CHAPTER III

DESIGN OF MECHANICAL SPLICE AND TEST SET UP

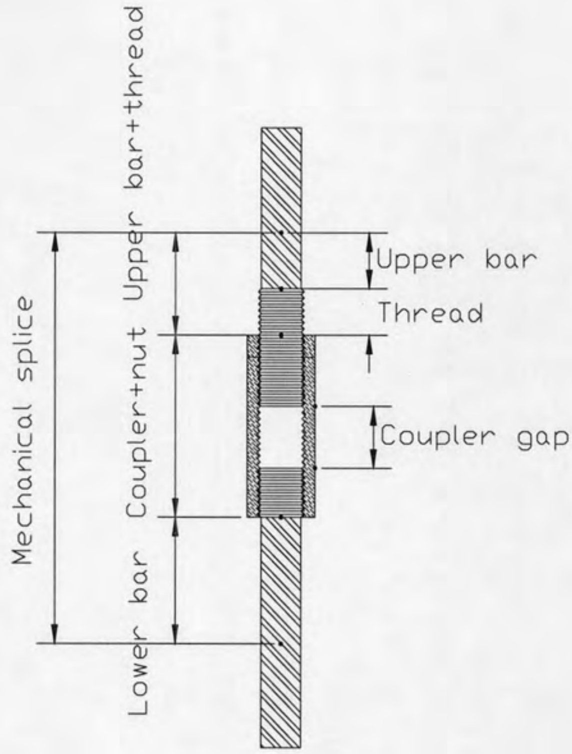
In this chapter, The test setup for monotonic tensile test, compression test, cyclic loading test and slip test are described.

3.1 Concept of mechanical splice model used in this study

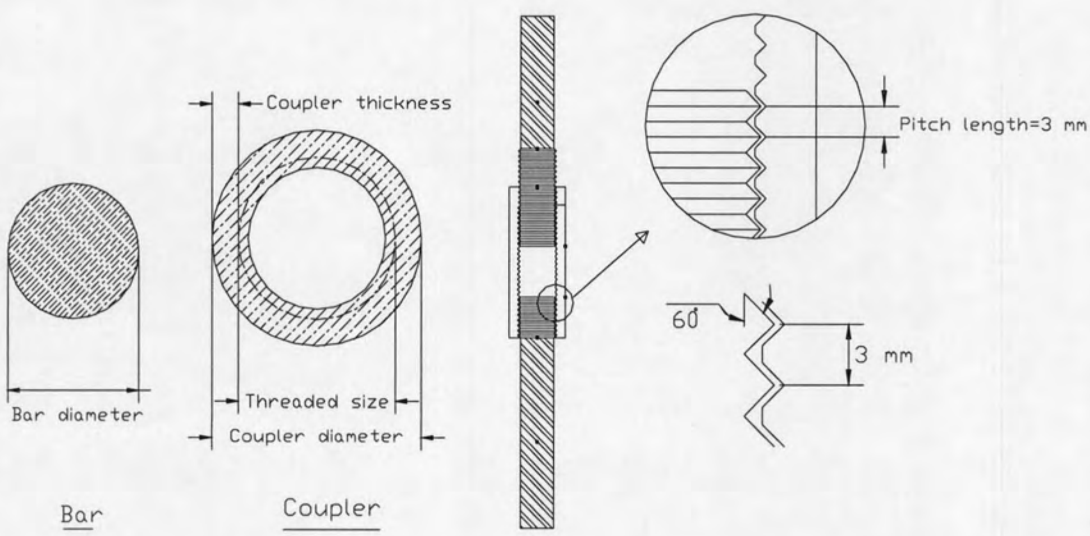
In general, mechanical splices are classified into many types depending on mode of application. Basically, mechanical splices are used to connect bars so as to transfer tension or compression forces. This paves the way towards the determination of the coupler's tension strength which should be larger than that of the reinforcing bars or at least $1.25 f_y$ as specified in the provisions of the 1997 Uniform Building Code (UBC) as well as in American Concrete Institute (ACI). This will ensure sufficient strength in splices so that yielding will occur in the reinforcing bar and thereby, failure will occur at the bar.

