Business environment analysis & strategy	PEST/SWOT/5-force competitor's analysis/Mission statement
2	Market	Product comparison/Market positioning/UTAUT
3	Specification	Literature review/ Expert interview
4	Design	Literature review/ Compression-shear test/ Impermeability test
5	Development	Three-dimensional finite element models "ANSYS"
6	Business analysis	Marketing plan/Operations plan/Financial plan
7	Manufacture & sell	Marketing communication plan & budgeting

3.1 Phase 1: Business environment analysis & strategy

The main objectives of the business environment analysis are listed below:

1) To identify business problems and eliminate potential obstacles that might happen to our commercialization stage
2) To provide solutions to those business problems
3) To understand situation of the business environment
4) To develop potential goals and visions of our business

We use economic data from Bank of Thailand, Office of the National Economic and Social Development Council and Government housing bank and demographic data from United Nation. Three tools are used to analyse current business situations that might affect our business. Chapter 5 begins with information of company background and project rationale including competitive advantage of our company. PEST is used to analyse external influence that might affect our business which are political, economic, social and technological factors as illustrated in Section 5.1. 5-force analysis is used to analysis our bargaining power compared to 5 stakeholders which are our competitors, suppliers, customers, potential substitution and new entrants. SWOT is used to summarize both internal and external factors. We use our strength and opportunity to present to the customers and provide solutions to our weaknesses and threats as illustrated in Section 5.1. We also review the current situation of precast concrete system as illustrated in Section 1.1.

3.2 Phase 2: Market

The objective of the first part of this phase is to identify the product differences and our product positioning to make clear understanding of benefits and disadvantages of our product as illustrated in Section 5.1 and 5.2. To compare our product with competitive products, we conduct in-depth interview with composite material and swimming pool expert who is Chulalongkorn University instructor in the topic of aerospace material, Ajarn Vicha Mektrakarn, and let him compare major attributes and limitations between 3 types of structure as shown in Section 2.5. After the comparison is arrange in table we plot the product positioning in 2 graphs according to price per quality and price per flexibility as shown in figure 5-10 in Section 5.2.2.

Moreover, to understand the technology acceptance behavior of customers, three models on technology adoption have been reviewed in Section 2.9. Three models are compared and each dependent variable is explained in Chapter 6. 1-on-1 interviews are conducted to gather customer behavior and reason behind each answer on using precast concrete swimming pools on their responsible projects within 1 hour. The questionnaire consists of 2 sections. Section 1 is for demographic information such as age, gender, area of construction industry and experience in construction industry and precast construction technique. Section 2 consists of factors which have potential impact on the adoption of precast concrete swimming pools. The first section is written down by interviewees whereas the second section is asked and written down by the interviewer since it includes the question “why” on each question. Section 2 is structured by 7 point Likert scale to indicate the degree of agreement of interviewees.

3.3 Phase 3: Specification

In this phase, the main goal is to find appropriate material in term of life span in our environmental condition. We explore the possible material to use as rubber seal and review the rubber properties. According to Section 2.4, we found that the cause of rubber degradation is due to the attack of heat, ultraviolet (UV) light, oxygen. Hence, we have to limit these factors to slow down aging process. Hence, if we design the joint that rubber does not expose to outer environment, we can achieve longer rubber lifetime. We have 3 possible options on rubber seal as follow:

1) We need to acquire the actual GINA gasket. We need to call and buy samples of the GINA gasket from Trelleborg in Netherland, to send us the material for the shear capacity test with the precast swimming pool joint.

2) To develop the new kind of material, we contact chemical expert to consult about the rubber development.

3) We can also select the available rubber in the market such as elastomeric bearings which their properties are according to Thai Industrial Standard 951-2533 (1990) and study its behavior on shear resistance and water impermeability.

3.4 Phase 4: Design

The goal of this phase is the design of joints for strength and leakage preventive mechanism in order to apply the concept of precast construction method to swimming pool structures. In this study, after we reviewed literature in Section 2.1

and 2.2, dry flat joints in conjunction with elastomeric bearings are chosen and their compression-shear behavior as well as leakage prevention performance are investigated in chapter 4. The prototype of swimming pool structure designed for this experiment conforms to real conditions including shear force from panel weight and water pressure.

3.4.1 Compression-shear test

The objective of this test is to investigate the ability to resist shear force of elastomeric bearings in joints of precast in Section 4.2. According to Section 2.6, we have to develop the test setup from Zhou & Mickleborough (2005). Eleven flat joints with elastomeric bearings were tested. The contact surface is 200 mm × 200 mm. The pressure on rubber seal is set at 1 MPa and 2 MPa in order to compare with normal flat joint of Zhou & Mickleborough (2005). The load cells are installed for both horizontal and vertical direction. The LVDTs measure the vertical displacements at both sides of the specimen as shown in figure 4-4(b). The loading is applied at strain rate of 0.04 per second until the final shear strain is equal to 1. The selected loading rate is half of the lowest rate of Wei, Yuan, Igarashi, Tan, Iemura, & Zhu (2016). The natural bearing pad rubber with the hardness level of 60 and 70 are used and their properties are according to Thai Industrial Standard 951-2533 (1990).

3.4.2 Impermeability test

The objective of this study is to investigate appropriate stress distribution on contact surface between concrete and rubber seal for leakage preventive purpose. For the impermeability test, according to Section 2.7, we do not find any appropriate test setup from literature review since they does not simulate out swimming pool conditions. Hence, we need to develop new test setup which allow actual water pressure and shear force in Section 4.3. The test is designed with full depth to simulate shear force from the panels and water weight. The specimen consists of 2 parts which are attached by six Post-tensioning BBR bars. We use the result in this phase and implement on Phase 5. Three dimensional finite element models were created using ANSYS to study stress distribution on contact surface between concrete and rubber seal.

3.5 Phase 5: Development

Our goal of this phase is to design the first version of our product. This essentially incudes post-tension position for our prototype. We use the result, from phase 4 of stress distribution on contact surface between concrete and rubber seal as shown in Section 4.5. We need to use finite element programming to develop the swimming pool and determine the proper position and value of post-tensioning force.

3.6 Phase 6: Business plan

The objective of this phase is to provide direction for the commercialization part. It includes 3 main parts which are operations plan, marketing plan and financial plan. Marketing plan, in Section 5.2, includes market segmentation, market positioning, the 4Ps marketing mix and marketing communication budgeting. Operations plan includes demand forecast and production capacity in Section 5.3.2, location, equipment and workforce in Section 5.3.3 and raw material and suppler management in Section 5.3.4. Financial plan is in Section 5.4 including revenue forecast, cost calculation, balance sheet, income statement and scenario analysis.

CHAPTER IV
DESIGN AND DEVELOPMENT

4.1 Prototype design and calculation

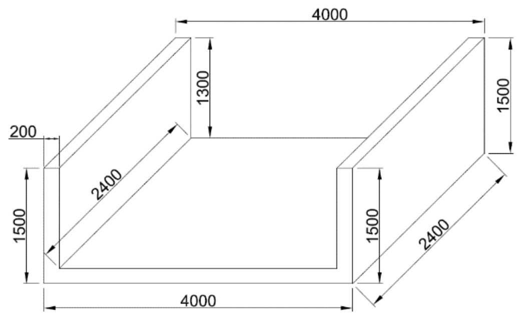
To apply the concept of precast construction method to swimming pool structures, the critical problem is the design of joints for strength and leakage preventive mechanism. In this study, dry flat joints in conjunction with elastomeric bearings are chosen and their compression-shear behavior as well as leakage prevention performance are investigated.

The prototype of swimming pool structure designed for this experiment conforms to real conditions including shear force from panel weight and water pressure. The dimensions of the concrete swimming pool segment are 2400 mm × 4000 mm × 1500 mm with the thickness of 200 mm as shown in figure 4-1(a). Here, the ultimate load is computed according to ACI 318-89 code as shown in Eq. (1) where U is ultimate loads, D is dead loads and L is live loads.

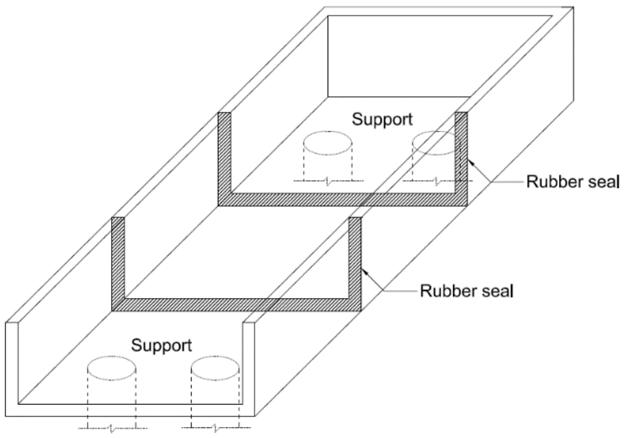
$$U = 1.4\,D + 1.7\,L \qquad (1)$$

The weights of concrete segment and water cause an average shear stress of 0.1256 MPa on the rubber seal. The rubber seals are installed at all joints as shown in figure 4-1(b). All segments are connected together under the confinement of external post tension tendon.

First, the experiment of compression-shear test is conducted in dry condition to study the shear capacity of the rubber seals. The test setup allows direct shear without moment in concrete joints. Hardness, rubber type and loading rate all have influences on the shear capacity Arditzoglou, Yura, & Haines (1995); Wei, Yuan, Igarashi, Tan, Iemura, & Zhu (2016). These factors are controlled and essentially prescribed to the experiment. The second experiment concerns the leakage preventive mechanism of the rubber seals. The precast concrete joint with a rubber seal, submersed under water, is tested subjected to a required shear force in order to verify the impermeability performance. The natural bearing pad rubber according to Thai Industrial Standard 951-2533 (1990) is used in both experiments.



(a)



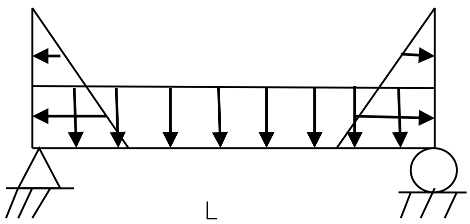
(b)

Figure 4-1 Prototype of a precast swimming pool; (a) Dimensions in mm of the precast concrete segment; (b) The connections of precast segments and rubber seals

4.1.1 Structural calculation

We are the first to develop push-off test with intermediate which the size of specimens calculated from the structural analysis as follows:

1) Calculation of structural analysis of walls



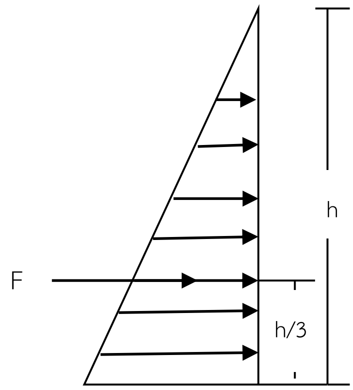


Figure 4-2 Load illustration on precast swimming pool structures component

Use L = 4 m as width of the swimming pool structures

and h = 1.5 m as depth of the swimming pool structures

$$q = \gamma h$$

$$q = (1000)\,(1.5)$$

$$= (1500)\ \text{kg/m}^2$$

$$F = (1500)\,\frac{1}{2}\,(1.5)$$

$$= 1125\ \text{kg/m}$$

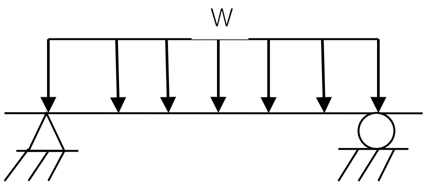
$$F_U = 1125 \times 1.7 = 1912.5\ \text{kg/m}$$

$$-M = -F\left(\frac{h}{3}\right)$$

$$= -(1125)\left(\frac{1.5}{3}\right)$$

$= -956.25$ kg.m/m # <u>moment at the bottom of walls</u>

2) Calculation of structural analysis of floor



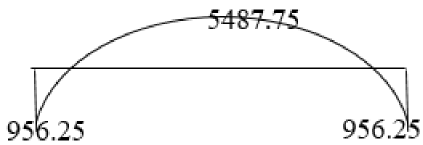


Figure 4-3 Load illustration and bending moment diagram on floor component

Finding thickness of the floor

$$\text{Floor thickness} = \frac{L}{20}\left(0.4 + \frac{f_y}{7000}\right) = \frac{400}{20}\left(0.4 + \frac{4000}{7000}\right) = 8.19 \text{ cm. use 20 cm.}$$

Finding moment at the midspan of floor

D.L. = 0.20 × 1 × 2400 = 480 kg/m^2

H.L. = 1500 kg/m^2

$$W_U = 1.4\,(480) + 1.7\,(1500) = 3222 \text{ kg/m}^2$$

$$M_{mid\ span} = \frac{wl^2}{8} - 956.25 = \frac{3222(4)^2}{8} - 956.25 = 5487.75 \text{ kg.m/m}$$

Reinforced Concrete Design Using $f_c' = 280$ ksc

and $f_y = 4000$ ksc

$$\rho_b = \beta\,\frac{0.85 f_c'}{f_y}\,\frac{6120}{6120+f_y} = 0.85\,\frac{(0.85)(280)}{4000}\,\frac{6120}{6120+4000} = 0.03058$$

Mid span: Effective depth = 20 – 2.5 = 17.5 cm

$$R_U = \frac{5487.75 \times 100}{0.9\,(100)(17.5)^2} = 19.91 \text{ kg/cm}^2$$

$$\rho = \frac{0.85 f_c'}{f_y}\left(1-\sqrt{1-\frac{2Ru}{0.85 f_c'}}\right) = \frac{0.85(280)}{4000}\left(1-\sqrt{1-\frac{2(19.91)}{0.85\,(280)}}\right) = 0.0052$$

A_S = 0.0052(100) (17.5) = 9.1 cm^2/m. use DB20 @030m as bottom steel of floor

Edge:
$$R_U = \frac{956.25 \times 100}{0.9\,(100)(17.5)^2} = 3.469$$

$$\rho = \frac{0.85(280)}{4000}\left(1-\sqrt{1-\frac{2(3.469)}{0.85\,(280)}}\right) = 0.00087 < \rho \text{ min}$$

A_S min = 0.002 × 100 × 17.5 = 3.5 cm^2/m. use DB12 @ 0.30 m. as top steel of floor

$$\text{Check Shear } V_U = \frac{WL}{2} = \frac{3222(2.4)}{2} = 3866.4 \text{ kg/m}$$

$$V_U \le \phi V_C = (0.53)(0.85)\sqrt{280}\,(100)(17.5) = 13192 \text{ kg.}$$

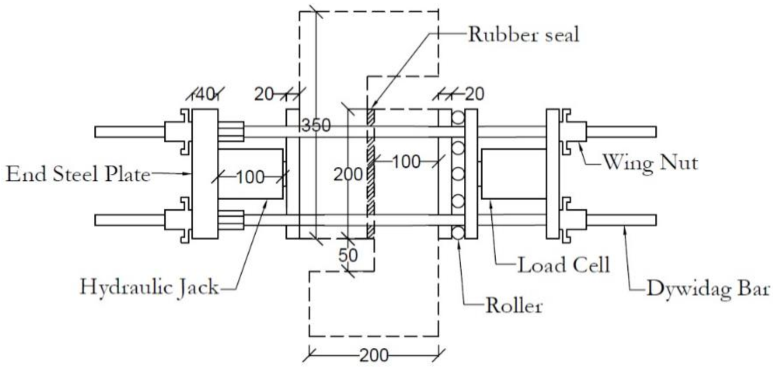
According to the calculation, the width of contact surface of 200 mm and steel reinforcement are used for both test setups to simulate real condition.

4.2 Compression-shear test

4.2.1 Test setup

The objective of this test is to investigate the ability to resist shear force of elastomeric bearings in joints of precast. The test setup is similar to Zhou & Mickleborough (2005) which allows direct shear in concrete joints with confinement as shown in figure 4-4(a). The horizontal force from hydraulic jack represents the normal stress from post-tension. The contact surface is 200 mm × 200 mm. The pressure on rubber seal is set at 1 MPa and 2 MPa in order to compare with normal flat joint of Zhou. The load cells are installed for both horizontal and vertical direction. The LVDTs measure the vertical displacements at both sides of the specimen as shown in figure 4-4(b). The loading is applied at strain rate of 0.04 per second until the final shear strain is equal to 1. The selected loading rate is half of the lowest rate of Wei, Yuan, Igarashi, Tan, Iemura, & Zhu (2016). The natural bearing pad rubber with the hardness level of 60 and 70 are used and their properties are according to Thai Industrial Standard 951-2533 (1990).

The test identifier is denoted as Mi-XX-TT-n, where M represents monotonic loading following with i representing confinement from post-tensioned tendon (in MPa). XX is the hardness level of rubber which is 60 or 70. TT represents the thickness of the bearing pad. Lastly n represents the test number under the same condition. Since design practice limits the shear strain at 50 percent, this experiment is observed until strain reaches 100 percent.



(a)

(b)

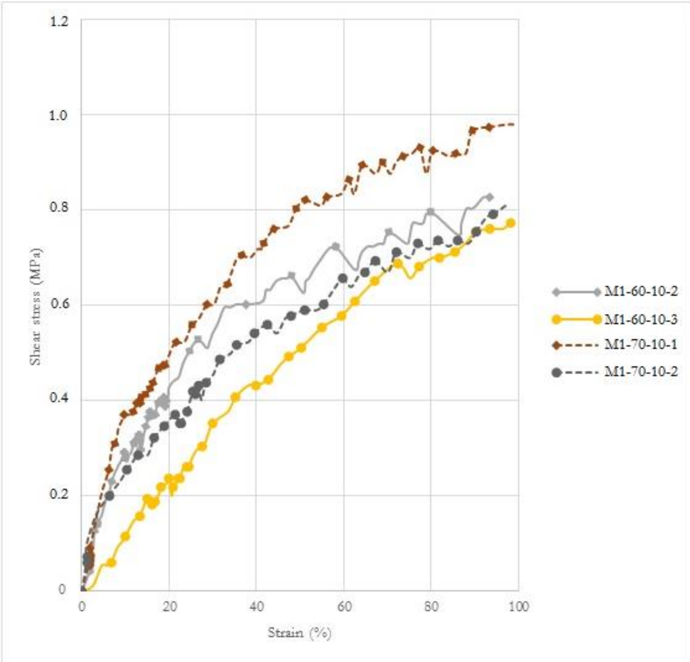
Figure 4-4 Compression-shear test; (a) Specimen dimensions; (b) Actual test setup

4.2.2 Experimental result

Eleven flat joints with elastomeric bearings were tested. Throughout the loading process, none of the specimen exhibits any slippage. The stress-strain curves for both levels of confinement, as shown in figure 4-5 and figure 4-6, shows similar trends. The slope is higher at the beginning and gradually decreases until it reaches 100% strain. The rubbers of hardness 70 have higher shear stress than the rubbers of hardness 60 throughout the loading process.

Final shear stress and shear modulus of all specimens are summarized in table 4-1. Shear modulus is calculated according to ASTM D 4014 (1995). The average final shear stresses for 10 mm-thick rubbers are compared with the results of unsealed joints by Zhou & Mickleborough (2005) as shown in table 4-2. The final shear stress increases with the higher levels of the confinement and hardness. The confinement of 2 MPa yields final stresses 38.03 % and 41.11 % more than those of 1 MPa for rubber hardness level of 60 and 70, respectively. Hardness level of 70 yields final stresses 11.03 percent and 12.51 percent more than hardness level of 60 for confinement of 1 MPa and 2 MPa, respectively. However in all cases, the final shear stress is considerably more than the required shear stress due to the concrete segment and water weights.

The final shear stress comparison in table 4-2 is also plotted as shown in figure 4-7. The shear resisting mechanism of the rubber seal joint is different from that of unsealed joint. The rubber seal joint resists shear by the shear properties of rubber while the unsealed joint resists shear by friction between concrete surfaces. At the lower confinement at 1 MPa, rubber seal joints have higher final shear stress than unsealed joints. At the higher confinement at 2 MPa, rubber seal joints have lower final shear stress than unsealed joints. The shear resistance in rubber grows at the lower rate than the shear resistance from friction.