With respect to the mechanical splice model used in this study. The couplers are designed to have the strength less than that of the reinforcing bars. On the other hand, the coupler is designed to have adequate ductility by designing the gap length in the coupler. So when earthquake occurs, the coupler is going to yield before the bars. So, the coupler will act as a fuse in a column to absorb energy and can be replaced after an earthquake.

This may be used in the construction of precast structures especially in precast columns. Figure 3.1 shows the configuration of the mechanical model employed in this study.



(a) Definition of mechanical splice components



(b) Sectional view (c) Threads of the threaded coupler and bar

Figure 3.1 Mechanical splice employed in this study

The detailing of the threaded bars is shown in Figure 3.2 .The threaded bars consists of two parts. The first part is called upper threaded bar with a thread length equal to the sum of twice thread length and lock nut length. The second part is called the lower bar with a thread length equal to the thread diameter. This configuration is designed in a manner such that bars are not rotated when assembling the mechanical splice. In connection to this, after rotating the coupler from the upper bar to the end of the lower bar, the lock nut is utilized to clamp the coupler. This process is required when assembling precast components in actual construction.

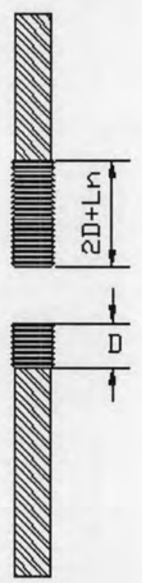


Figure 3.2 Threaded bar used in this study

where

D = the thread length (24 mm)

Ln = length of lock nut (10 mm)

The process of assembling the mechanical splices is illustrated in Figure 3.3. In the first step, a lock nut and a coupler are assembled with the upper bar. Then, the coupler is turned to reach the lower bar. Finally, the lock nut is lowered to clamp the coupler and the upper bar.

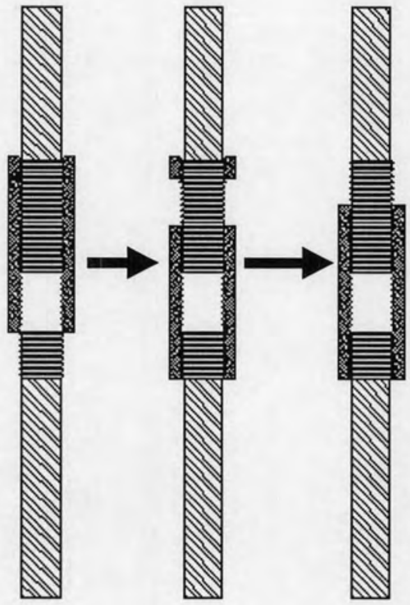


Figure 3.3 Process of assembling the mechanical splice

3.2 Material properties for plain bars and couplers

The threaded bars used for this study are 20mm-diameter reinforcing bars with a SD50 grade. The stress-strain relation of the bar from the tensile test is shown in Figure 3.4. The bar has yield and ultimate strengths of 553.2 MPa and 662.7 MPa, respectively. The modulus of elasticity is equal to 206 MPa. The percentage of elongation at failure is 16%.

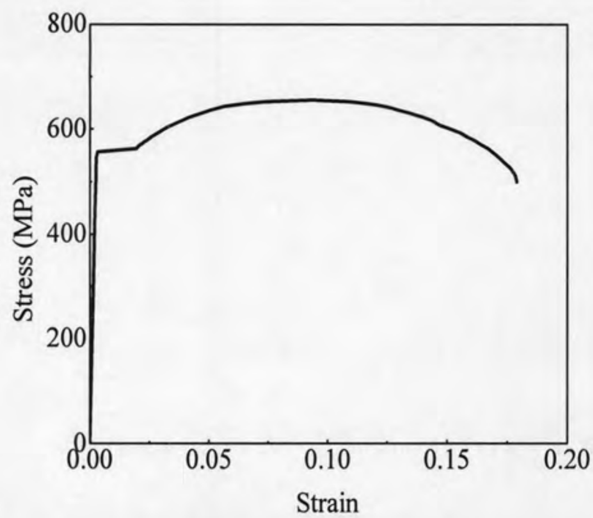


Figure 3.4 Stress-strain relation of reinforcing bar used in this study

The threaded couplers used in this study are produced from SS400 mild steel. The coupler specimens are designed with various thicknesses and lengths with the threaded size of M24×3.0, as shown in Figure 3.5. The stress-strain relation of the SS400 steel is shown in Figure 3.6. For the SS400 steel, the yield strength is 445 MPa and the ultimate strength is 535 MPa. The percentage of elongation is 12.70 % at failure.