Note: M1-60-10-1 is an outlier and excluded

Figure 4-5 Shear stress-strain curve of 10-mm-thickness rubber with confinement of 1 MPa

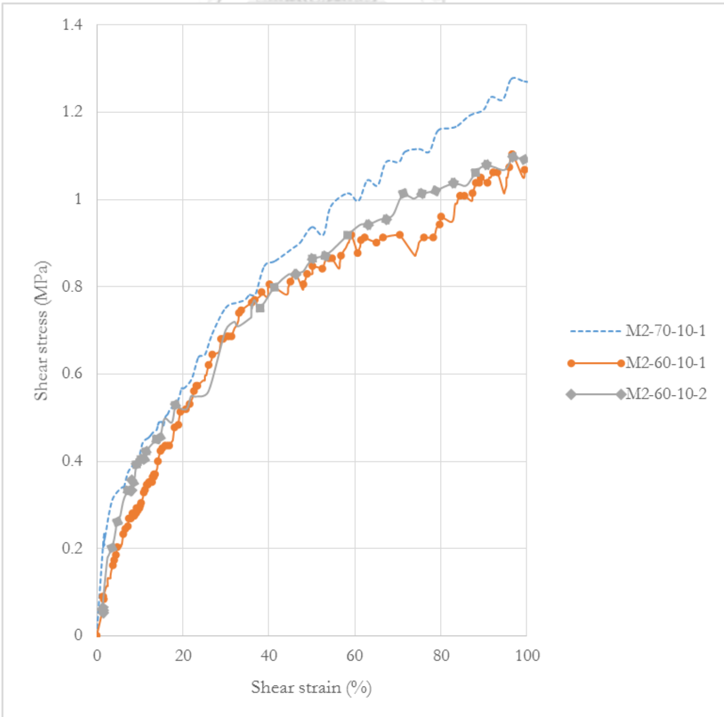


Figure 4-6 Shear stress-strain curve of 10-mm-thickness rubber with confinement of 2 MPa

Table 4-1 Experimental results of compression-shear test on joints

Specimen	Final shear stress* (MPa)	Shear modulus** (MPa)
M1-60-10-1	0.46	1.60
M1-60-10-2	0.81	1.96
M1-60-10-3	0.76	1.01
M1-60-20-1	0.77	0.95
M1-60-20-2	0.66	0.88
M1-70-10-1	0.95	2.05
M1-70-10-2	0.79	1.50
M2-60-10-1	1.06	2.25
M2-60-10-2	1.10	2.68
M2-60-20-1	0.80	0.91
M2-70-10-1	1.23	2.73

*final shear stress is the shear stress at 100% strain

**Shear modulus is calculated by taking the secant modulus from the point of 2% maximum stress to the point at 25% shear strain according to ASTM D 4014 (1995)

Table 4-2 Final shear stress comparison

Confinement	Final shear stress			
	Mx-60-10	Mx-70-10	Unsealed joints	Required shear stress
	MPa	MPa	MPa	MPa
1 MPa	0.78	0.87	0.68	0.13
2 MPa	1.08	1.23	1.47	

*results by Zhou & Mickleborough (2005)

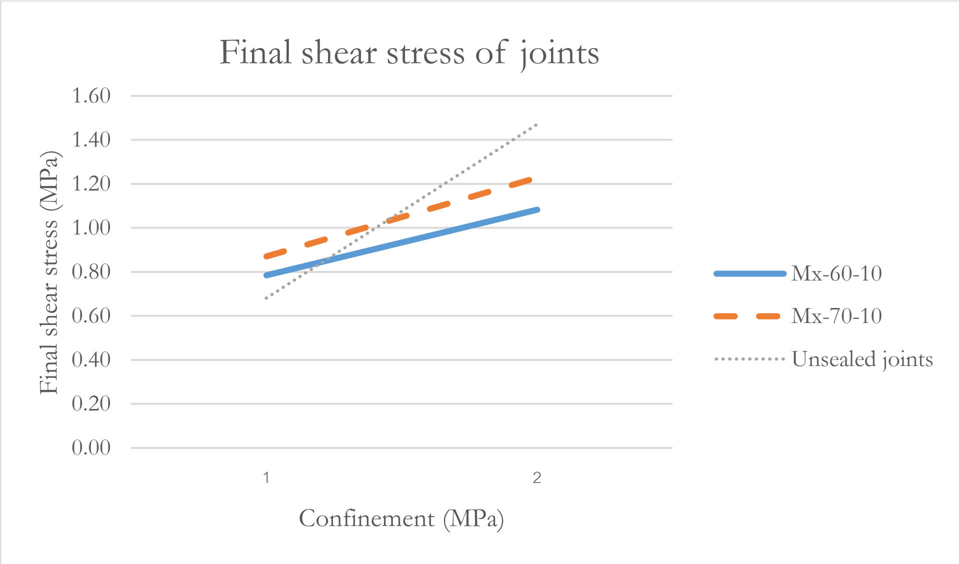


Figure 4-7 Final shear stress comparison

In conclusion, according to figure 4-7, at the confinement level of 1 MPa, rubber helps increase shear capacity of the joint. However, at the confinement of 2 MPa, concrete-to-concrete joint resists higher shear stress than the joint with rubber. According to table 4-2, joints with rubbers of all hardness levels are able to resist higher shear stress than the required shear stress of 0.13 MPa. The criteria of the required shear stress is based on the dimensions of the concrete swimming pool segment which are 2400 mm × 4000 mm × 1500 mm with the thickness of 200 mm and full water level as shown in section 4.1. Trade secret of the precast concrete swimming pool is in table 4.2. Using rubber of hardness 60 with confinement 1 MPa of 0.78 MPa is enough to resist shear stress from the concrete segment prototype of 0.13 MPa. Even we apply elastomeris bearings as rubber seal and normal posttensioning process, these final shear stresses have never been found before.

4.3 Impermeability test

The objective of this study is to investigate appropriate stress distribution on contact surface between concrete and rubber seal for leakage preventive purpose. Both German water permeability standard DIN 1048 and Lopez, Masters, & Bolton

(2010) test setup are not appropriate to our experiment. Hence, we develop our own test setup to simulate the real condition of swimming pool.

4.3.1 Specimens and test setup

The test are conducted with actual water pressure and shear force according to our prototype as shown in figure 4-8. Hence, the test is designed with full depth to simulate shear force from the panels and water weight. The specimen consists of 2 parts which are attached by six Post-tensioning BBR bars as shown in figure 4-9. Two levels of Post-tensioning force are applied on each Post-tensioning BBR bar. Each Post-tensioning force on the first trial is 123.56 kN and on the second trial is 247.13 kN as the posttensioning process is shown in figure 9. One part of the specimen is attached to strong wall with four Post-tensioning BBR bars in order to assume this part as rigid and ensure no horizontal and vertical movement. The vertical force is applied to the other part of the specimen by hydraulic jack and measured by load cell. The magnitude of jacking force, 110.71 kN, computed from to the weight of water and segment of prototype plus shear force carried by rubber seal (required shear stress times contact area of rubber seal). The water is applied to the specimen and observed.

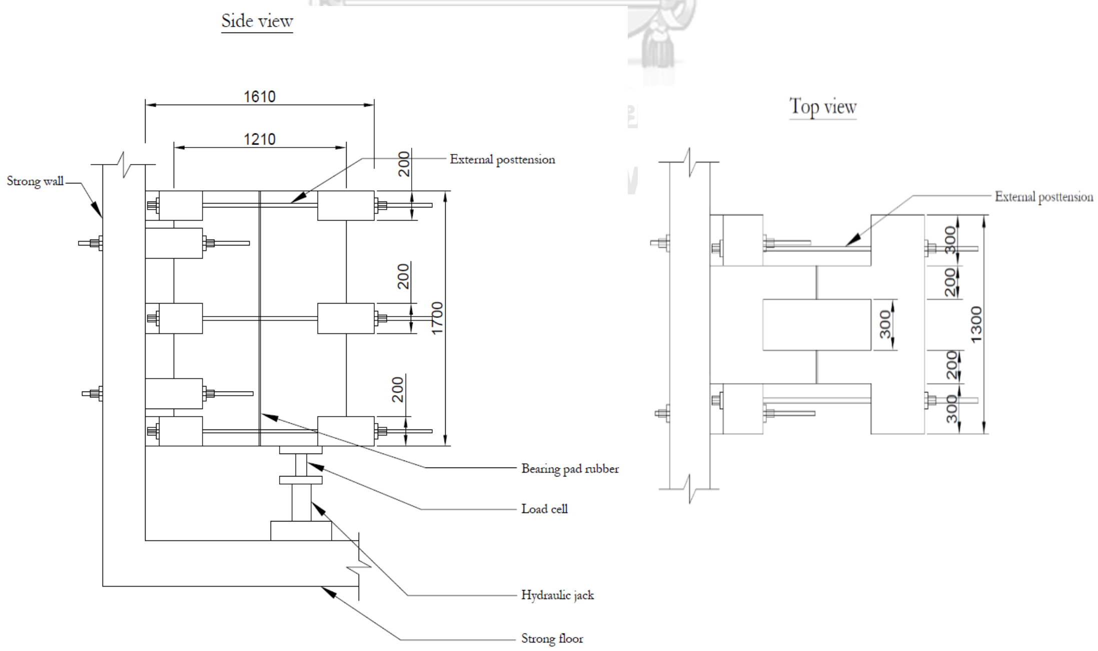


Figure 4-8 Specimen and experimental setup

Figure 4-9 Posttensioning process

4.3.2 Numerical model

Three dimensional finite element models were created using ANSYS. Geometric and material properties were both taken into account. Eight-node hexahedron elements (SOLID185) were used to study stress distribution on contact surface between concrete and rubber seal. Since both concrete and rubber specimens are symmetric volume, the half modelling is used as shown in figure 4-10. The near-strong-wall segment is fixed on x-axis, y-axis and z-axis. The far-strong-wall segment is fixed on only y-axis. The boundary conditions can be described below.

1) At y = -H; given displacement in Y direction equals to zero
2) z = 0 is set as symmetric boundary condition to simplify the model
3) At (x,y) = (0,-H); given displacement in X and Y direction equal to zero to prevent rigid body motion
4) 40 kN post-tensioning forces are applied at 3 positions of this segment as shown in figure 4-10 according to the experimental setup as shown in figure 4-9.

The Materials properties are shown below. The concrete compressive strength is according to the prototype assumption. The rubber Young's modulus, shear modulus and Poisson ratio are according to AASHTO specification, 1992.

Concrete compressive strength = 20 MPa

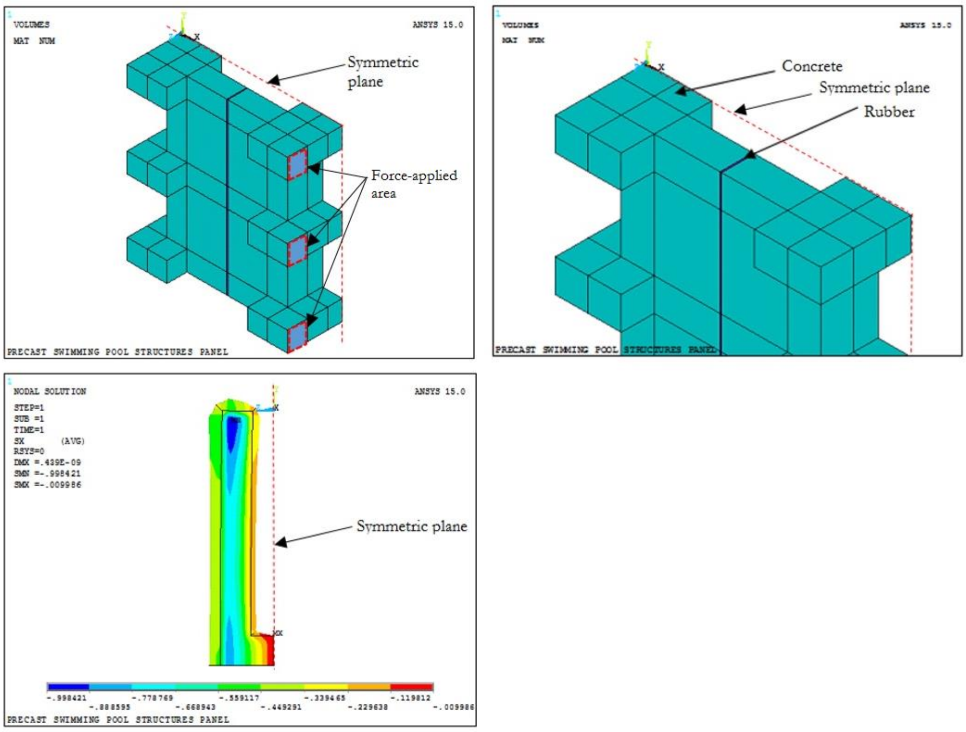
Concrete Poisson ratio = 0.2

Concrete Young's modulus = $4733*\sqrt{f_c'}$

Rubber Young's modulus = 4.5 MPa

Rubber shear modulus = 1.5 MPa

Rubber Poisson ratio = 0.49



Note: Stress value in MPa is shown as 40 kN post-tensioning force is applied

Figure 4-10 Solid volume and stress distribution on rubber surface

In figure 4-10, color chart shows that the post-tensioning force of 40 kN distributes lowest compressive stress at the bottom of the specimen of 0.01 MPa. If we apply 247.13 kN, the compressive stress is 0.06 MPa. As shown in figure 4-11, the stress distribution of rubber is studied on 3 planes which are far symmetric plane, mid thickness and near symmetric plane. Each plane is plotted according to mid rubber and contact surface. Figure 4-12 shows that both far and near symmetric planes have lower compressive stress than mid thickness of concrete segment because of the displacement of rubber along the concrete segment edge. This is similar to the top edge of the concrete segment which has lower compressive stress than the other part of rubber surface. At the same plane, compressive stress at contact surface is higher than those of the mid-rubber position.

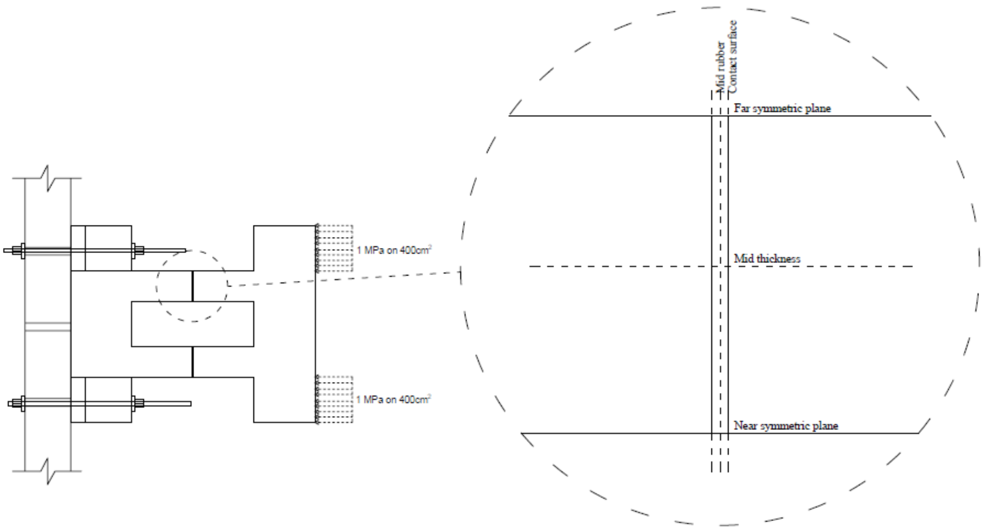


Figure 4-11 Rubber plane explanation

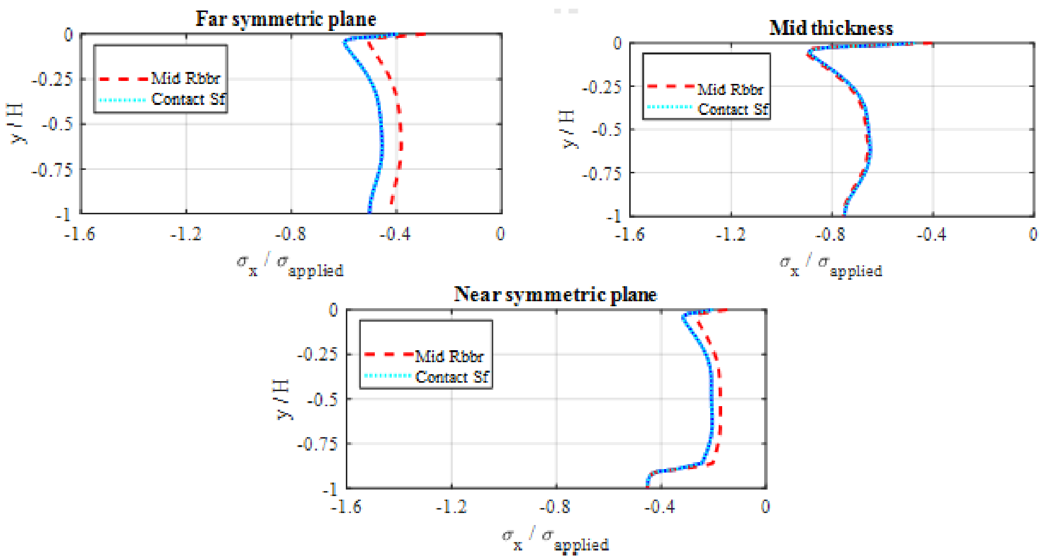


Figure 4-12 Axial stress in X direction of rubber

4.3.3 Experimental result

According to the numerical model, the lowest compressive stress distributes at the bottom of the specimen. However, the actual magnitude of stress might slightly differs from the model since the concrete-rubber contact surface in the simulation is perfectly uniform. On the first trial, the confinement to the rubber seal was induced by the Post-tensioning force of 123.56 kN on each BBR bar. The water level was gradually increased up to 400 mm above the bottom of the specimen. The specimen failed to contain water and it leaked at both sides and at the bottom of the specimen at the rate of 800 ml per minute.

On the second trial, the Post-tensioning force of 247.13 kN was applied on each BBR bar. The water level was gradually increased and the specimen was able to store water until the water level reached 1000 mm. Water leaked only at 6 spots on both sides of the specimen at much slower rate of 40 ml per minute without any leakage at the bottom. However, the waterproof behavior of the rubber seal improved with time as we found only 2 leakage spots 14 days later. Finally at 21 days later, there was no leakage and the specimen was able to store water to its full capacity, up to 1500 mm above the specimen bottom, as shown in figure 4-13.

On the same day, shear stress was applied to the rubber seal to simulate the real condition. A vertical jacking load of 110.71 kN was applied at the far-strong-wall segment. The vertical movement was measured 1.5 mm, and the water leaked at the same 6 spots on both sides of the specimen at rate of 75 ml per minute. Similar to what happen earlier, the waterproof behavior of the rubber seal improved with time as we found only 1 leakage spot left 14 days later. 21 days later, no leakage occurred as shown in table 4-3.

Lastly, at day 90 we decided to unload the vertical force and no leakage occurred. The vertical jacking load was reapplied and no leakage occurred. We unloaded for 30 minutes and applied vertical jacking for the second time. The water leaked at rate of 6 ml per minute for 1 hour. After no leakage left, we decided to unload again for 30 minutes and reapplied vertical jacking for the third time. The water leaked at rate of 40 ml per minute.

Table 4-3 Impermeability test result

	First trial	**Second trial**
Post-tensioning force per BBR bar	123.56 kN	247.13 kN
Day 1	Leakage occurred along both sides and bottom of the specimen at the rate of 800ml/minute	6 spots of leakage occurred at both sides of the specimen at the rate of 40ml/minute
Day 14	-	2 spots of leakage occurred
Day 21	-	no leakage occurred
Day 21 and apply jacking load	-	6 spots of leakage occurred at both sides of the specimen at the rate of 75ml/minute
Day 35	-	1 spot of leakage occurred
Day 42	-	no leakage occurred
Day 90	-	no leakage occurred
Day 90 and apply jacking load	-	no leakage occurred
Unload for 30 minutes and apply jacking load for the second time	-	leakage occurred at the rate of 6 ml/minute for 1 hour
Unload for 30 minutes and apply jacking load for the third time	-	leakage occurred at the rate of 40 ml/minute

(a) (b) (c)

Figure 4-13 Impermeability test (a) Water is filled up to the top level of 1500 mm above bottom; (b) Rubber seal at the connection of the precast segments; (c) Shear stress is applied to the segment by hydraulic jack at the bottom

4.4 Discussion & limitation

In this paper, the precast construction method is adapted to use with the swimming pool structure. Critical problems for such an application are found at the connections between the precast segments, concerning the capability to transfer shear force and the water leakage prevention. Elastomeric bearings are chosen to be used as rubber seals at the connections. Two experiments have been conducted: compression-shear test and impermeability test. Results from the first experiment indicate that elastomeric bearings is capable to resist shear force from precast segment and water weights of the swimming pool prototype. Shear capability of rubber increases with the confinement and hardness level. However, thicker rubbers tend to have lower shear capability than thinner rubbers.

Results from the second experiment indicate that elastomeric bearings can be used as rubber seal to prevent water leakage under our predetermined conditions. There are problems with non-uniform confinement stress in the rubber seal resulted from concentrated prestressing forces and unsmooth concrete surface. However, after the rubber creeps for 21 days, the rubber can fully prevent water leakage.