Figure 3.5 Different lengths of couplers

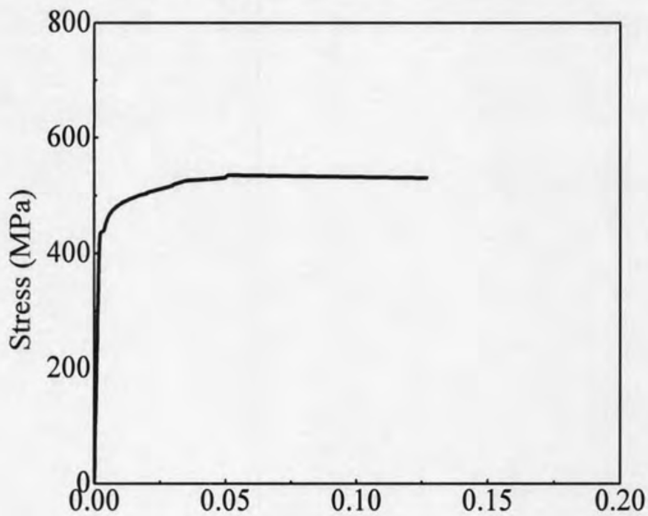


Figure 3.6 Properties of SS400 steel

3.3 Monotonic tensile test of mechanical splices

3.3.1 Specimens

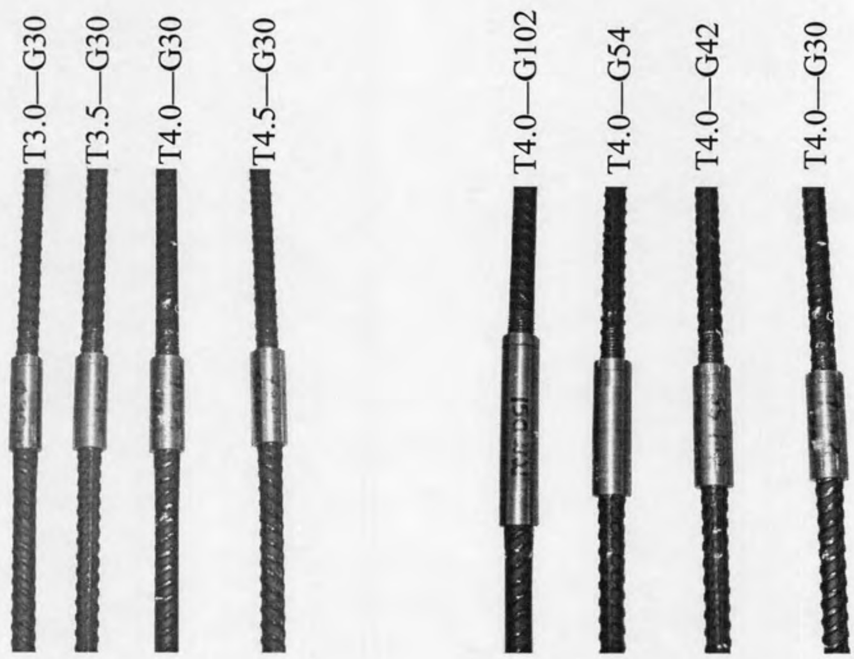
The coupler thicknesses are 3.0mm, 3.5mm, 4mm, 4.5mm and gap lengths are 30, 42, 54 and 102 mm. Table 3.1 shows the parameters. Table 3.2 lists the specimen names. T and G are represented for coupler thickness and gap length between the coupler and threaded bars respectively. Figure 3.7 shows the specimens subjected to tensile test.