We note here that this paper limited only at 2 confinement levels for both experiments. The compression-shear test should be revisited at different confinement levels to confirm the relationship between final shear stress and confinement. For impermeability test, the higher confinement level and finished concrete surface may result in a shorter rubber creep time. The findings from this research lead to the new application of elastomeric bearings. This new knowledge can further apply to other kinds of watertight structures or immersed structures such as water tanks, man holes, and basements.

4.5 Model development

Three dimensional finite element models were created to investigate stress distribution on contact surface between concrete and rubber seal. Geometric, solid element and material properties were taken into account. Eight-node hexahedron elements were used to study the stress distribution. Figure 4-14 shows isometric view of the pool. We decided to install parabolic post-tensioning into both end segments in order to prevent ununiformed loading distribution on rubber as shown in figure 4-15.

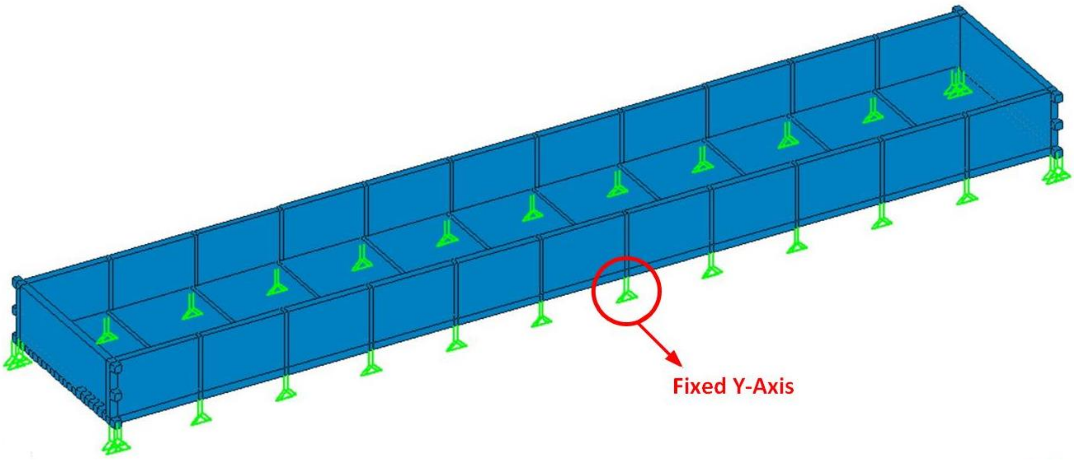


Figure 4-14 Isometric view of swimming pool

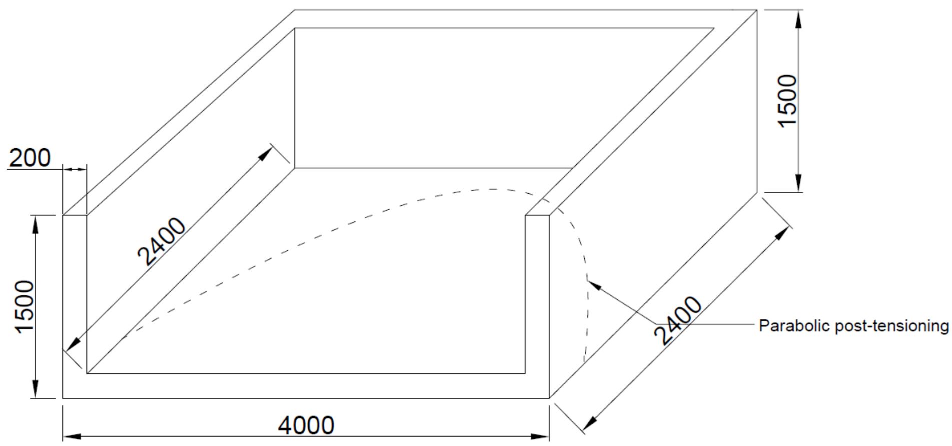
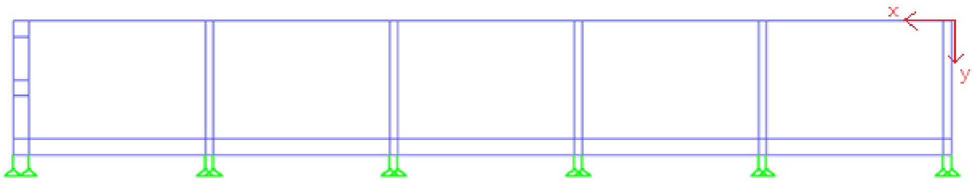
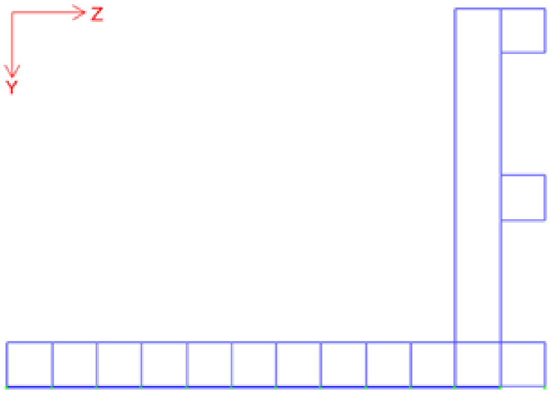


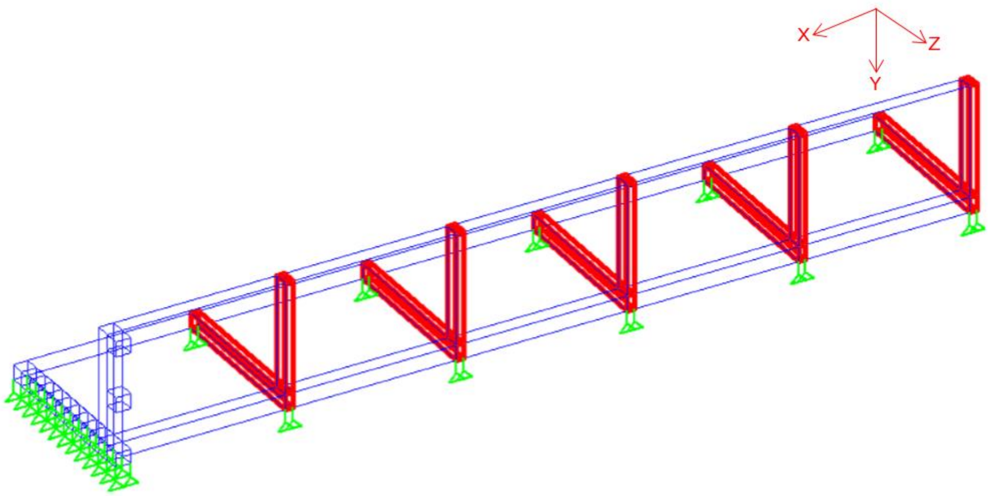
Figure 4-15 Parabolic post-tensioning in edge segment.



(a)



(b)



(c)

Figure 4-16 Quarter modelling of swimming pool; (a) Geometric information on X-Y plane; (b) Geometric information on Y-Z plane; (c) Isometric view of the pool with highlighted rubber

Since both concrete and rubber specimens are symmetric volume in both axis x and axis z, the quarter modelling is used to study the stress distribution as shown in figure 4-16. All segments are fixed on y axis. The boundary conditions can be described below.

1) In figure 4-17, 6.178 MPa parabolic post-tensioning parabolic forces simulate uniformed compressive stress as the calculation is shown in the following page. 6.178 MPa post-tensioning forces are applied at 3 positions on both end segments as shown in figure 4-18.
2) At y = -H; given displacement in Y direction equals to zero for all segments as shown in figure 4-19.
3) z = 0 is set as symmetric boundary condition to simplify the model and x = 0 is set as symmetric boundary condition as shown in figure 4-20.

The Materials properties are shown below. The concrete compressive strength is according to the prototype assumption. The rubber Young's modulus, shear modulus and Poisson ratio are according to AASHTO specification, 1992.

Concrete compressive strength = 20 MPa

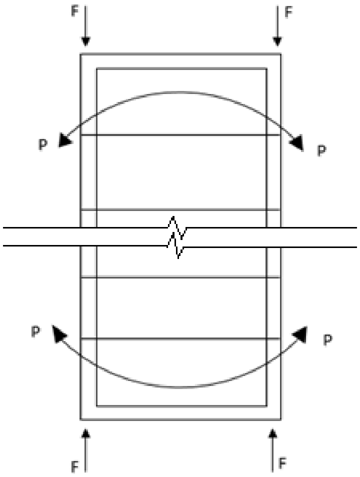
Concrete Poisson ratio = 0.2

Concrete Young's modulus = $4733*\sqrt{f_c'}$

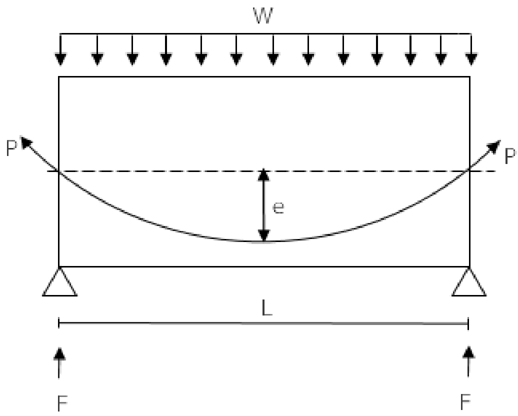
Rubber Young's modulus = 4.5 MPa

Rubber shear modulus = 1.5 MPa

Rubber Poisson ratio = 0.49



(a)



(b)

Figure 4-17 Uniformed compressive stress caused by parabolic post-tensioning; (a) Actual post-tensioning; (b) Uniformed stress

The parabolic post-tensioning causes uniformed compressive stress as the calculation is shown below.

$$Pe = WL^2/8$$

Given P = 247.13 kN

e = 15 cm

L = 4 m

$$W = \frac{(247.13)(0.15)(8)}{(4)^2}$$

= 18.53 kN/m

Thickness = 0.2 m

$$\text{Stress} = \frac{18.53}{(0.2)}$$

= 92.674 kN/m^2

= 0.0927 MPa > required stress 0.06 MPa

$$F = \frac{\square\square}{2}$$

$$= \frac{18.53 \times 4}{2}$$

= 37.06 kN

The applied post-tensioning force = 247.13 kN on 400 sq.cm.

The applied post-tensioning stress = 6.178 MPa

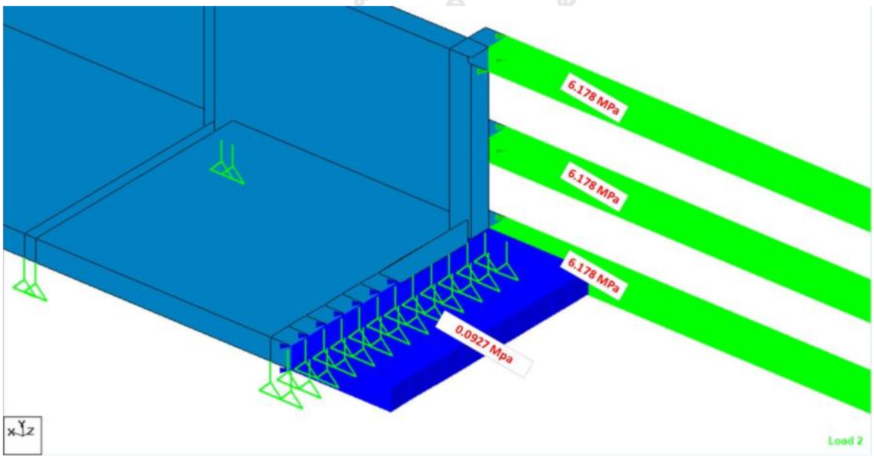


Figure 4-18 Loading condition

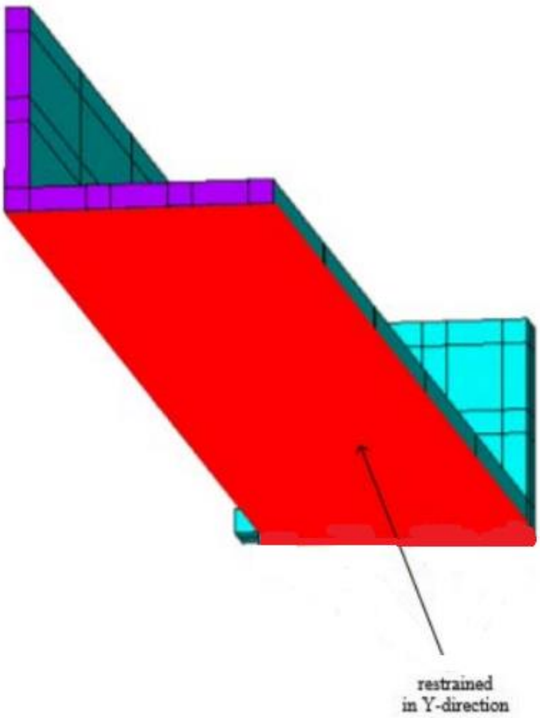


Figure 4-19 Support condition at base

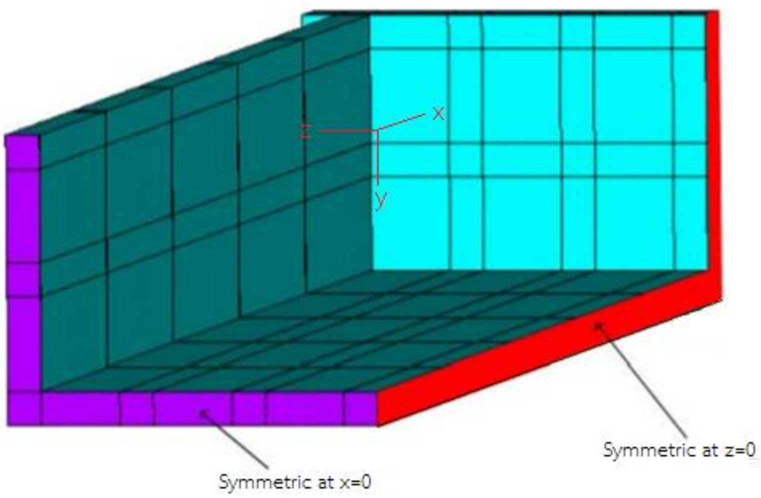


Figure 4-20 Symmetric boundary condition

Figure 4-21 shows the definition of rubber from rubber 1 to rubber 5 starting at the nearest rubber to the edge segment. Figure 4-22 shows stress paths definition. We study 6 paths which are path 1, 2 and 3 on vertical axis and path 4, 5 and 6 on horizontal axis.

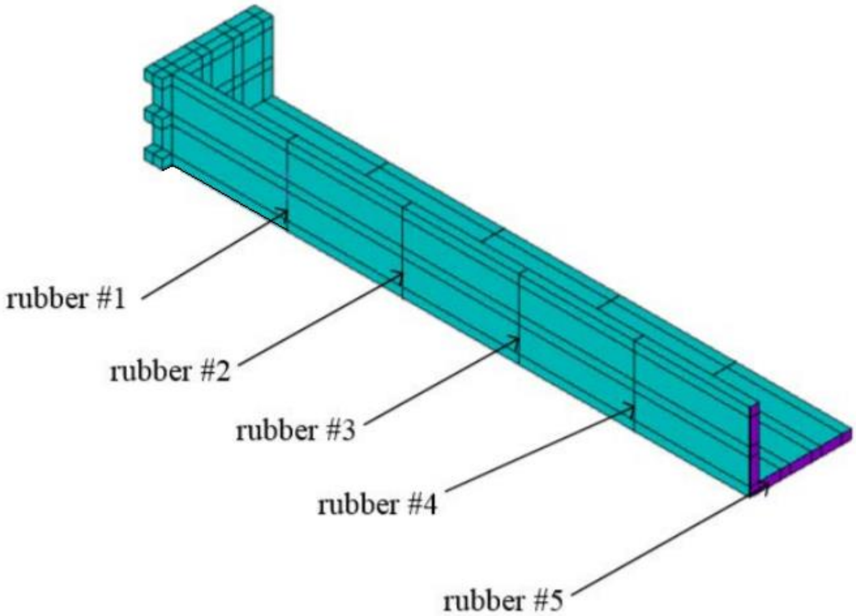


Figure 4-21 Rubber designation

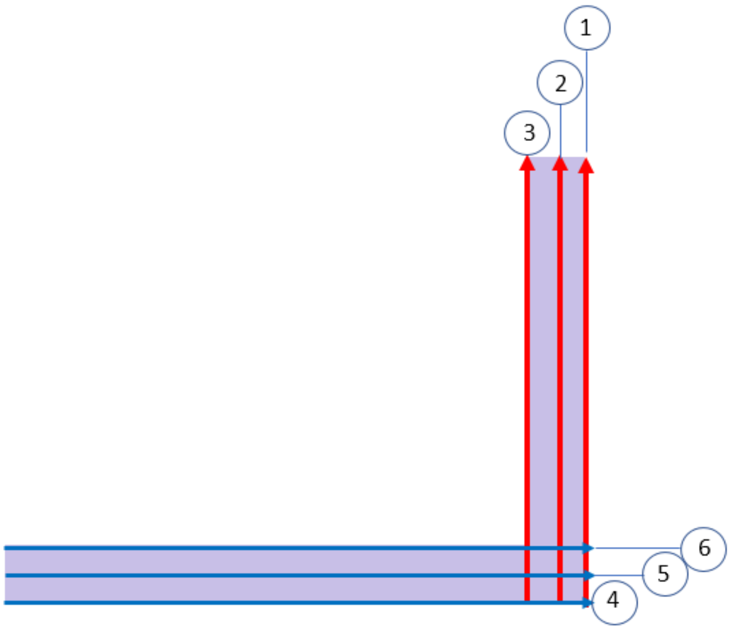


Figure 4-22 Stress paths definition

In figure 4-23 to figure 4-27, color charts show that the post-tensioning force distributes more uniform compressive stress on all 5 rubbers. The parabolic post-tensioning force helps uniformed stress distribution. The minimum compressive stress is in horizontal part of rubber#5 at 1.23 MPa in path 4 which is above the minimum compressive stress on rubber at 0.06 MPa of section 4.3.3.

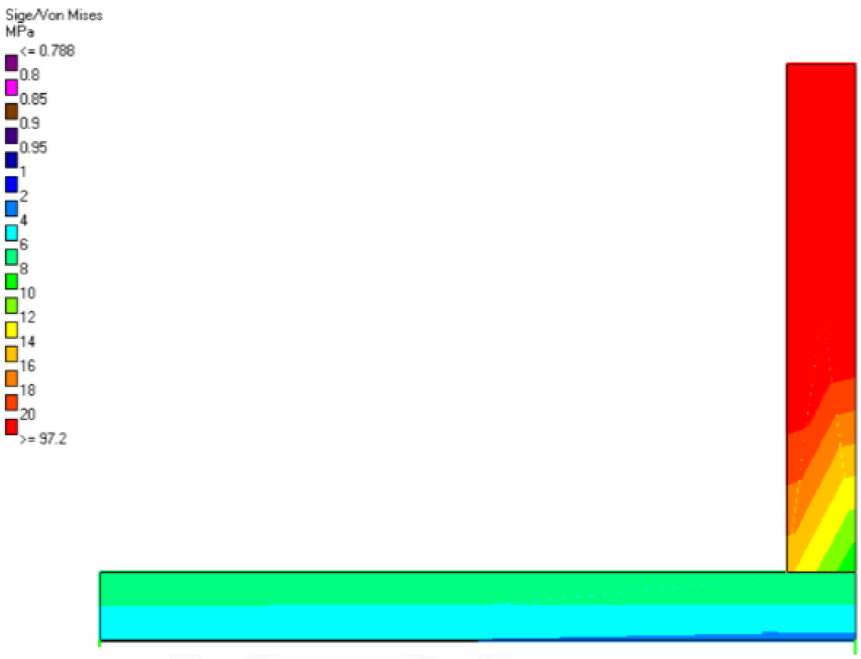


Figure 4-23 Stress contours at the mid-thickness region of rubber #1

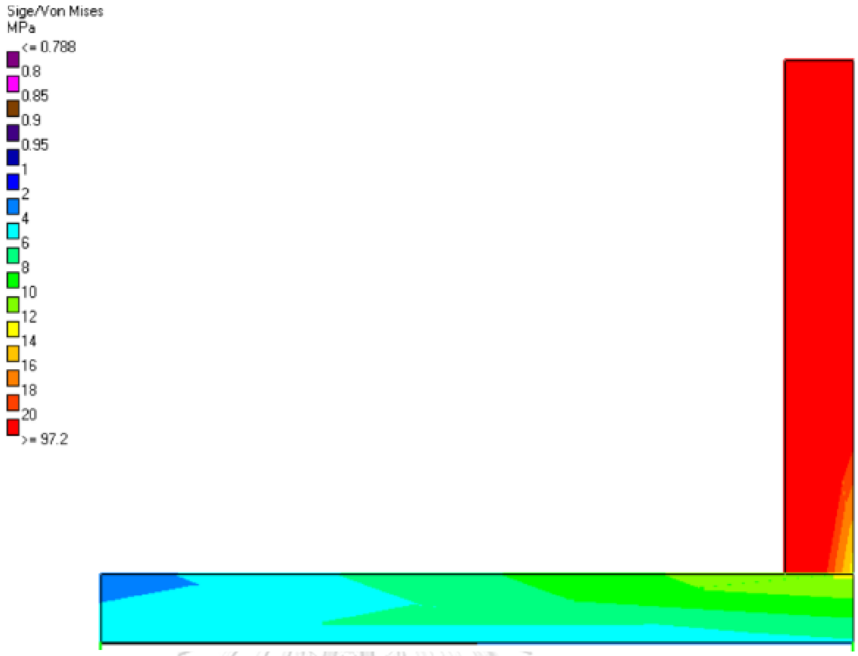


Figure 4-24 Stress contours at the mid-thickness region of rubber #2

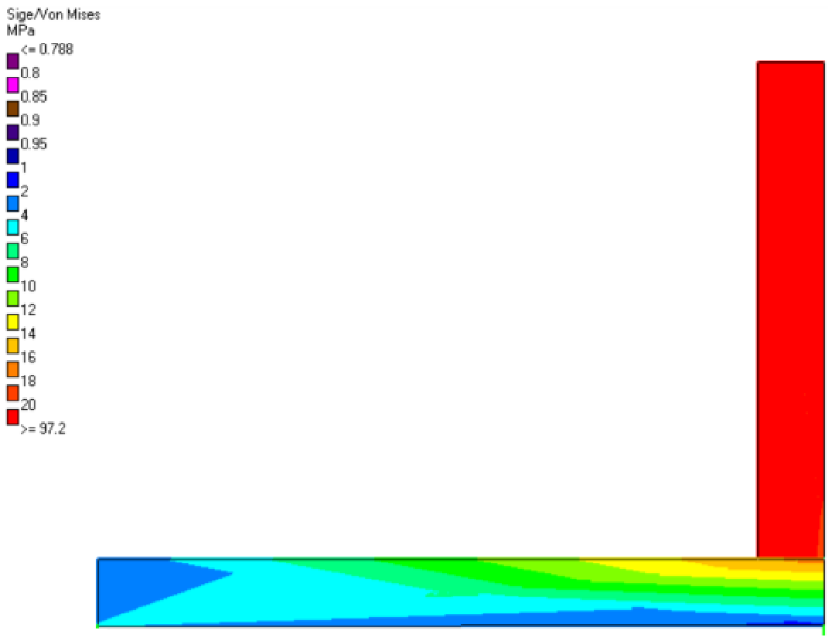


Figure 4-25 Stress contours at the mid-thickness region of rubber #3

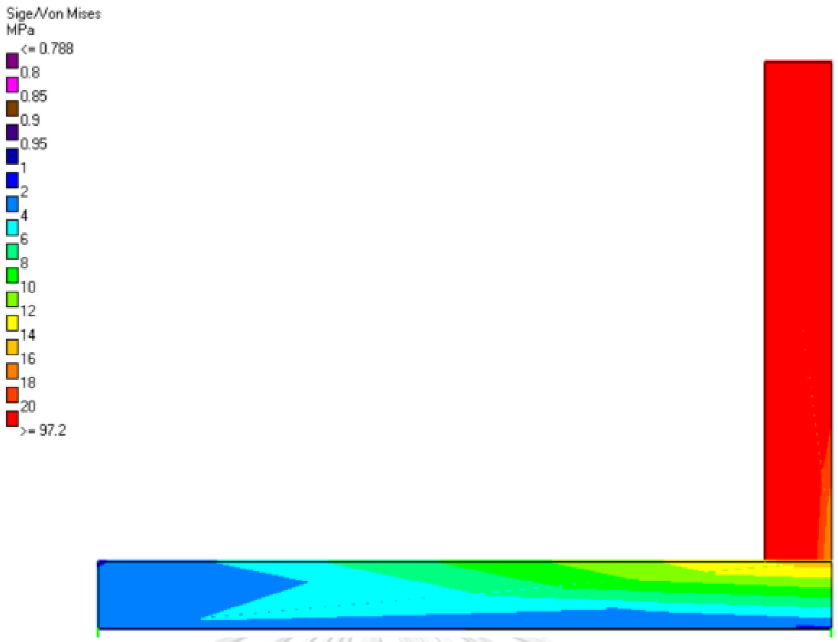


Figure 4-26 Stress contours at the mid-thickness region of rubber #4

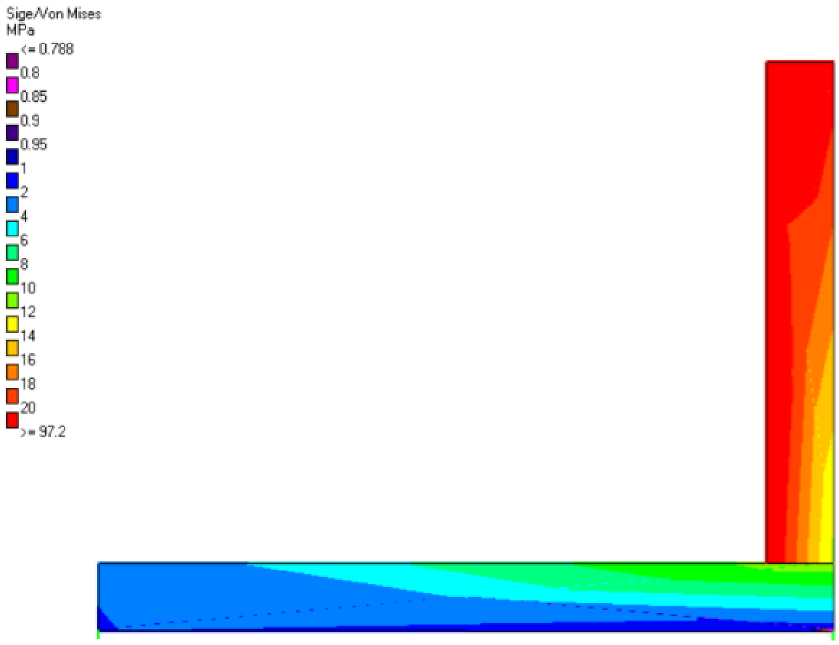


Figure 4-27 Stress contours at the mid-thickness region of rubber #5

According to stress path definition in figure 4-22, compressive stress is plotted into 6 paths for 5 rubbers. The stress is highest in rubber 1 and lowest in rubber 5 similar to color chart as shown in figure 4-28, 4-29, 4-30, 4-31, 4-32 and 4-33.

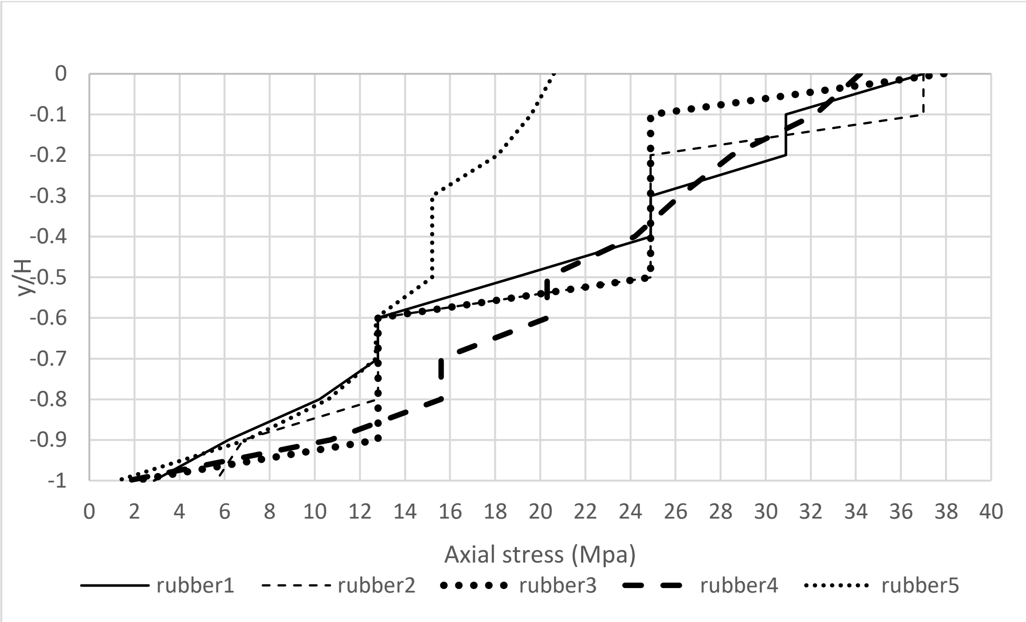


Figure 4-28 Stress distribution along the path No.1

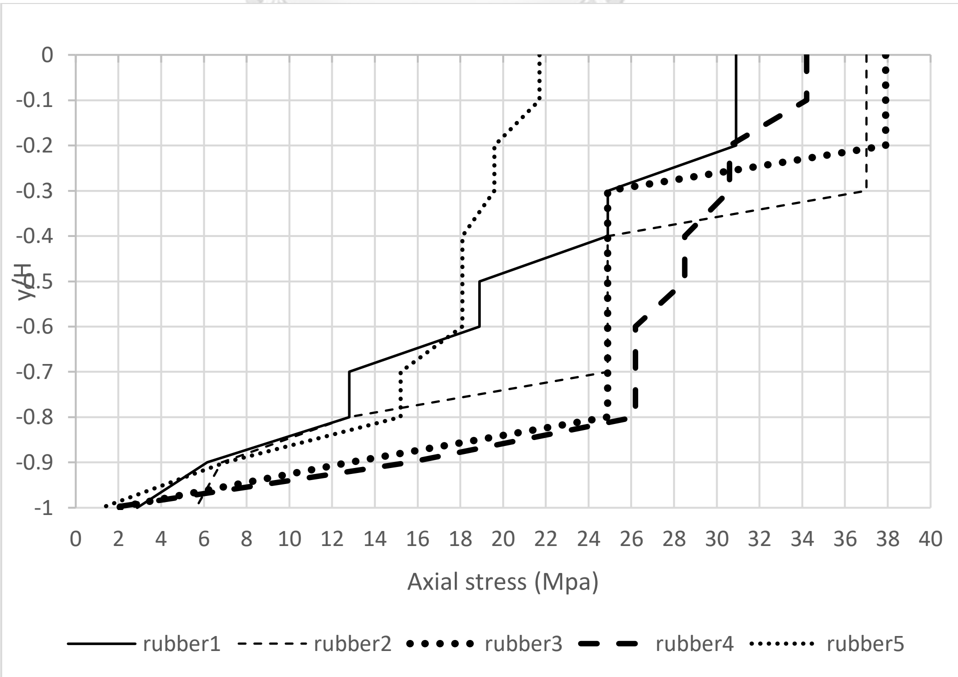


Figure 4-29 Stress distribution along the path No.2

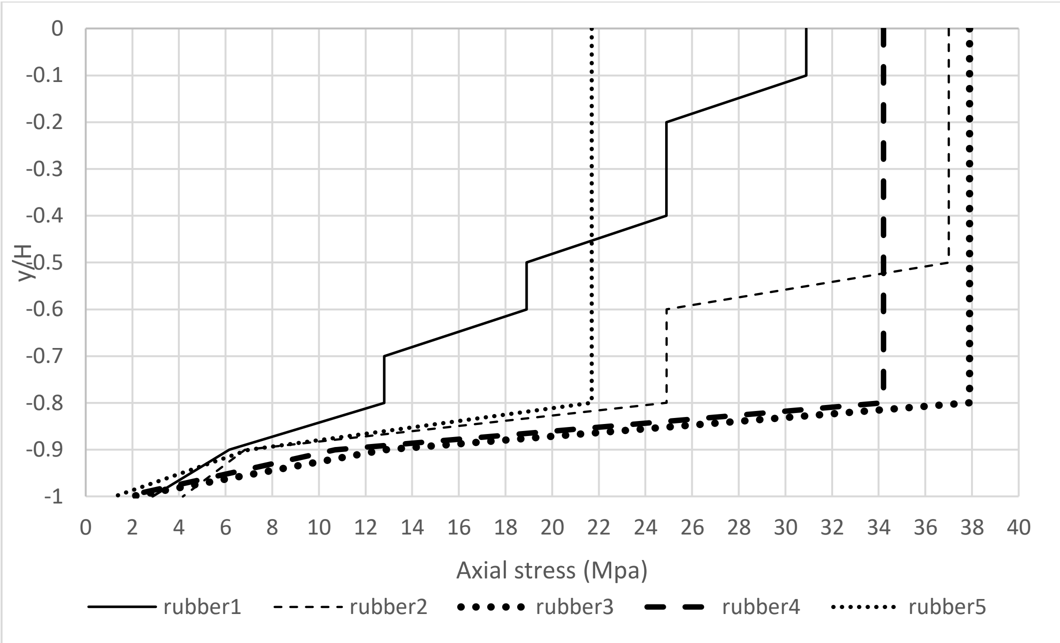


Figure 4-30 Stress distribution along the path No.3

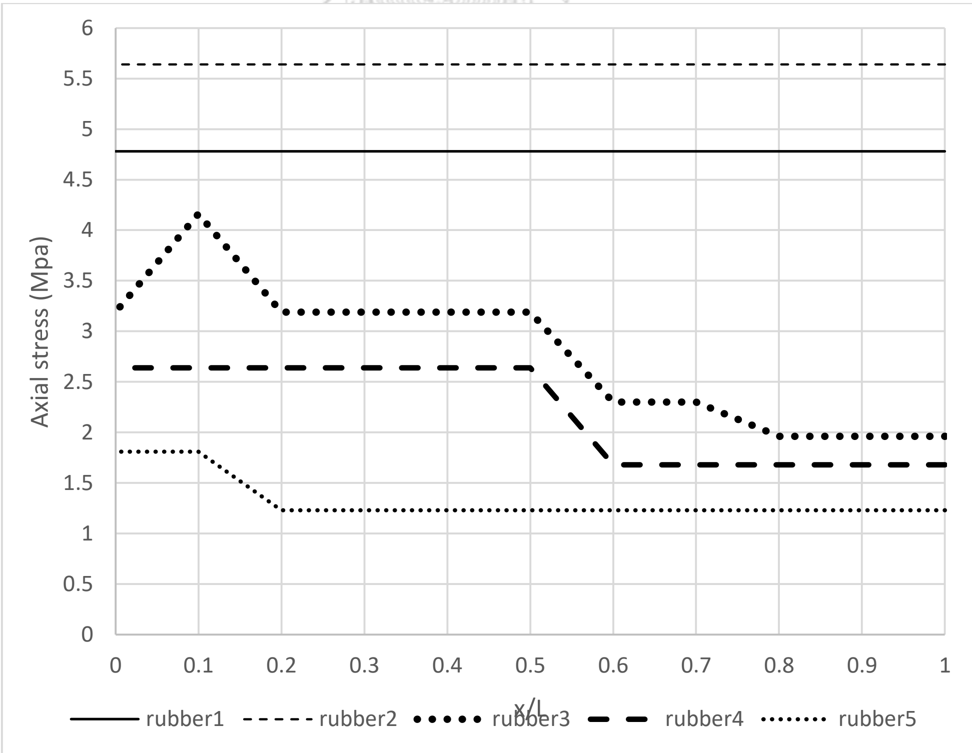


Figure 4-31 Stress distribution along the path No.4

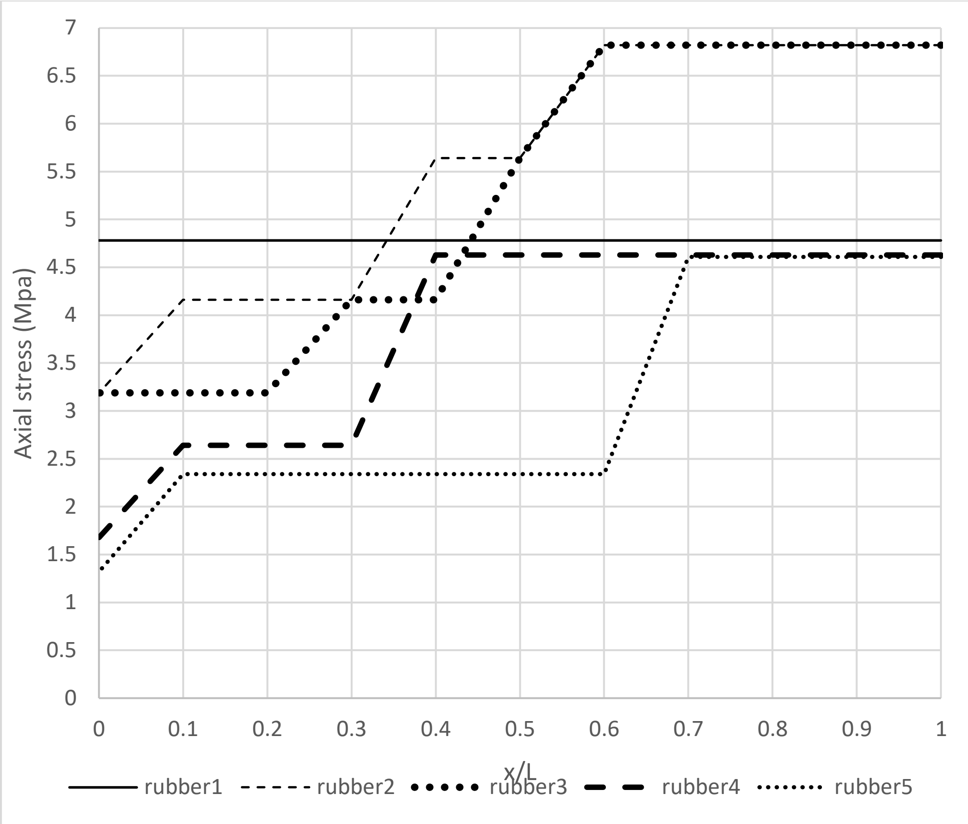


Figure 4-32 Stress distribution along the path No.5

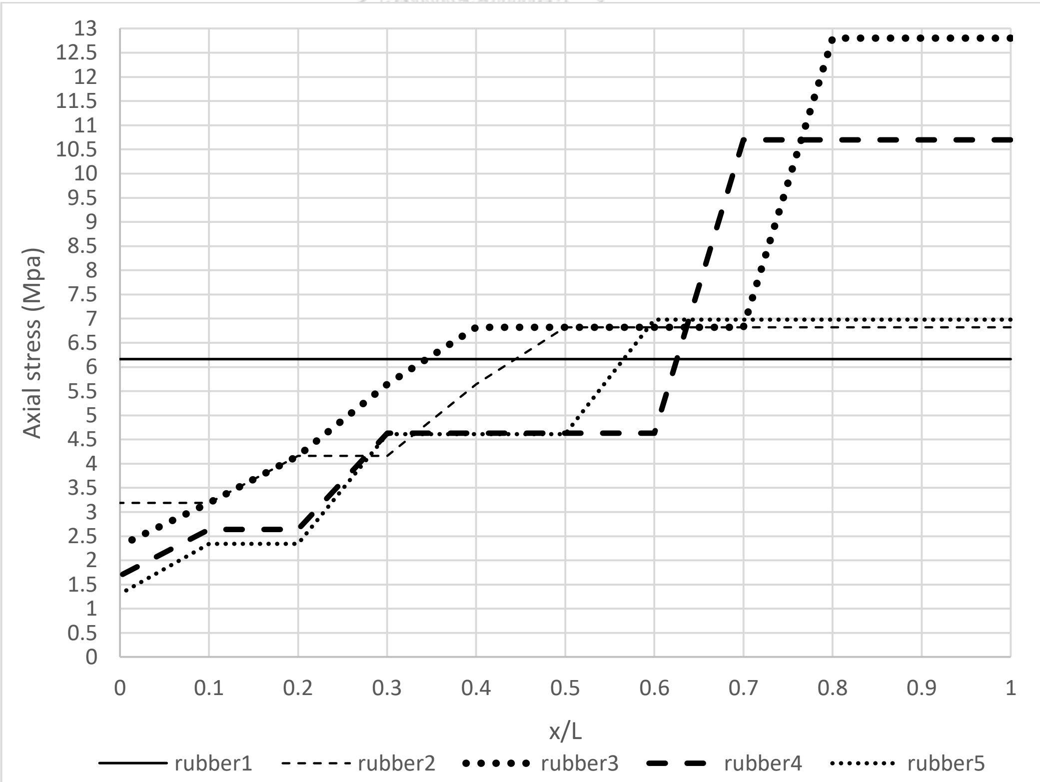


Figure 4-33 Stress distribution along the path No.6

According to the result from section 4.3.3, the minimum compressive stress that prevent water leakage at any point on contact surface is at 0.06 MPa. We conducted this model simulation to assure that the minimum compressive stress on rubber between the actual-size swimming pool segments is higher than 0.06 MPa. The minimum compressive stress is in rubber#5 path 4 at 1.23 MPa which is above the minimum compressive stress on rubber at 0.06 MPa.