Table 3.1 Test cases for tension test

Gap (mm)	Thickness (mm)				Coupler Length (mm)
	3	3.5	4	4.5	
30	√	√	√	√	78
42		√	√		90
54		√	√		102
102		√	√		150
Total	10 Cases				

Table 3.2 Specimens used in this study for tension test

Specimen Name	Properties	
	Thickness (mm)	Gap (mm)
Control Bar	-	-
T3.0-G30	3.0	30
T3.5-G30	3.5	30
T3.5-G42	3.5	42
T3.5-G54	3.5	54
T3.5-G102	3.5	102
T4.0-G30	4.0	30
T4.0-G42	4.0	42
T4.0-G54	4.0	54
T4.0-G102	4.0	102
T4.5-G30	4.5	30



(a) Different thicknesses (b) Different gap lengths

Figure 3.7 Mechanical splice specimens for tensile test

3.3.2 Test setup

The test setup is shown in Figures 3.8. The grip length was 340 mm but the gage length was 200 mm. The elongation of each specimen was measured by a displacement-transducer in the elastic range as shown in Figure 3.9. Tests are conducted to ascertain that the setup yields correct measurement of the modulus of elasticity as shown in Figure 3.10. The deformation in the inelastic range is measured by a digital vernier as shown in Figure 3.8.