CHAPTER V

BUSINESS PLAN

5.1 Business environment analysis

5.1.1 Company background and project rationale

Our company is founded in 2005. We specialize on civil engineering and construction. Our 2 main business units are plant construction contractor and housing development. Figure 5-1 shows our work on a 16000-sq.m. food plant at Bhuddamonton sai 7 in 2008 and Figure 5-2 shows our construction work of the second housing project namely “The Season Phetkasem 69” in 2013. In 2015, after we finished 3 projects of housing estate, each project consists of the structure of swimming pool which consumes time and relies heavily on workmanship. More importantly, it is also accountable for the total time of the whole project which is the critical problem for all construction contractors. Hence, we found this great opportunity to decrease both cost and time of swimming pool structure especially the time of the whole project. That is the reason why we initiate “structural system for precast concrete swimming pool”. Figure 5-3 shows the swimming pool in our second project clubhouse.

Figure 5-1 Our previous construction work on a 16000-sq.m. food plant at Bhuddamonton sai 7

Figure 5-2 The second housing estate project namely “The Season II Phetkasem 69”

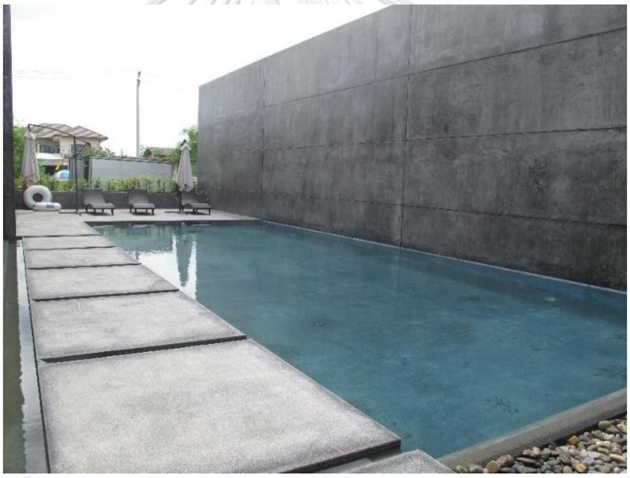
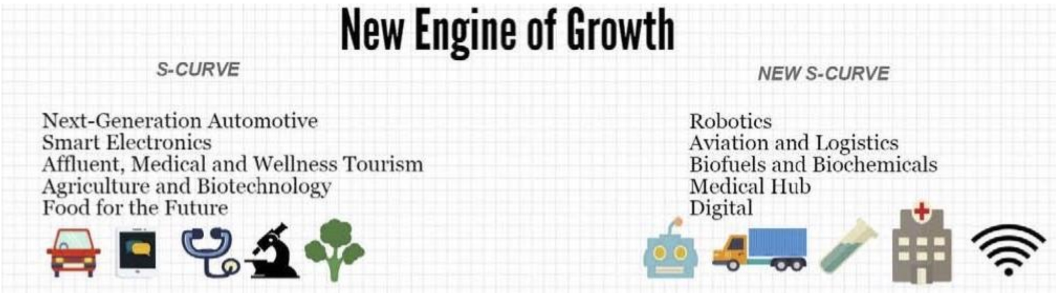


Figure 5-3 The swimming pool in our second project clubhouse

In term of human resource, our company already has 10 civil engineers plus 30 engineering-related staffs including 5 foreman supervisors and 25 masons who specialize on civil engineering field and construction. Hence, to initiate this project is found comparatively easier for us and we can hire staffs from our headquarter at daily rate.

5.1.2 Macro analysis

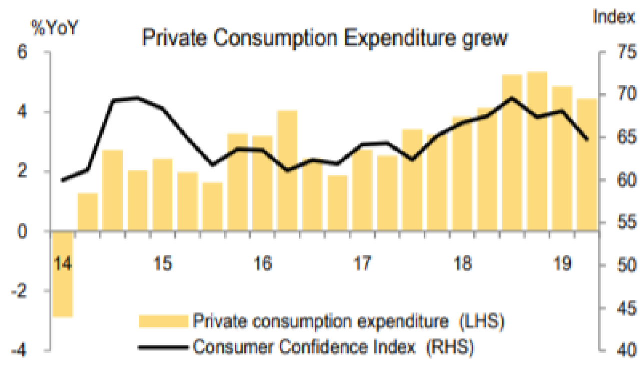
5.1.2.1 Politics – Due to political uncertainty, since 2005 Thailand has been repeating in protest, coup and re-election. Thai government’s policies have been changed frequently during this decade. Ten clusters that the government and Board of Investment (BOI) support are next-generation automotive, smart electronics, medical and wellness tourism, biotechnology, food, robotics, aviation and logistics, biofuel and biochemical, medical hub and digital industry as shown in figure 5-4. Moreover, the latest government policies to promote and support economy does not include construction technology and domestic accommodation in their plan. Hence, there is only neutral political impact to our project.



Source: Division of Economic Information, Department of International economic affairs, Ministry of Foriegn Affairs, Thailand

Figure 5-4 The latest Thai government policy called "Thailand 4.0" promoting 10 industries

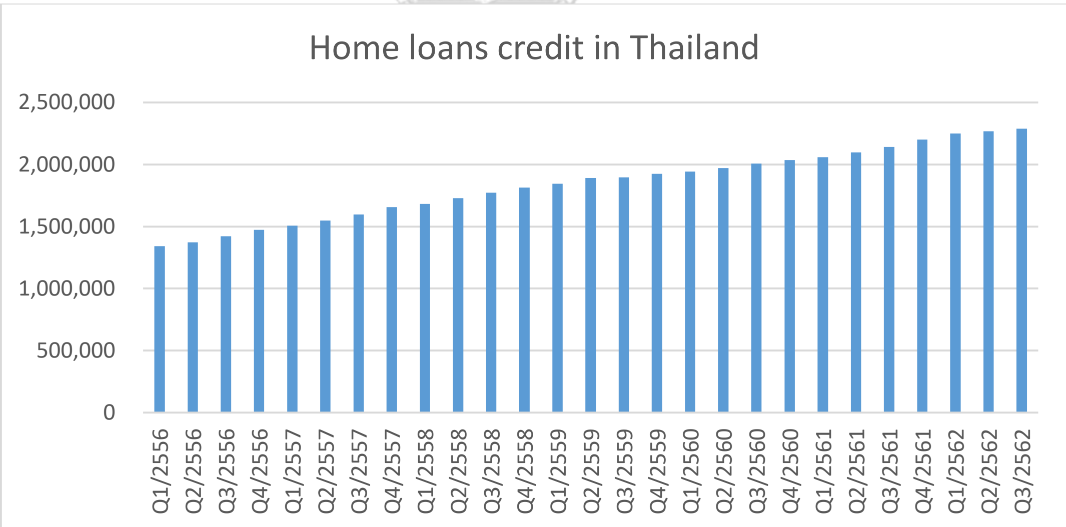
5.1.2.2 Economic – Real estate industry in Thailand had been growing continuously from 2017 to 2018. In the first and second quarter of 2019, private consumption expenditure expanded by 4.9 and 4.4 percent respectively. In the first and second quarter of 2019, private consumption expenditure expanded by 4.9 and 4.4 percent respectively which are better than private consumption expenditure in 2017 and 2018 as shown in figure 5-5. Moreover, The Bank of Thailand lowered the policy interest rate 25 bps in August 2019 and in November 2019 to 1.25 percent which enhance the consumption expenditure and a positive factor for the real estate sector.



Source: NESDC, University of the Thai Chamber of Commerce

Figure 5-5 Private consumption expenditure and consumer confidence index

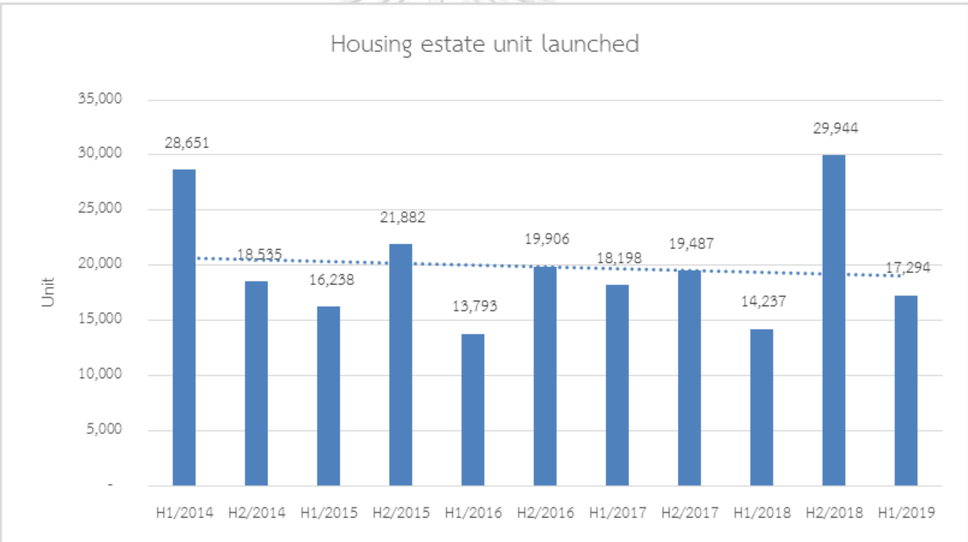
According to the Bank of Thailand, as shown in figure 5-6, the amount of home loans in quarter 3 of 2019 was valued at 2.28 trillion Baht which increase by 6.5% compared to quarter 3 of the previous year and increase by 14% compared to quarter 3 of 2017. In term of housing demand, this is considered as a continuous growth of housing purchases while interest rates are still low.



Source: Bank of Thailand

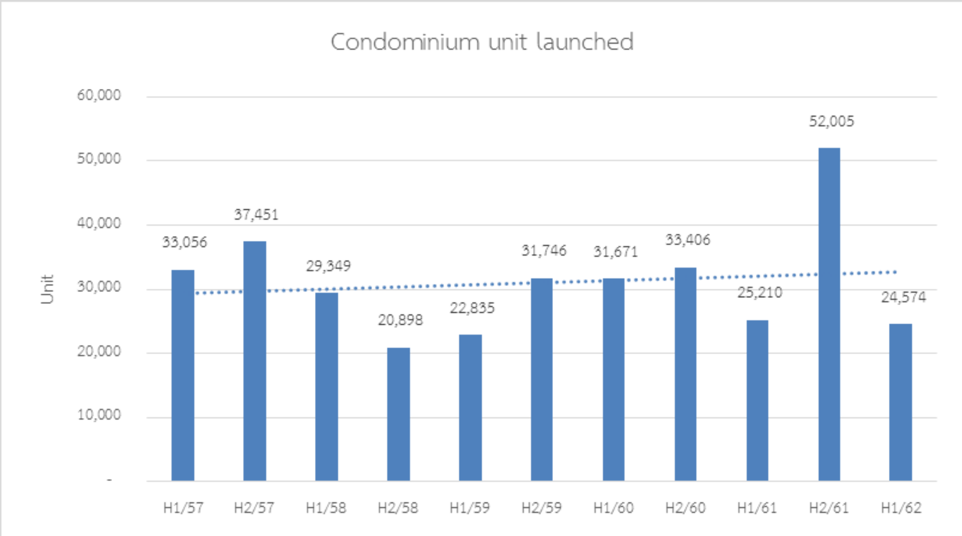
Figure 5-6 Home loan credits in Thailand

According to government housing bank, housing estate launched in the first half of 2019 increase from those in the same period of 2018 as shown in figure 5-7. However it is found fluctuated when it is compared with the same period throughout these 6 years and the trend line of housing estate launched is found as a gradual decline. In contrast to condominium unit launched, it is found an incline trend during these 6 years as shown in figure 5-8 and this is normal according urbanization trend of Bangkok city. The number of condominium unit peaks in the second half of 2018. The results from these 2 graphs reflect neutral effect on condominium launched and housing estate launched since there is no significant sign of real estate crisis or immediate decline in housing and condominium launched.



Source: Realestate information center, Government housing bank, Thailand

Figure 5-7 Housing estate unit launched in Bangkok and suburban area



Source: Realestate information center, Government housing bank, Thailand

Figure 5-8 Condominium unit launched in Bangkok and suburban area

5.1.2.3 Social – Urbanization in Bangkok seems to be irresistible. The population of Bangkok has been increasing throughout 70 years. Even there is a sign of decelerated growth in population, it is predicted by United Nation that the population is continuously increase until 2035 at 12.6 million citizens as shown in table 5-1. Consequently, it is considered as positive effect towards Bangkok accommodation real estate. While, the number of condominiums and housing accommodations has to increase following another 2.1 million citizens in 2035, our project can serve this positive demand for at least 16 years.

Table 5-1 Bangkok population forecast by United Nation

Year	Population	Growth Rate (%)	Growth
2035	12,679,614	0.94%	579,002
2030	12,100,612	1.21%	708,908
2025	11,391,704	1.57%	852,289
2020	10,539,415	1.83%	189,211
2019	10,350,204	2.43%	947,433
2015	9,402,771	2.60%	1,133,726
2010	8,269,045	2.60%	997,029
2005	7,272,016	2.60%	876,587
2000	6,395,429	0.87%	272,035
1995	6,123,394	0.78%	234,559
1990	5,888,835	2.21%	609,708
1985	5,279,127	2.25%	555,984
1980	4,723,143	4.22%	881,120
1975	3,842,023	4.32%	732,078
1970	3,109,945	3.77%	525,479
1965	2,584,466	3.74%	433,613
1960	2,150,853	4.67%	439,147
1955	1,711,706	4.71%	351,706
1950	1,360,000	0.00%	

Source: United Nation World Urbanization prospect

5.1.2.4 Technology - In construction field, precast construction system is commonly used for many decades worldwide. Modern high-rise buildings, houses and bridges employ this system. Precast construction system has advantages over cast-in-situ system on many aspects: less on-site construction time, less curing time, less energy and water consumption, lower environmental impact and lower overall construction cost [อ้างอิง]. Moreover, on quality aspect, cracks and leakages are still found in cast-in-situ system since the quality of work heavily relies on workmanship and the frequent problems are segregation, under-consolidation and improper curing process. Consequently, precast system is increasingly utilized and continuously replacing the use of cast-in-situ system. However, it is not applicable for immersed structures since the leakage prevention is the major concern. Hence, this is an opportunity to introduce immersed precast structures while normal precast structures are well accepted in this era. Figure 5-9 shows differences of swimming pool working process between traditional system and our precast system.

(a) (b) (c)

Figure 5-9 Comparison of swimming pool working process between traditional system and our precast system; (a) working process of traditional construction system; (b) and (c) working process of our precast construction system

5.1.3 Five-force analysis

1) Bargaining power of customers (strong force)

- Backward integration (weak force) – Our customers are the construction contractors, the only way to do backward integration in to have their own factories or on-site casting. It is unlikely to do both ways because of their limitation of time and size of on-site working area. It is impossible to devote limited working area for casting precast structures. Moreover, it is impossible for them to do backward integration in at least 5 years since it takes time to acquire academic knowledge of our product.

- Big size of individual buyers (strong force) – There are few number of big individual buyers. From the population of 9 listed condominium developer public companies. There are 16 construction contractor companies which are operating condominium construction for them as shown in table 5-2. These 16 companies are accountable for all 59 projects in Bangkok. Hence, we must ensure the best quality and customer service to keep these few customers with us.
- Substitute availability (strong force) - Even we offer the better product in terms of lower time of installation and lower cost, the quality of product still essentially matters.

Table 5-2 16 construction contractor companies which are operating construction for 9 SET listed condominium developer public companies

Company Name	List of Contractors (Condominium Project)
L.P.N.	1. Lumpini Project Management Service Co., Ltd. (LPS)
AP	1. SQE Construction Co., Ltd. 2. Syntec Construction Public Co., Ltd. 3. Construction Lines Co., Ltd.
Ananda	1. Helix Co., Ltd. 2. A Build Management Co., Ltd. 3. Pre-Built Public Co., Ltd.
LH	1. Ritta Co.,Ltd. 2. Syntec Construction Public Co., Ltd. 3. Construction Lines Co., Ltd. 4. Pre-Built Public Co., Ltd.
Sansiri	1. Ritta Co.,Ltd. 2. Construction Lines Co., Ltd. 3. Si Pharaya Construction Co.,Ltd.
SC Asset	1. Ritta Co.,Ltd. 2. Uwork 999 Co., Ltd. 3. A Build Management Co., Ltd. 4. Construction Lines Co., Ltd. 5. Koranit Construction Co.,Ltd. 6. Pre-Built Public Co., Ltd.
Supalai	1. Syntec Construction Public Co., Ltd. 2. Construction Lines Co., Ltd. 3. KTech Construction Public Co., Ltd.
Noble	1. Syntec Construction Public Co., Ltd. 2. Power Line Engineering Public Co., Ltd.
Origin	1. Enlighten Project Management Co., Ltd. 2. Natnicha Co., Ltd.

2) Bargaining power of suppliers (weak force)

- High variety of suppliers (weak force) - Our main raw materials are concrete and steel, we currently have a long-term-fixed-price contract with at least 2 suppliers in each category. After the contract ends, there are many suppliers available in the market. All contract with suppliers are as follow;

a) Concrete – Our company has contract that fixes price with 2 concrete suppliers from 2018 to 2020 namely Kanjana concrete and Fast concrete at THB 1820 per cubic meter.

b) Steel - Our company has contract that fixes price with a steel supplier from 2018 to 2020 namely Sarpsomboon at THB 19.04 per kilogram.

c) Rubber seal - Our company has contract that fixes price with a rubber seal supplier at THB 4000 per piece.

- Forward Integration (weak force) - Moreover, it is impossible for them to do forward integration in at least 5 years since it takes time to acquire academic knowledge of our product.

- Large overall supply (weak force) - The large overall supply lessens the effect of any single supplier on the company. This means that these materials are available everywhere and no shortage of them.

3) Threat of new entrants (weak force)

- High cost of doing business (weak force) - There are 2 types of new entrants which are the completely new entrants and the new entrants who are already in the construction industry. We have advantage on the completely new entrants since we already have knowledge and human resource in construction industry for 14 years. Hence, it is costly for those completely new to develop competitive business. For the new entrants who are already in the industry. Even they have human resource, it takes time to develop such academic knowledge and execute the project.

4) Competitive rivalry (weak force) – There is no immersed precast factory in this region. The precast concrete swimming pool structure is totally new to the market. Apart from concrete structure, there 2 available alternatives of swimming pool structure which are vinyl structure and fiberglass. We conducted an in-depth

interview with composite material and swimming pool expert who is an engineering instructor at Chulalongkorn University and let him compare major attributes and limitations between 3 types of structure as shown in table 5-3. Both vinyl and fiberglass are not preferred by architects since their limitation on finishing and size. However, our precast model is better than the traditional concrete structure in terms of cost, installation time, quality-controlled and waste reduction.

5) Threat of substitution (weak force) – There is no newer technology of immersed precast structure or precast swimming pool structure.

5.1.4 Risk plan

To avoid rival imitation, we have to apply for a patent at Department of intellectual property (DIP) via Chulalongkorn University Intellectual property institute (CUIP). Since we use common elastomeric bearings as rubber seal, it cannot be licensed on the new application of existing elastomeric bearings. Instead, the installation process using elastomeric bearings has to be patented. The procress includes joint design, segment design, contact surface, the use of elastomeric bearings and external posttensioning.

Table 5-3 Properties comparison between 3 types of swimming pool structure by in-depth interview with composite material and swimming pool

	Concrete structure	Vinyl liner structure	Fiberglass (composite structure)	Precast structure
Cost of structure size 4meter x 10meter	THB 286k	THB 200-300k	THB 126k	THB 190k
	Plus finishing THB 82-246k	plus liner THB 328k		plus finishing THB 82-246k
Cost of pile work	THB 300k	THB 300k	THB 300k	THB 150k
Total cost	THB 668-832k	THB 828-928k	THB 426k	THB 422-586k
Construction time (not include pile or supports)	15-30 days	7 days	1 day	1-3 days
Factory controlled quality	Low	Medium	High	High
Customized shape	Flexible	Partially flexible	Fixed size, only arch angle and maximum length of 10 meters	Flexible
Architect preference	Most frequent use	Least preferable	Least preferable	Most frequent use
Load bearing	Concrete structure	Concrete structure	Fiberglass (composite structure)	Concrete structure
Leakage prevention material	Concrete	PVC	Fiberglass	Concrete
Material life time	50 years	10 years	30 years	50 years
Other benefit	-	-	Waste reduction	Waste reduction

5.1.5 SWOT analysis

1) Strength – Firstly, our company already has 10 civil engineers plus 30 engineering-related staffs including 5 foreman supervisors and 25 masons who specialize on civil engineering field and construction. Hence, to initiate this project is found comparatively easier for us in term of human resource and we can hire staffs from our headquarter at daily rate. Secondly, we currently have housing projects in hand which consist of swimming pools. Hence, we can try and implement our precast structure on our projects and invite potential customer for fabrication exhibition. Thirdly, we already have steel formwork which fully depreciated. Hence, the cost of formwork is zero. Lastly, since there is no need for recruitment, we have less time for preparation to start the project.