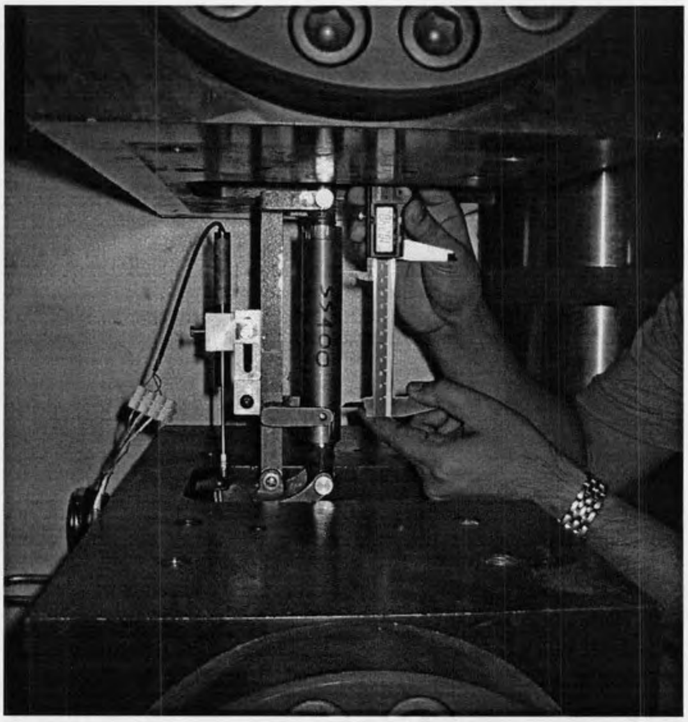


Figure 3.8 Test set-up for monotonic tensile test

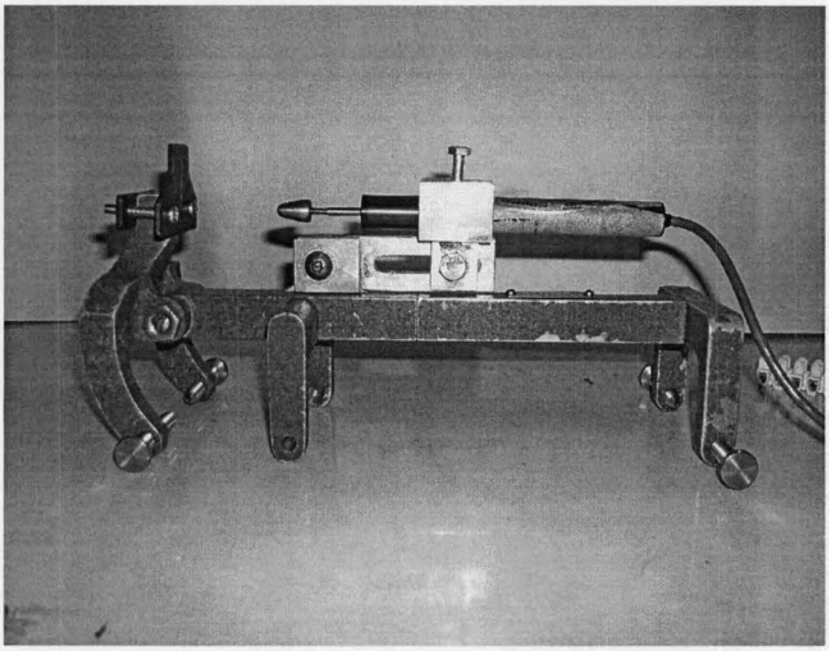


Figure 3.9 Displacement transducer with adapters

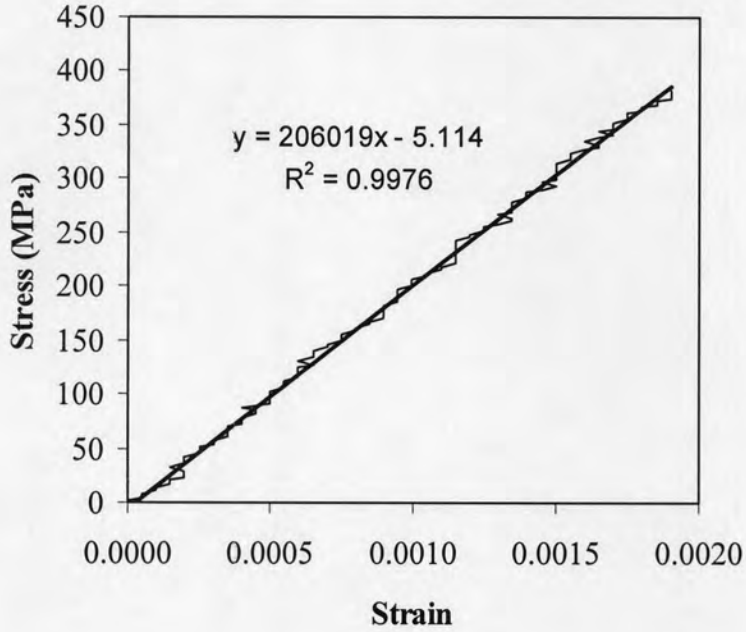


Figure 3.10 The modulus of elasticity of steel bar

A displacement-transducer is connected to an actuator load cell, and an actuator transducer to the data-logger which was then connected to the computer as depicted in Figure 3.11.