2) Weakness – We have never been a manufacturer. We have to acquire new knowledge on assembly line and production line for the highest efficiency. Moreover, we have to change our stakeholder position. In other words, our current competitors are our new customers. We have to contact and introduce them our new product.

3) Opportunity – According to Macro analysis and Five-force analysis, economic evidence shows that the amount of home loans and new condominium launched continuously increase throughout these 5 years and the trend line shows a similar increasing trend. Moreover, Bank of Thailand also decrease policy interest rate to encourage home loan. For the social factor, it is predicted by United Nation that the population is continuously increase until 2035 at 12.6 million citizens and the number of condominiums and housing accommodations has to increase following another 2.1 million citizens in 2035, our project can serve this positive demand for at least 16 years. From technological perspective, precast construction system is commonly used for many decades worldwide. It is not as difficult as the era of non-precast structure and we have to be the first to introduce precast construction. Considering stakeholders, our suppliers have less bargaining power than us since long-term-fixed-price contract with at least 2 suppliers in each category and there are many alternative suppliers available in market. Moreover, we have advantage on the

completely new entrants since we already have knowledge and human resource in construction industry for 14 years.

4) Threat – According to Macro analysis and Five-force analysis, the only threat is the significantly less bargaining power to customers since there are only 16 big customers in the market and we have to persuade them to implement our product. Hence, we must ensure the best quality and customer service to keep these few customers with us. However, since precast concrete has been used in Thailand for more than 10 years and commonly used in these 5 years, it is not too difficult to make them familiar with the product.

5.1.6 Vision and mission

1) Vision – Our company aims to introduce and sell products to customers with sustainanble growth.

2) Short term mission 1-5 years - Produce and deliver at least 15 swimming pool structures to customer annually which equals to approximately THB 15.76 million revenue.

3) Long term mission 5-10 years - Produce and deliver at least 30 swimming pool structures to customer annually which equals to approximately THB 31.52 million revenue.

5.2 Marketing plan

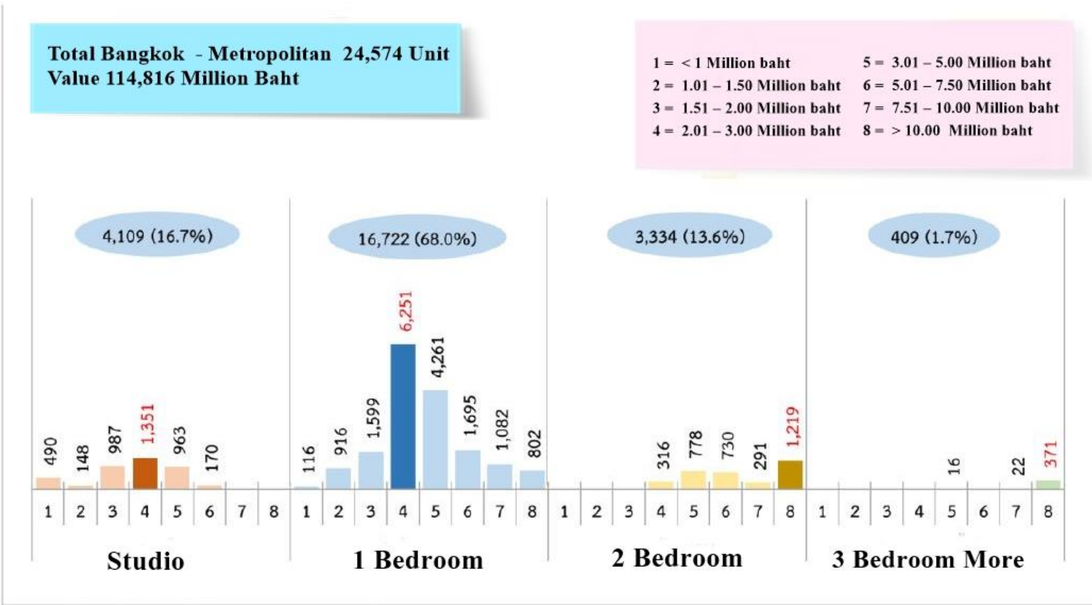
5.2.1 Objectives of marketing

For brand awareness, we expect to reach all 59 projects and educate all construction contractor firms and structural designer firms within the first 3 months.

For initial purchase, according to our main goal, another performance index is to deliver at least 15 structures to customers in the first year.

5.2.2 STP

Segmentation – We focus on all high-end and medium-class condos in Bangkok since they must have swimming pool as their customers' minimum requirement. Most low-class condominiums do not provide such facilities. According to the classification of Government housing bank, Thailand, medium class condominium is ranged from THB 50,000 to 150,000 per sq.m. An average size of studio type and 1-bedroom type are 40 sq.m. Hence, as shown in figure 5-10, the medium-class and high-end-class condominium of studio and 1-bedroom types are ranged from number 4 to number 8. An average size of 2-bedroom type is 60 sq.m. Hence, for 2-bedroom type, medium and high classes are ranged from number 5 to number 8.

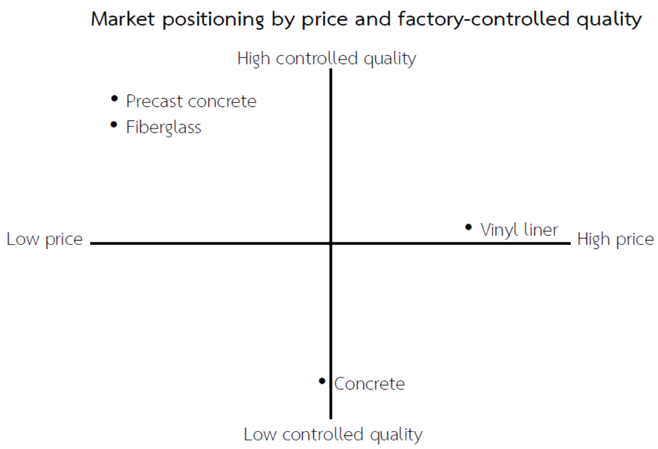


Source: Realestate information center, Government housing bank, Thailand

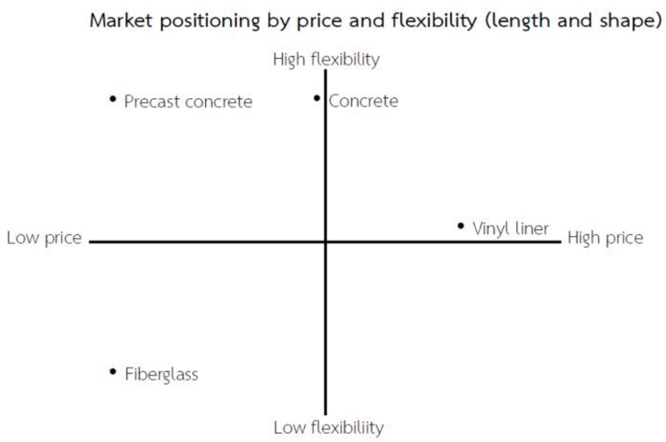
Figure 5-10 Bangkok condominium segmentation by price

Targeting – Public companies are our main target since they have considerably more projects per company than private companies as our first reason. Moreover, they have guaranteed good governance and higher potential to expand projects than small companies. Secondly, due to higher loan restriction, small companies tend to find it difficult to survive in the new era. We found that all 9 developer companies have on average 59 projects in Bangkok annually. At this point we have limitation on distance from factory to customer' s site according to transportation cost. Hence, we focus only in Bangkok and suburban area.

Positioning – "Same function with 25% cheaper and 70% faster". By new technology, our product provides more value to customers than traditional one in term of cost per quality. Our new structure has shorter installation duration than the traditional structures by 70 percent. Moreover, it is cheaper by 25 percent while its function remains the same. In comparison, for price and quality, precast structures and fiberglass hold the best value at comparatively lowest price and highest quality as shown in figure 5-11(a). However, when it is compared in term of price and flexibility as shown in figure 5-11(b), only precast concrete structure hold the best value since the fiberglass structure has limitation in length of the pool.



(a)



(b)

Figure 5-11 Market positioning; (a) market positioning by price and factory-controlled quality; (b) market positioning by price and flexibility

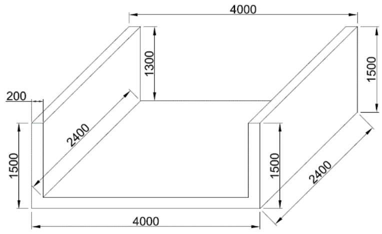
5.2.3 Marketing Mix 4Ps

1) Product – Concrete segment's dimensions are 2.4 meter width x 4 meter length x 1.5 meter height as shown in figure 5-12 and 5-13. Each segment weigh 8,064 kilogram. A regular condominium swimming pool size 4 meters x 20 meters has 9 segments.

Service – We include transportation to customer's site and fabrication process. The fabrication process is on average of 11 hours including 8 hours of laying process and 3 hours of Post-tensioning process.

2) Price – The cost of our structures (excluding finishing) is THB 8,500 per sq.m. and we price it at THB 15,000 per sq.m. including transportation and fabrication. Compared to the traditional structure, its cost is THB 14650 per sq.m. and an average price is THB 20,000 per sq.m.

3) Distribution channel – We sell our product directly to our 16 construction contractors which is business-to-business model. This project will start with 2 salesmen whose tasks are educating potential customers, bringing back customer requirements and after-sell service.



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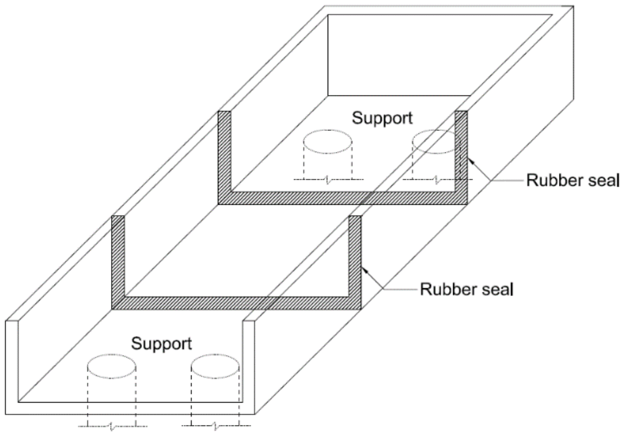


(b)

Figure 5-12 The first prototype design; (a) Dimensions in mm of the precast concrete segment; (b) The connections of precast segments and rubber seals

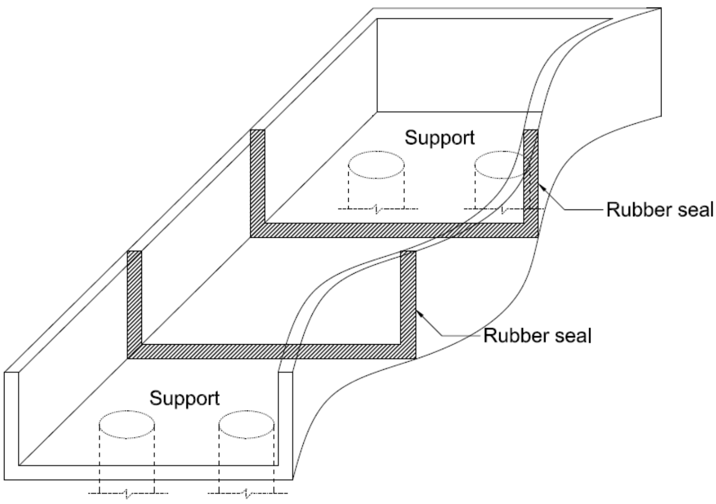


Figure 5-13 Prototype of flexible shape of precast swimming pool

4) IMC – All the marketing promotions and campaigns aim to support product introduction and direct sell. Since there is a b-to-b model and there are only 16 customers, no online marketing advertisement is required. The marketing communication plan and budget is provided as shown in table 5-4. To educate potential customers and to introduce our product, we plan to visit 10 construction contractors in the first quarter and the other 6 construction contractors in the second quarter. Our goal is to build brand awareness and invite them to visit our construction site and observe actual fabrication process. In the second quarter, we expect to welcome 6 on-site visits. Moreover, we plan to have an exhibition in a construction material fair namely "Architect Expo" aiming to educate more potential customers and building more brand awareness. In the third quarter, we expect to welcome 4 on-site visits. In the last quarter, we plan to have another exhibition in a construction material fair namely "Thailand building fair".

Table 5-4 Marketing communication budget

No.	Objectives	Marketing Activities	Budget (THB)	Cost per unit	Unit	Q1	Q2	Q3	Q4
1	Brand awareness	Construction material fair	200,000	100000 per event	2 events	-	Architect Expo (April)	-	Thailand building fair (Oct)
2	Brand awareness	Company visit	16,000	1,000 per company	16 companies	10 companies	6 companies	-	-
3	Initial purchase	On-site observation	20,000	2,000 per company	10 companies	-	6 companies	4 companies	-

5.3 Operations plan

5.3.1 Objectives of operations

Our operations consists of 2 main parts which are production and on-site fabrication. We aim to deliver our product to the customers with 3 main goals:

1) Time – The on-site fabrication finishes up to maximum of 2 days. Each project finish within 20 days after the order is placed
2) Cost – The cost of operations including production, on-site fabrication and transportation is lower than the traditional product by at least 25%
3) Quality – Water leakage must not occur throughout the water impermeability check prior to the transportation and fabrication

5.3.2 Demand Forecast & Production Capacity

We expect to deliver 15 structures to 15 projects from 59 Bangkok projects of public companies annually. For 4 meters times 20 meters size, we need 2 edge segments and 7 middle segments. Hence, the duration of production is 7 days according to the production process as shown in figure 5-14. So the annual maximum production capacity is 52 swimming pools annually. From our target of 15 structures per year, the total annual working day is 105 days per year.

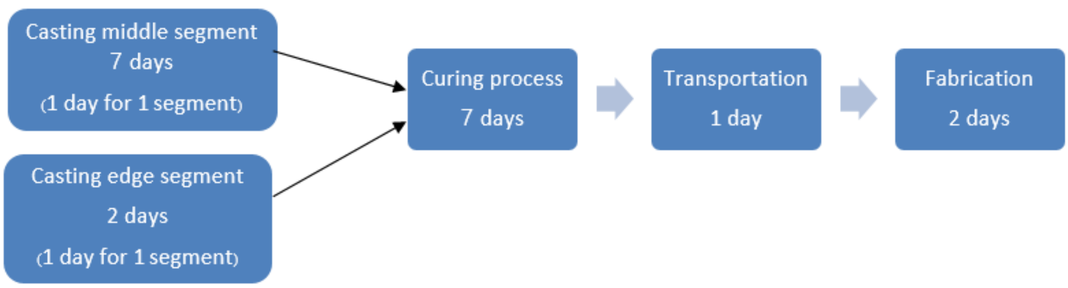


Figure 5-14 Operations process

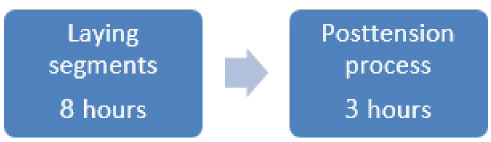


Figure 5-14 Fabrication process

For on-site fabrication process, it includes laying concrete segments and posttension. It takes up to maximum of 8 hours of laying process and 3 hours of Post-tensioning process as shown in figure 5-15. From total 11 hours, we then spare up to maximum of 2 days for the whole fabrication process. In sum, the whole operation process is 17 days.

5.3.3 Location, equipment and workforce

The smallest land area for precast concrete plant is 2 rai. We choose Khet Songkanong, Nakornpatom province since it is 50 kilometers to Bangkok and cheaper price of land compared to other directions around Bangkok. Moreover, Our company have good relationship with local officials and government. Consequently, it is easier and cheaper to acquire any required licenses such as construction license and production license.

Main equipments and plant consist of:

1) Metal sheet roof and steel truss size 15 meters x 30 meters including concrete flooring with thickness of 15 cm as shown in figure 5-16.

2) 20-ton girder crane

3) 500 steel formworks size 0.4m x 1 m

Figure 5-15 Expected factory atmosphere

For human resource, since the demand for the product is just 15 structures per year and each production duration is 7 days, we use daily staffs who already employed by our company including:

1) 1 civil engineer
2) 1 foreman
3) 4 masons

For fabrication, daily staffs include;

1) 1 civil engineer
2) 1 foreman
3) 3 masons
4) 1 crane

5.3.4 Raw material & Supplier management

1) Concrete – Our company has contract that fixes price with 2 concrete suppliers from 2018 to 2020 namely Kanjana concrete and Fast concrete at THB 1820 per cubic meter.

2) Steel - Our company has contract that fixes price with a steel supplier from 2018 to 2020 namely Sarpsomboon at THB 19.04 per kilogram.

3) Steel formwork – We already have, in stock, 500 steel formworks with size 0.4 m x 1 m. Moreover, the depreciation of the formworks are all deducted. Even if there is any damages on formwork, we can buy a replacement at the same price of THB 285 per piece.

4) Rubber seal - Our company has contract that fixes price with a rubber seal supplier at THB 4000 per piece.

Our raw material supplier lists are also provided in table 5-5

Table 5-5 Supplier list of concrete, steel and steel formwork

Order	Concrete provider	Contact Number
1	N.C.Siam Marketing Co.,Ltd.	099-429 7555
2	Kanchana concrete Co., Ltd.	02 444 2800
3	OR Seng Huat (1982) Co., Ltd.	02 212 6961
4	Five KT Concrete Co., Ltd.	02-312-5962
5	First Mat Products Co., Ltd.	02-906-5601
6	City Cement Co., Ltd.	02-416-7260
7	Inter Concrete Co., Ltd.	090-735-9697
8	SPP concrete subtavee Co., Ltd.	02-0651070
9	Concrete Siam Co., Ltd.	099-239-2866
10	CC Cement Co., Ltd.	02-8816065
11	Fastconcrete Co., Ltd.	02-034 3999
Order	**Steel provider**	**Contact Number**
1	Sub Somboon Steel (Ung Chiang Mong) Co., Ltd.	02-421-1308
2	Phornnaronglohakit Part., Ltd.	02-287-4097
3	Grand-steel Co., Ltd.	02-431-2439
4	Vanich-Charoen-steel-trading Co., Ltd.	02-450-3925
5	Lohahcharoen Co., Ltd.	02-291-5050
6	Lert siam Steel Co., Ltd.	02-294-5999
7	SIAMCHAI STEEL CO., LTD.	02-819-4700
8	V.R.STEEL CO.,LTD.	02-450-3355
9	Asia Metal Co., Ltd.	02-338-7222
10	ZUBB STEEL CO., LTD.	02-431-0043
Order	**Steel formwork provider**	**Contact Number**
1	Chokdee Steel Co., Ltd.	098-907 9927
2	Kjviengthong Part., Ltd.	02-490-1616
3	VIRIYA SAHAKOL CO., LTD.	088-2190507

Order	Concrete provider	Contact Number
4	SKcompact1989 Part., Ltd.	02-539-8553
5	Waraporn-steel Co., Ltd.	080-042-0927
6	Num Bablek Limited Parintnership Part., Ltd.	082-6954361
7	CN-Metalform Co., Ltd.	098-268-9927
8	Chotika-Intergroup Co., Ltd.	02 191 7169
9	BoomSteel Co., Ltd.	061-793-8888 , 095-556-9545
10	Thanavong Engineering Co., Ltd.	02-706-4311-3, 02-763-8718-9

5.3.5 Raw material and inventory plan

Our operations is made to order. Hence, there is no raw material stock needed.

5.3.6 Distribution plan

To fabricate 1 swimming pool structure, it takes 5 to 10 concrete segments. We can deliver these segements by outsourcing trailer. The cost of 1 day trailer is THB 10,000 per day.

5.4 Financial plan

5.4.1 Objectives of financial plan

Our financial plan goal is to estimate sufficient fund for project operations and forecast profit or loss for the first five years. Moreover, breakeven is also calculated to understand minimum sales that cover the total cost per year.

5.4.2 Revenue forecast

According to market forecast, we expect to sell 15 swimming pool structures in the first year. Let's assume that an average size of condominium swimming pool is 80 sq.m. and customers order 8 structures with pile work and 7 structures without pile work. The calculation is shown as follow;

1) Structure with pile work is THB 15,000 per sq.m. which is THB 1,200,000.