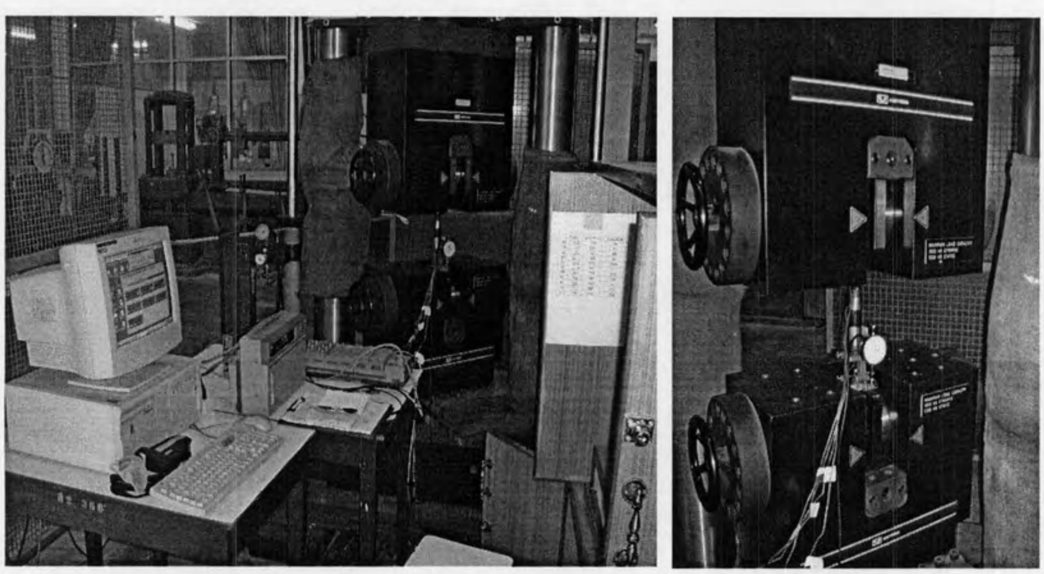


Figure 3.11 Actuator and other instruments used in the study

3.3.3 Test procedures

The test is done under the displacement control mode with the cross head speed of about 0.50 mm/min which is within the range specified in ASTM standard E 8M-04 for tension testing of metallic materials. The range specified in this code is 1.15-11.5 MPa/s (or 0.069-0.69 mm/min for gauge length equal 200 mm). The grip pressure used in the test was 50 bars. The test was paused every 0.1 mm by referring to the reading from displacement transducer during elastic range.

After yielding of the specimen, the actuator cross head speed is increased to 1.0 mm/min. Then, the measurements of all deformations, as mentioned above, are conducted at every 0.5 mm by referring to the reading from displacement transducer. Figure 3.12 shows the parts of a splice measured by a digital caliper in the test.

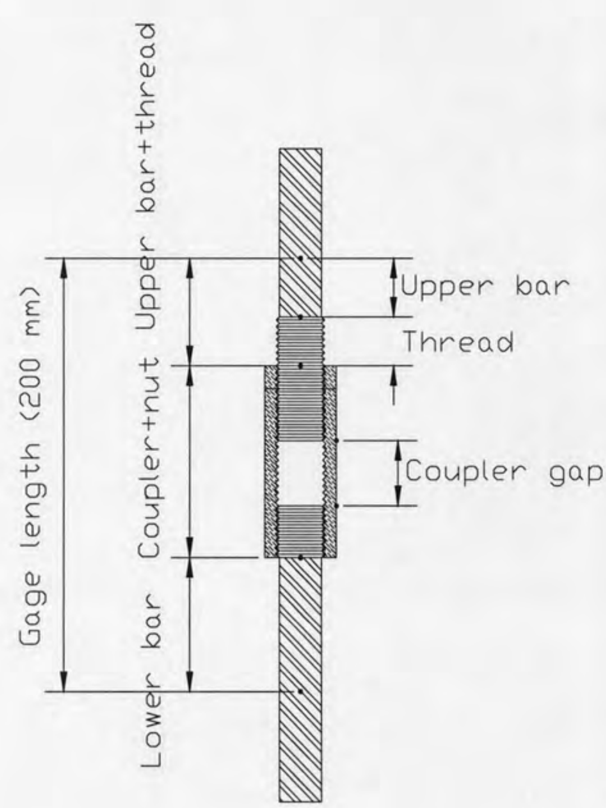


Figure 3.12 Part of mechanical splice measured by digital caliper

3.4 Monotonic compressive test of mechanical splices

3.4.1 Buckling length

From the study of Dhakal and Maekawa in 2002, it is found that the buckling length of the reinforced concrete column may occur in various modes of buckling depending on the stiffness of lateral ties. The buckling length is computed from the product of the stable buckling mode and the tie spacing. Figure 3.13 shows the flow chart of buckling length determination.

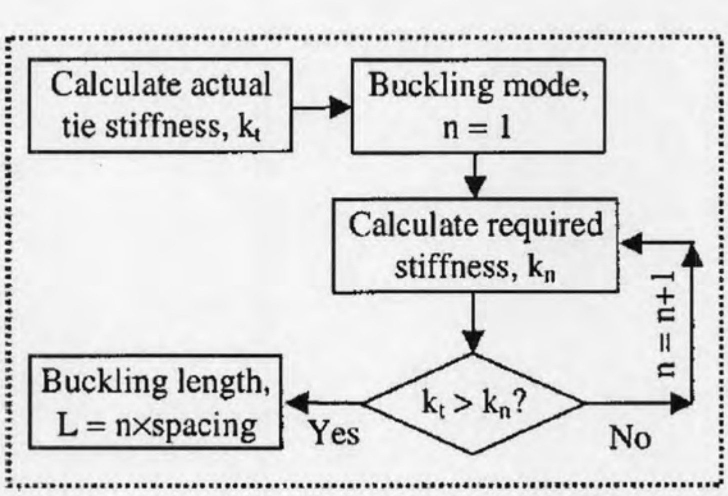


Figure 3.13 Flowchart of buckling length determination (Dhakal and Maekawa, 2002)