2) Structure without pile work is THB 11,000 per sq.m. which is THB 880,000.
3) In sum, Total revenue is THB 15,760,000

5.4.3 Cost calculation

The cost of precast plant is categorized into 3 main cost which are labour cost, cost of material and depreciation. These 3 cost are calculated as follow;

5.4.3.1 Labour cost

1) Production process - Engineer, foreman and masons team costs THB 3,400 per day. Each order needs 7 days which is THB 23,800 per order.

2) Fabrication process - Engineer, foreman, masons and crane team costs THB 10,000 per day. Each order needs 2 days which is THB 20,000 per order.

3) Transportation - Each project needs 2 trailers which is THB 20,000. In sum, each project operation includes labour cost of THB 63,800. For 15 projects, it costs THB 957,000 per year.

4) Salesperson - According to marketing plan, we need 2 salesmen which cost THB 600,000 per year. For sales commission of THB 40,000 per project, the total commissions cost THB 600,000.

5.4.3.2 Cost of material

Table 5-6 Cost of sales calculation

Labour cost		
Production team	357,000.00	
Fabrication team	90,000.00	
Crane	210,000.00	
Transportation	300,000.00	
Sales commission	600,000.00	
Cost of material		
Concrete	900,000.00	
Steel	999,600.00	
Rubber seal	480,000.00	
Bore pile work	1,800,000.00	
Cost of sales		5,736,600.00

Production team*

1) 1 civil engineer – THB 1,000 per day
2) 1 foreman – THB 800 per day
3) 4 masons - THB 400 per day

Fabrication team**

1) 1 civil – THB 1,000 per day
2) 1 foreman – THB 800 per day
3) 3 masons – THB 400 per day
4) 1 crane – THB 7,000 per day

1) Concrete – Each project needs 30.4 cubic meter which is approximately THB 60,000

2) Steel – Each project needs 3,500 kilogram of steel which is THB 66,640.

3) Rubber seal – Each project needs 8 pieces of rubber seal which is THB 32,000. In sum, each project material cost is THB 158,640.

4) Bore pile work – We outsource pile work which cost THB 15000 per pile.15 piles cost THB 225,000 for each project. According to the forecast, customers order 8 structures with pile work. It costs THB 675,000 per year as shown in table 6-6.

5.4.3.3 Depreciation

1) Factory – The metal sheet roof, truss and concrete flooring cost THB 900,000. The lifetime duration is 20 years. Hence, the factory depreciation is THB 45,000 per year.

2) Girder crane – The price of girder crane is THB 4,000,000. The crane depreciation is THB 200,000 per year. In sum, the depreciation is THB 245,000 per year as shown in table 5-7.

Table 5-7 Depreciation calculation

Depreciation	THB	
Factory	45000	
Girder crane	200000	
Total depreciation		245000

5.4.4 Balance sheet

Balance sheet is illustrated as shown in table 5-8

Table 5-8 Balance sheet of the first year

Asset		
1-year operating cash	THB	2,181,000.00
Factory		900,000.00
Girder crane		4,000,000.00
Total asset	THB	7,081,000.00
Shareholder's equity		
Equity capital	THB	7,081,000.00
Total equity and liability	THB	7,081,000.00

5.4.5 Income statement

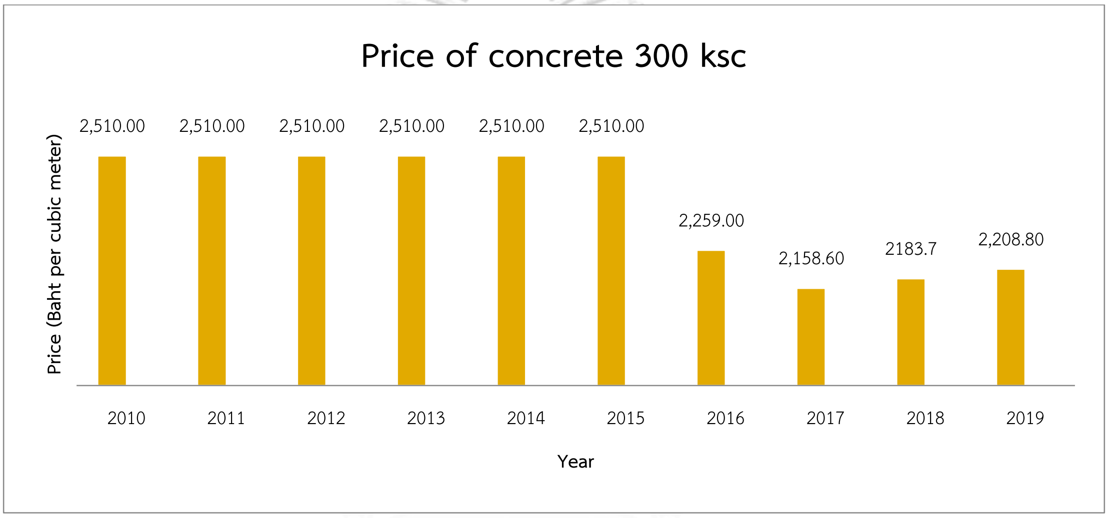
From the assumption of chapter 5.4.2, 5.4.3 and 5.4.4, income statement is illustrated as shown in table 5-9

Table 5-9 Income statement of the first five years

Sales	THB	
Structure with pile work	9,600,000.00	
Structure without	6,160,000.00	
Total sales		15,760,000.00
Labour cost		
Production team	357,000.00	
Fabrication team	90,000.00	
Crane	210,000.00	
Transportation	300,000.00	
Sales commission	600,000.00	
Cost of material		
Concrete	900,000.00	
Steel	999,600.00	
Rubber seal	480,000.00	
Bore pile work	1,800,000.00	
Cost of sales		5,736,600.00
Gross profit		10,023,400.00
Operating expenses		
Advertisement expense	236,000.00	
Sales salaries	600,000.00	
Rent (land)	600,000.00	
Depreciation	245,000.00	
Total operating expenses		1,681,000.00
EBIT		8,342,400.00
Tax		1,668,480.00
Net income	THB	6,673,920.00

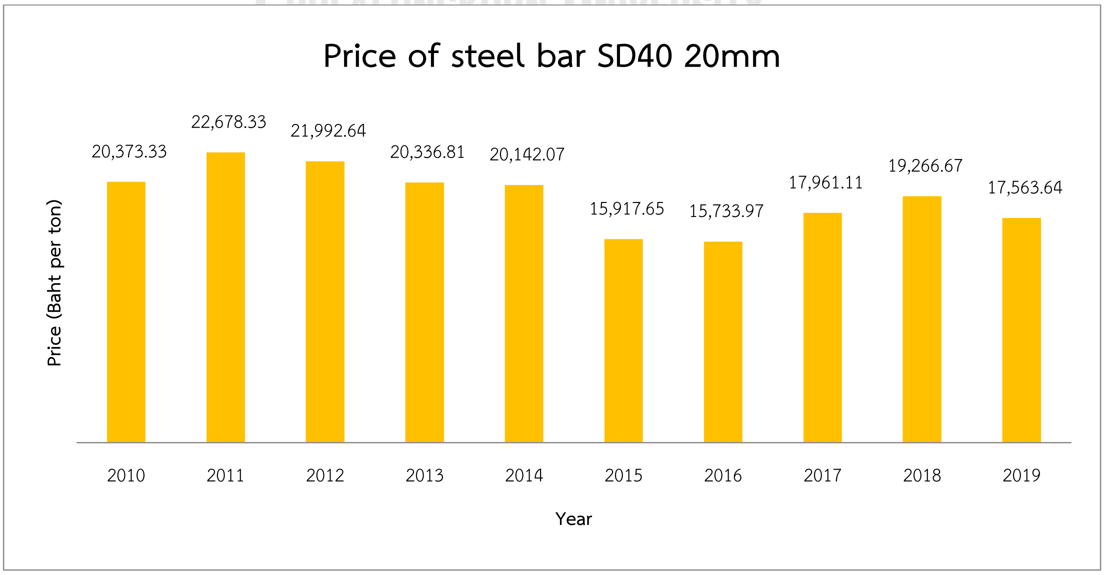
5.4.6 Scenario analysis

For the worst case scenario, we assume a half sales of that we expected 15 structures per year. Hence, we assume sales of 7 structures per year. In these 10 years, the price of concrete, steel and rubber bearing pad are shown in figure 5-16. In this scenario analysis, we use the highest price in 10 years. We use price of concrete 300 ksc at THB 2,510 per cubic meter, steel at THB 22,678.33 THB per ton in 2011 and rubber at THB 129.96 per kilogram in 2011. The income statement of this scenario is shown in table 5-10.

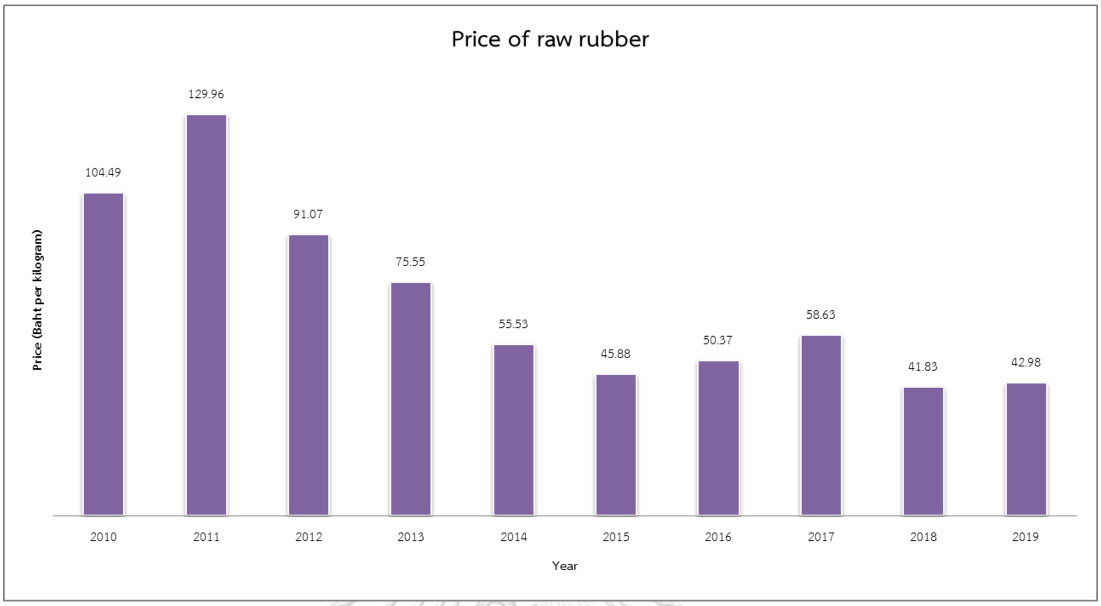


Source: Economic and trade indices database, Ministry of Commerce

(a)



Source: Economic and trade indices database, Ministry of Commerce



(b)

Source: Rubber Authority of Thailand

(c)

Figure 5-16 Average price of main materials from 2010 to 2019; (a) concrete 300 ksc; (b) Steel bar SD40 20mm; (c) raw rubber

Table 5-10 Income statement for scenario analysis

Sales	THB	
Structure with pile work	4,800,000.00	
Structure without	2,640,000.00	
Total sales		7,440,000.00
Labour cost		
Production team	166,600.00	
Fabrication team	42,000.00	
Crane	98,000.00	
Transportation	140,000.00	
Sales commission	280,000.00	
Cost of material		
Concrete	477,445.65	
Steel	602,336.36	
Rubber seal	677,315.96	
Bore pile work	900,000.00	
Cost of sales		3,383,697.97
Gross profit		4,056,302.03
Operating expenses		
Advertisement expense	236,000.00	
Sales salaries	600,000.00	
Rent (land)	600,000.00	
Depreciation	245,000.00	
Total operating expenses		1,681,000.00
EBIT		2,375,302.03
Tax		475,060.41
Net income	THB	1,900,241.62

If we cannot achieve 15 structures per year, we also need to find minimum sales on breakeven point. The operating expenses are fixed cost which is THB 1,681,000. Gross profit of 15 structures is THB 10,023,400. Hence, gross profit of selling one structure is THB 668,226.67. The minimum sales at breakeven point is 2.52 structures per year which is 3 structures per year as shown in table 5-11.

Table 5-11 Income statement assuming sales at breakeven point

Sales	THB	
Structure with pile work	1,200,000.00	
Structure without	1,760,000.00	
Total sales		2,960,000.00
Labour cost		
Production team	71,400.00	
Fabrication team	18,000.00	
Crane	42,000.00	
Transportation	60,000.00	
Sales commission	120,000.00	
Cost of material		
Concrete	180,000.00	
Steel	199,920.00	
Rubber seal	96,000.00	
Bore pile work	225,000.00	
Cost of sales		1,012,320.00
Gross profit		1,947,680.00
Operating expenses		
Advertisement expense	236,000.00	
Sales salaries	600,000.00	
Rent (land)	600,000.00	
Depreciation	245,000.00	
Total operating expenses		1,681,000.00
EBIT		266,680.00
Tax		53,336.00
Net income	THB	213,344.00

5.4.6 Capital budgeting

In this part, we calculate IRR, ROE and net profit margin to evaluate investment attractiveness of the project. The internal rate of return is 21% as shown in table 5-12 on the assumption that 15 structures of sales start at year2 and continue until year 5. Return on equity is 6,673,920/7,081,000 = 94.25%. Net profit margin is 6,673,920/15,760,000 = 42.35%.

Table 5-12 Internal rate of return of the project

Year	1	2	3	4	5
Net cash	- 7,081,000.00	6,673,920.00	6,673,920.00	6,673,920.00	6,673,920.00
IRR	86%				

In comparison to public construction material companies, their ROE range is 10-30% and net profit margin range is 5-20%. Our ROE is considerably higher than public construction material companies and our NPM project is above the upper range of public construction material companies. Hence, our project with the revenue assumption of selling 15 structures per year is found investible.

CHAPTER VI

MARKET ACCEPTANCE

6.1 Comparison on models of technology adoption

According to chapter 2.9, three models on technology adoption have been reviewed. In comparison, the theory of reasonable action (TRA), technology acceptance model (TAM), and universal theory of the application and use of technology (UTAUT) are decision-making models, which is also called the attitude-behavior model or attitude-decision model (Blythe, 2013; Köck, 2014). These models are all therefore based on the underlying assumption that attitudes or predispositions based on knowledge, experience and messages from others, have an effect on behavioral intentions and therefore behavior (Bagozzi & Burnkrant, 1979). Therefore, the core assumption of all three models is that individuals form attitudes based on certain types of input, which in turn influence behavioral intentions and then behavior. However, this does not mean that all three models are equally as effective, since their internal structures influence the extent to which they predict behavior in different domains. Thus, selecting a model depends on the decision domain.

The TRA is the oldest the model, including only attitudes and social influence as factors in the decision (Bagozzi & Burnkrant, 1979; Blythe, 2013). To overcome this problem, it is possible to extend the model with suitable external variables, but it remains less predictive than alternative decision models (Yousafzai, Foxall, & Pallister, 2010). In the case of the construction industry, the TRA has a significant disadvantage because it neglects attributes of technology. Therefore, it would not reflect the adoption of a technology like immersed precast structure very well.

The TAM has an advantage over the TRA because it does specifically consider characteristics of a given technology, such as perceived ease of use and perceived usefulness (Köck, 2014). This is very useful for considering technology adoption in the construction industry because it specifically investigates the characteristics of the technology, rather than just examining individual perceptions and beliefs. This moves the TAM outside the domain of individual attitudes, which is where the TRA focuses. However, when considering the adoption of a construction technology like immersed precast structures, it is not sufficient to only consider the technology aspects. Social norms and facilitating conditions would also be relevant.

The UTAUT, unlike either the TRA or the TAM, investigates all three aspects of technology adoption: perceived technology characteristics, social context, and broader facilitating factors in adoption (Köck, 2014). It has been shown to be similar in efficacy to the TAM despite its less parsimonious nature (Dwivedi, Rana, Chen, & Williams, 2011). In the context of the construction industry, the UTAUT has several advantages. In particular, it considers the social and context-related factors in technology adoption. For example, it could include the social acceptance of immersed precast structure technology, as well as availability of training programs and suppliers for implementation.

In conclusion, the UTAUT is the most suitable model for investigating technology adoption in the construction industry, because it includes technology characteristics, social influence and external context.

For application on precast swimming pools, the UTAUT can be applied to different consumer technology adoption contexts. One such example is the adoption of immersed precast structure, which is a technology that allows for faster and cheaper swimming pool construction. The consumers of this technology would be construction companies.

The four components that predict the intention to adopt technology under the UTAUT include performance expectancy, effort expectancy, social influence and facilitating factors (Dwivedi, Rana, Chen, & Williams, 2011). In the case of immersed precast structure technology, conditions in these factors that could lead to adoption could include:

1) Performance expectancy: The immersed precast structure will increase performance of construction project in terms of time and cost compared to existing technologies.

2) Effort expectancy: It will take no effort of new training and new skills to the company' s staffs. Moreover, there is no need to use any new equipment to support the structures.
3) Social influence: When many companies use this new technology and decrease their project time, it is pressured to construct faster.
4) Facilitating factors: The existing use of Post-tensioning and precast helps staffs understand the protocol of the structures

The UTAUT then argues that these factors will contribute to the behavioral intention to adopt precast swimming pools. Several authors have used UTAUT to investigate adoption of technology. The UTAUT is the most suitable model for investigating technology adoption in the construction industry since it includes the most complete factors to the model. Table 6-1 summarizes previous studies that have used UTAUT in to investigate the adoption of technology in the construction industry. A variety of technologies have been examined, including information technologies like e-procurement (Afolabi, et al., 2019) and building information management (BIM) (Howard, Restrepo, & Chang, 2017), wood-based materials (Barrane, Kururanga, & Poulin, 2019) and wearable devices for safety (Sandoval & Kwon, 2019).

Each experiment is analyzed differently. Two studies use descriptive statistics (Barrane, Kururanga, & Poulin, 2019; Sandoval & Kwon, 2019) since the sample size is relatively small. One study used structural equation modelling (SEM) to test the full UTAUT (Howard, Restrepo, & Chang, 2017). Another uses categorical regression to investigate the effects of different characteristics on adoption (Afolabi, et al., 2019). This was similar to a fifth study, which used multiple hierarchical regression to investigate different aspects of adoption (Sargent, Hyland, & Sawang, 2012).

Table 6-1 Summary of prior studies on UTAUT in construction technology

Author	Year	Research area	Population	Sample size	Response rate	Statistical Analysis
Afolabe, Ibe, Aduwo, Tunji-Olayeni, Oluwunmi and Ayo-Vaughan	2019	E-procurement	Nigerian construction engineers	759	43.30%	Descriptive statistics and Categorical regression (CAT-REG)
Barrane, Karuranga and Poulin	2019	Wood-based technology	Construction Engineers in Quebec	28	NR	Content analysis and Descriptive statistics
Howard, Restrepo and Chang	2017	Building information modelling (BIM)	Construction firms	84	NR	Structural equation modelling (SEM)
Sandoval and Kwon	2019	Smart wearable safety technologies	South Korean construction firms	15	NR	Descriptive statistics
Sargent, Hyland and Sawang	2012	Information technology	Australian construction firms	146	22.60%	Multiple hierarchical regression

Note: NR = not reported

6.2 Research variables

Both independent and dependent variables in this research are developed based on literature review of previous study. 12 items are used to measure dependent variables. The factor that affect the adoption of precast concrete swimming pools are measure using a seven-point Likert scale ranging from 1 to 7 (1 = strongly disagree; 7 = strongly agree). Moreover we also include “why” question at the end of each item to have more understanding on each answer.

6.2.1 PCS performance expectancy

Performance expectancy refers to how potential a user believe that employing PCS will help improve a user's job performance. It is to ensure whether a user believe in competitive advantage and perceived usefulness of the technology. Moreover, it is moderated by age and experience. For instance, the effect of this factor is stronger for younger users because they are more familiar to the benefit of precast concrete buildings over cast-in-situ buildings than the earlier generations. In addition, the effect of this factor is stronger for a user with more experience in precast concrete buildings because of their understanding in the benefit of the system. The item for performance expectancy are adapted from Sapasgozaar (2017). In our case, we introduce the benefit and superior performance of precast swimming pool in terms of lower timer and cost which the users already have experience on normal precast concrete structures. However, we want to ensure that the users believe in different form of precast structures or not.

6.2.2 PCS effort expectancy

Effort expectancy refers to the amount of effort the users have to put on implementing the PCS. It is combination of perceived ease of use and complexity. In our case, precast concrete system has been widely used for decades. We expect no change in working skills and knowledge. The users who are familiar with precast structures are asked whether they believe it or not. The item for effort expectancy are adapted from Howard, Restrepo, & Chang, 2017.