The actual tie stiffness, k_t, is determined using Equation (3.1)

$$k_t = \left(\frac{E_t A_t}{l_e}\right)\left(\frac{n_l}{n_b}\right) \tag{3.1}$$

where

E_t = elastic modulus of the tie

A_t = cross-sectional area of the tie

l_e = leg-length

n_l = number of tie legs along the buckling direction

n_b = number of longitudinal reinforcing bars prone to simultaneous buckling.

Figure 3.14 depicts some typical values for n_l and n_b for various section types as presented by Dhakal and Maekawa (2002).

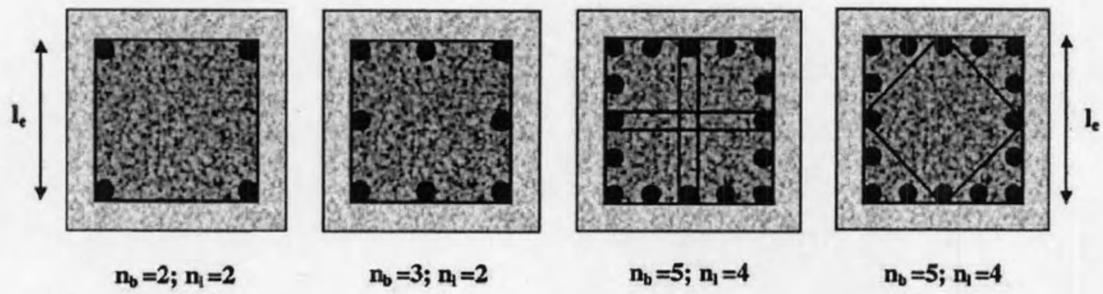


Figure 3.14 Values of n_l and n_b for common reinforcement arrangements

The stiffness of the lateral tie of the column section in Figure 3.15 could be obtained equal to 18711.76 N/mm. The required spring stiffness then could obtained from the product of equivalent stiffness, k_{eq}, and $\pi^4 EI/s^3$ (where s represents the tie spacing) as specified in Table 3.3.

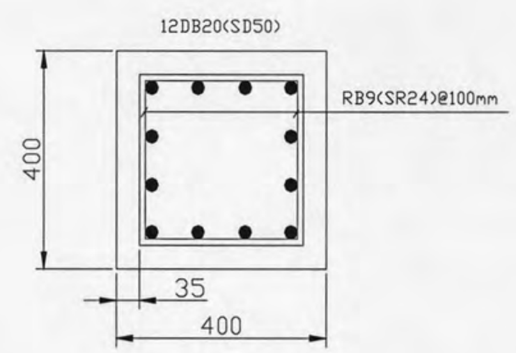


Figure 3.15 Column properties used in this study

Table 3.3 Required spring stiffness for different buckling modes

Stable buckling mode, n	Equivalent Required Stiffness k_{eq} (Lateral Ties Eliminated in)			Average of centrals L/2 and L/3, k_{eq}
	Central L/2	Central L/3	Central L/4	
1	0.7500	0.7500	0.7500	0.7500
2	0.1649	0.1649	0.1649	0.1649
3	0.0976	0.0976	0.0371	0.0976
4	0.0758	0.0137	0.0137	0.0448
5	0.0084	0.0084	0.0084	0.0084
6	0.0063	0.0063	0.0032	0.0063
7	0.0052	0.0022	0.0022	0.0037
8	0.0046	0.0016	0.0016	0.0031
9	0.0013	0.0013	0.0008	0.0013
10	0.0011	0.0006	0.0006	0.0009