6.2.3 Facilitating conditions

Facilitating conditions refers to the degree that the users believe that existing knowledge, resources, equipment and external entities are available to support the use of PCS. In our case, no extra knowledge, resources, and equipment are needed but it depends on whether the users believe this information or not. The items for facilitating conditions are adapted from Sapasgozaar, et al. (2017).

Table 6-2 summarizes the preliminary items selected to measure the UTAUT variables. The questionnaire items are adapted from two prior instruments, including a general questionnaire developed for "Building Information Modelling" (Howard, Restrepo, & Chang, 2017) and a questionnaire developed for construction project scanner (Sapasgozaar, Shirowzhan, & Wang, 2017). Each variable is measured through a series of three items, which should reflect the same underlying construct. The items for social influence and behavioural intention are adapted from Howard, Restrepo, & Chang, 2017.

Table 6-2 Measures of key factors

Variable	Items	Source
Performance Expectancy	I would find the PCS useful. Using the PCS decreases overall time of our construction project. Using the PCS increases the performance in our construction project.	Sapasgozaar, Shirowzhan, & Wang (2017)
Effort Expectancy	My interaction with PCS would be clear and understandable. It would be easy for me to become skilled at working with PCS. I would find PCS easy to use.	Howard, Restrepo, & Chang (2017)
Social Influence	The use on PCS of other construction companies has impact on the use of PCS. The senior management of this business has influence in the use of PCS. In general, the organisation has supported the use of PCS.	Howard, Restrepo, & Chang (2017)
Facilitating Conditions	I have the resources necessary to use the PCS. I have the knowledge necessary to use the PCS. The PCS is not compatible with other devices I use.	Sapasgozaar, Shirowzhan, & Wang (2017)

Behavioral Intention	I intend to work with PCS in the next 12 month. I predict I would use PCS in the next 12 month. I plan to use PCS in the next 12 month.	Howard, Restrepo, & Chang (2017)

6.3 Population and data sampling

In this research, we focus on potential customers who have decision authority on employing new construction technique in their projects. Indispensably, their responsible projects of condominiums must consist of swimming pools. The related stakeholders in these criterion are structural designers, construction contractors and developers in Thailand. These 3 types of stakeholders are interviewed. The details of sampling criteria are described below.

1) The interviewees must have authority to make decision on employing precast concrete swimming pools in their projects.
2) The interviewees must have at least 6-year experience in construction related fields.
3) The interviewees must have at least 6-year experience on using precast construction technique and have fundamental knowledge on precast construction technique.
4) The interviewees must be the highest position in each project.
5) The interviewees' projects must be residential buildings which consist of swimming pool.

6.4 Research instrument

For data collection method, the 1-hour interviews are conducted to gather customer behavior and reason behind each answer on using precast concrete swimming pools on their responsible projects. The questionnaire consists of 2 sections. Section 1 is for demographic information such as age, gender, area of construction industry and experience in construction industry and precast construction technique. Section 2 consists of factors which have potential impact on the adoption of precast concrete swimming pools. The first section is written down by interviewees whereas the second section is asked and written down by the interviewer since it includes the question "why" on each question. Section 2 is structured by 7 point Likert scale to indicate the degree of agreement of interviewees. The scales are shown in table 6-3.

Table 6-3 7 point Likert scale used in this research on the adoption of precast concrete swimming pool

level	Rating scale
Strongly Disagree	1
Disagree	2
Somewhat disagree	3
Undecided	4
Somewhat agree	5
Agree	6
Strongly agree	7

6.5 Interview results

After we interviewed executive-level manager of 7 construction-related firms, interviewees give similar high score (above 5) for all questions of performance expectancy and effort expectancy. Moreover, their comments are significantly positive. They understand the benefit of using precast concrete swimming pools over cast-in-situ swimming pools in terms of lower time and cost. Additionally, interviewee E explained more that precast concrete swimming pool (PCS) will definitely minimize working process, labour and on-site activities with controlled working quality. Thailand is facing shortage of quality labour and sufficiency of unskilled workers Interviewee G also added that layout design is much easier since the space does not require columns.

For the factor of facilitating conditions, both structural designer and construction contractors give higher score than developers that they have necessary knowledge and resources to implement PCS in their projects including the existing devices can be used without any adaptation.

Social influence results give us a very clear understanding on interviewees' perspectives. Their answers are significantly similar especially the question on the first user. First user factor seems to be the most important effect and the only condition on their behavioral intention. The rest SI answers are also the same that they have authority to implement any new construction technique on their projects and senior managements and organizations always support them.

The result from dependent variable " behavioral intention" can be categorized into 2 groups. Firstly, developers and structural designer give similar answers with low score on BI (lower than 4). They want to use the product in the condition of not being the first user and wait to see the result from the first user. Their answers are not surprised since implementing PCS does noy benefit both parties directly. The lower overall project duration directly benefits contractors.

In conclusion, all parties understand the benefits of PCS and are confident on the superior performance of PCS over traditional (cast-in-situ) swimming pools. Additionally they have no concern on effort expectancy and facilitating conditions for PCS. However, the intention of use separate interviewees into 2 groups. The first group of structural designer and development decide not to be the first user even they understand the benefits of PCS. In other words, they will use PCS in the condition that the first user already employ PCS and no problem occurs. The second group of contractors who are directly benefited from PCS seems to be appealed and intend to influence the other group and are more willing to use PCS within 36 months.

Table 6- 4 Interview results

Name	A	B	C	D	E	F	G
Company	A	B	C	D	E	F	G
Company type	Developer	Structural designer	Construction Contractor	Construction Contractor	Construction Contractor	Developer	Developer
Age	36-45	36-45	36-45	36-45	46-55	30-35	30-35
Experience	6 to 10 years	more than 10 years	6 to 10 years	more than 10 years	more than 10 years	6 to 10 years	6 to 10 years
BI1	3	2	4	5	4	2	3
BI2	3	1	4	5	4	2	4
BI3	2	1	4	5	5	2	4
BI comment	We use in the condition of not being a first user.	We must design according to design code. Never be the first user.	We can request designers to use PCS. If the benefit of lower time and cost are worth influencing the desingers. Suppliers should provide proof of impermeability.	We see the benefit of PCS and it appeals us. We can use these benefits and influence owners to change construction technique by its benefit as we always do. Suppliers have to provide quality guarantee and inspection.	We will use PCS with 2 conditions. 1. Suppliers have to provide proof of impermeability 2. The first user employs this new method for more than 5-10 years	We have experienced the disability of impermeabilty of precast construction method.	We use PCS in condition of the first user employs this new system for more than 1 year without water leakage problem.

Name	A	B	C	D	E	F	G
PE1	6	7	7	6	6	5	6
PE2	6	7	7	5	6	6	6
PE3	7	7	7	5	6	5	6
PE comment			We know the benefit of precast in terms of significantly lower time and cost		Precast construction help minimizing working process, labour and on-site activities with controlled quality. In Thailand, we are facing shortage of quality labour and sufficiency of unskilled workers	Precast construction method is better than cast-in-situ in many aspects, whereas water leakage problem posts a more critical problem. We hired both ItalThai and SCG but both fail to cope with water leakage problem.	We found precast construction method useful in terms of 30 percent lower time. Additionally, layout design is much easier since the space does not require columns
FC1	5	7	7	6	5	5	4
FC2	4	7	7	5	5	5	4
FC3	4	7	7	5	5	5	5
FC comment		We always use both precast structure and rubber.	We are familiar with both precast structure and elastomeric bearings.		The suppliers have to provide product transportation and fabrication.	Labour quality is the main concern in both cast-in-situ and precast construction method	We have to train new knowledge and skills to our staffs

Name	A	B	C	D	E	F	G
EE1	5	7	6	5	6	6	5
EE2	6	7	6	7	6	6	5
EE3	4	6	6	7	6	6	5
SI1	7	7	7	7	7	7	7
SI2	6	5	5	6	5	5	4
SI3	6	6	5	5	5	5	4
SI comment		We have authority to choose construction technique.	Senior management and organization always suppport our decision on the use of construction technique. The only critical influence is to convince owners or designers.		If we are assured of the impermeability of PCS, we can influence developers to use it	Third party provide less influence than the proof of impermeability	

CHAPTER VII
CONCLUSION AND RECOMMENDATION

The study on structural system for precast concrete swimming pool can be categorized into 3 main domains which are engineering design and development, business plan and technology adoption. On engineering study, firstly, we use elastomeric bearings as rubber seal and develop joint design and swimming pool prototype. Secondly, we study the compression-shear behavior and water impermeability of rubber. Finally, we develop a full-scale test for the precast swimming pool structures.

On business study, we study the business environment analysis and provide strategies accordingly. The study includes operations plan, marketing plan and financial plan which also consists of scenario analysis. On customer side, we study the technology adoption and use of potential customers. The research items are developed and the interviews are conducted based on previous study.

7.1 Summary of research findings

The key research findings are found in relation to research objectives in section 1.3 which is summarized in table 7-1. The first objective is to develop joint design for precast structures which is capable of shear resistance and leakage prevention. The joint design starts with literature review on existing precast joints in precast concrete segmental bridges and existing precast joints in immersed tunnels in section 2.1 and 2.2. The prototype design and calculation of our structure is shown in section 4.1. The model development is in section 4.5.

The parabolic post-tensioning force helps generate uniform stress distribution. The minimum compressive stress is in horizontal part of rubber#5 at 0.11 MPa which is above the minimum required compressive stress on rubber at 0.06 MPa of section 4.3.3

The second objective of this research is to study compression-shear behavior and impermeability of rubber seals by developing new test setups for both experiments. The study starts with literature review on rubber behaviour, shear strength test setup and impermeability test setup in section 2.3, 2.6 and 2.7. Elastomeric bearings is capable to resist shear force. We developed compression-shear test setup similar to Zhou & Mickleborough (2005). However, the existing impermeability test is not compatible to our objective so we decided to design our own impermeability test. According to section 4.2, results from the first experiment indicate that elastomeric bearings is capable to resist shear force from precast segment and water weights of the swimming pool prototype. Shear capacity of rubber increases with the confinement and hardness level. However, thicker rubbers tend to have lower shear capacity than thinner rubbers. According to section 4.3, results from the second experiment indicate that elastomeric bearings can be used as rubber seal to prevent water leakage under our predetermined conditions. There are problems with non-uniform confinement stress in the rubber seal resulted from concentrated prestressing forces and unsmooth concrete surface. However, after the rubber creeps for 21 days, the rubber can fully prevent water leakage.

The third objective is to develop precast swimming pool structures for commercialization by applying the new joint design. In section 5.1, PEST, SWOT and 5-force competitor's analysis are used to analyse business environment. According to Macro analysis and Five-force analysis, the only threat is the significantly small bargaining power to customers since there are only 16 big customers in the market. Hence, we must ensure the best quality and customer service to keep these few customers with us. In section 5.1 and 5.2, Product comparison and Market positioning are provided. Our product position is superior to cast-in-situ system, vinyl liner and fiberglass in terms of cost, time, and flexibility. Its installation time is as equally fast as fiberglass. However, it offers higher flexibility of length than fiber glass. To compare with cast-in-situ system, it is 25% cheaper and 70% faster than cast-in-situ system. In chapter 6, UTAUT is employed to investigate the adoption of precast concrete swimming pool. All interviewees understand the benefits of precast concrete swimming pool (PCS) and are confident on the superior performance of PCS over traditional (cast-in-situ) swimming pools. Additionally they have no concern on effort expectancy and facilitating conditions for PCS. However, the intention of use separate interviewees into 2 groups. The first group of structural designer and developers decide not to be the first user even they understand the benefits of PCS. In other words, they will use PCS in the condition that the first user already employ PCS and no problem occurs. The second group of contractors who are directly benefited from PCS seems to be appealed and intend to influence the other group and are more willing to use PCS within 36 months. In section 5.2, 5.3 and 5.4, operations plan, marketing plan and financial plan are provided. For operations plan, the on-site fabrication finishes up to maximum of 2 days. Each project finish within 20 days after the order is placed. The cost of operations including production, on-site fabrication and transportation is lower than the traditional product by at least 25%. For marketing plan, we expect to reach customers in all 59 projects in the first year and educate all construction contractor firms and structural designer firms within the first 3 months. The marketing communication plan is shown in section 5.2. We focus on all high-end and medium-class condominiums in Bangkok since they must have swimming pool as their customers' minimum requirement. For financial plan, with the assumption that 15 structures of sales start at year 2 and continue until year 5, the return on equity is 94.25% with the annual return of THB 6,673,920 on investment of THB 7,081,000.

Table 7-1 Summary of research findings

Research objective	Section	Research tools	Research findings
1) To develop joint design for precast structures which is capable of shear resistance and leakage prevention.	Section 2.1, 2.2 and 4.1	Literature review on "existing precast joints in precast concrete segmental bridges" and "existing precast joints in immersed tunnels"	The concept of precast segments and Post-tensioning of precast concrete segmental bridge are usable and employed in our prototype design. The concept of rubber seal in immersed tunnels is also used in our prototype design. The prototype design and calculation of our structure is shown in Section 4.1
	Section 4.5	Three-dimensional finite element models	The post-tensioning force of 247.13 kN for each BBR bar was applied. Parabolic forces simulate the parabolic post-tensioning force in both edge segments. The parabolic post-tensioning force helps uniformed stress distribution. The minimum compressive stress is in horizontal part of rubber#5 at 0.11 MPa which is above the minimum compressive stress on rubber of section 4.3.3

Research objective	Section	Research tools	Research findings
2) To study compression-shear behavior and impermeability of rubber seals by developing new test setups for both experiments.	Section 2.3, 2.4, 2.6 and 2.7	Literature review on "rubber behaviour", "shear strength test setup" and "impermeability test setup"	Elastomeric bearings is capable to resist shear force. We developed compression-shear test setup from Zhou & Mickleborough (2005). However, the existing impermeability test is not compatible to our objective so we decided to design our own impermeability test.
	Section 4.2 and 4.3	Compression-shear test/ Impermeability test	Results from the first experiment indicate that elastomeric bearings is capable to resist shear force from precast segment and water weights of the swimming pool prototype. Shear capability of rubber increases with the confinement and hardness level. However, thicker rubbers tend to have lower shear capability than thinner rubbers. Results from the second experiment indicate that elastomeric bearings can be used as rubber seal to prevent water leakage under our predetermined conditions. There are problems with non-uniform confinement stress in the rubber seal resulted from concentrated prestressing forces and unsmooth concrete surface. However, after the rubber creeps for 21 days, the rubber can fully prevent water leakage.

Research objective	Section	Research tools	Research findings
3) To develop precast swimming pool structures for commercialization by applying the new joint design.	Section 1.1 and 5.1	PEST/SWOT/5-force competitor's analysis/Mission statement	According to Macro analysis and Five-force analysis, the only threat is the significantly small bargaining power to customers since there are only 16 big customers in the market. Hence, we must ensure the best quality and customer service to keep these few customers with us.
	Section 2.5, 5.1 and 5.2	Product comparison/Market positioning	Our product position is superior to cast-in-situ system, vinyl liner and fiberglass in terms of cost, time, and flexibility. Its installation time is as equally fast as fiberglass. However, it offers higher flexibility of length than fiber glass. To compare with cast-in-situ system, it is 25% cheaper and 70% faster than cast-in-situ system.
	Section 2.9 and 6	UTAUT	All interviewees understand the benefits of PCS and are confident on the superior performance of PCS over traditional (cast-in-situ) swimming pools. Additionally they have no concern on effort expectancy and facilitating conditions for PCS. However, the intention of use separate interviewees into 2 groups. The first group of structural designer and developers decide not to be the first user even they understand the benefits of PCS. In other words, they will use PCS in the condition that the first user already employ PCS and no problem occurs. The second group of contractors who are directly benefited from PCS seems to be appealed and intend to influence the other group and are more willing to use PCS within 36 months.

Research objective	Section	Research tools	Research findings
3) To develop precast swimming pool structures for commercialization by applying the new joint design.	Section 5.2, 5.3 and 5.4	Operations plan/Marketing plan/Financial plan	For operations plan, the on-site fabrication finishes up to maximum of 2 days. Each project finish within 20 days after the order is placed. The cost of operations including production, on-site fabrication and transportation is lower than the traditional product by at least 25%. For marketing plan, we expect to reach customers in all 59 projects in the first year and educate all construction contractor firms and structural designer firms within the first 3 months. The marketing communication plan is shown in Section 5.2. We focus on all high-end and medium-class condos in Bangkok since they must have swimming pool as their customers' minimum requirement. For financial plan, with the assumption that 15 structures of sales start at year 2 and continue until year 5, the return on equity is 94.25% with the annual return of THB 6,673,920 on investment of THB 7,081,000. However, The minimum sales at breakeven point is 2.52 structures per year which is 3 structures per year.

7.2 Contribution

According to Technopreneurship and Innovation management program regulation, the doctoral dissertation must meet all three main criteria: Technology, Innovation and Management. This research comply these requirement as shown in table 7-2.

Table 7-2 Research contribution in accordance to Technology, Innovation and Management (TIM)

Technology (T)	The process of structural fabrication with elastomeric bearings to resist shear force and leakage prevention relies on two indispensable technologies: external post-tensioning and simulation programming to measure and balance non-uniform confinement stress in the rubber seal resulted from concentrated prestressing forces.
Innovation (I)	The immersed precast system is developed to be applicable in immersed condition. The value of this research for precast concrete technology is to affirm water impermeability and shear capacity of structure with this new fabrication process.
Management (M)	The knowledge acquisition process requires the study on physical properties of materials and interaction between materials. Moreover, this research includes study for commercialization and complete business plan. The knowledge can also be further developed to other kinds of immersed structures such as water tanks, man holes and basements.

7.2.1 Contribution to theory

Elastomeric bearings have been widely used for compressive purpose for many decades. However, it has never been used for shear resistance and water leakage prevention. We studied these 2 behaviours and found that it is capable to apply with immersed precast structures. Results in Section 4.1 show that the elastomeric bearing is capable to resist shear force from precast segment and water weights of the swimming pool prototype. Results in Section 4.2 show that elastomeric bearings can be used as rubber seal to prevent water leakage under our predetermined conditions.

UTAUT has been widely used in the past 10 years. It is found as suitable model for investigating technology adoption in the construction industry since it includes the most complete factors to the model as we provided evidence from 5 recent studies in Section 6.1.

7.2.2 Contribution to practice

As we mentioned in Section 1.4, the application of rubber seals in this study increases the value of natural rubber and it is an opportunity to apply natural rubber to other applications in construction industry since it provide substantial shear and compressive resistance to structures. This new precast swimming pool structures definitely increase productivity of construction projects. The new system reduces working process, labour and on-site activities which are the major concerns of all construction contractors.

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APPENDIX

QUESTIONAIRE OF UTAUT

Personal Information (optional)						
Name:						
Organisation Name:						
Division/Business Unit:						
Email:						
Control Questions						
Sex		Male				
		Female				
		Under 25				
		26-35				
Age		36-45				
		46-55				
		Over 55				
		Construction/Engineering				
		Consultancy (cost management,project management, etc.)				
		Design/Architecture				
In which area of the		Property Development				
construction industry is		Operations (property management, facilities management, etc.)				
your organisation		Manufacturing				
specialized?		Logistics				
		Legal				
		Real Estate and Financial Institution				
		Other (please specify)				
		None				
How much experience		Less than 2				
do you have with BIM		2 to 5				
(years)?		6 to 10				
		More than 10				
BIM Involvement						
Please complete the following statement by selecting one of the following options:						
1	*Not at all*					
2	*To a little extent*					
3	*To some extent*					
4	*Undecided*					
5	*To a moderate extent*					
6	*To a great extent*					
7	*To a very great extent*					
BI1	I intend to work with PCS in the next 36 months…					
BI2	I predict I would use PCS in the next 36 months…					
BI3	I plan to use PCS in the next 36 months…					

BIM Perceptions	
Considering your personal opinion on PCS, please indicate your level of agreement with the following statements:	
1	Strongly Disagree
2	Disagree
3	Somewhat disagree
4	Undecided
5	Somewhat agree
6	Agree
7	Strongly agree
EE1	My interaction with PCS would be clear and understandable.
EE2	It would be easy for me to become skilled at working with PCS.
EE3	I would find PCS easy to use.
SI1	The use on PCS of other construction companies has impact on the use of PCS.
SI2	The senior management of this business has influence in the use of PCS.
SI3	In general, the organisation has supported the use of PCS.
PE1	I would find the PCS useful.
PE2	Using the PCS decreases overall time of our construction project.
PE3	Using the PCS increases the performance in our construction project.
FC1	I have the resources necessary to use the PCS.
FC2	I have the knowledge necessary to use the PCS.
FC3	The PCS is not compatible with other devices I use.

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