By including the effect buckling, the average flexural rigidity of the main bar, which is expressed as $EI=0.5E_sI\sqrt{(f_y/400)}$ was represented by (EI) in the product of equivalent stiffness, k_{eq}, and π^4EI/s^3. The variation of the equivalent stiffness, k_{eq}, from the first mode to second mode (0.75 and 0.1649) was performed. Finally, the smaller of the required spring stiffness (14886.48 N/mm) comparing to the lateral tie stiffness (18711.76 N/mm) occurred in the second mode. From that the buckling length was obtained by the product of the stable buckling mode and the tie spacing as $L_{buckling} = 2\times100 = 200\,mm$.

This quantity is then used in compression and cyclic tests of the steel bar and mechanical splice.

3.4.2 Specimens

The mechanical splice specimens used in the monotonic compressive test were designed to have the length equal to 200mm. This value equals to the buckling length of the longitudinal reinforcement of a reinforced concrete column as mention above.

The parameters of the specimens are listed in Table 3.4 and Table 3.5 for all test cases. Figure 3.16 shows sample of specimens.

Table 3.4 Specimens with descriptive parameters for compression test

Specimen Name	Parameters	
	Thickness (mm)	Gap (mm)
CB-com	-	-
T4.0-G30-com	4.0	30
T4.0-G42-com	4.0	42
T4.0-G54-com	4.0	54
T4.0-G102-com	4.0	102

Table 3.5 Test cases for compressive test

Gap (mm)	Thickness (mm)				Remark	Coupler Length (mm)
	3	3.5	4	4.5		
30			√		1.25D	78
42			√		1.75D	90
54			√		2.25D	102
102			√		4.25D	150
Total	4 Cases					

Figure 3.16 Sample of specimens subjected to compression test

3.4.3 Test set up

For the monotonic compressive test, the displacement transducer was used in the elastic range until it reached 80% of the yield load of coupler (Figure 3.17).The deformation after the yielding of the coupler was measured using a vernier caliper.

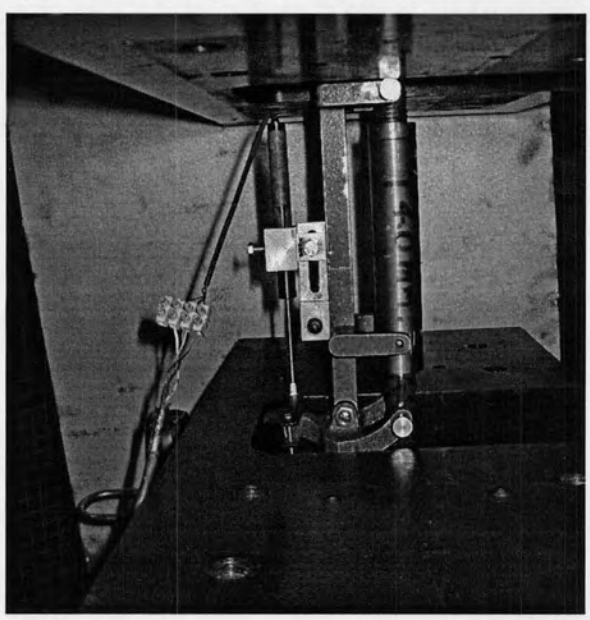


Figure 3.17 Displacement transducer installed at the deformometer to measure the deformation at the elastic range

3.4.4 Test procedures

The test started under the displacement control mode using a constant cross head speed equals to 0.5 mm/min and a grip pressure of 50 bars.

All specimens were tested until the buckling of the bar was disturbed by the actuator cross head.

3.5 Cyclic test

3.5.1 Specimens

The parameters of the specimens are listed in Table 3.6 and Table 3.7 for all test cases. Figure 3.18 shows sample of specimens subjected to cyclic test.

Table 3.6 Specimens with descriptive parameters for cyclic test

Specimen Name	Thickness (mm)	Gap (mm)
CB-cyclic	-	-
T4.0-G30-cyclic	4.0	30
T4.0-G42-cyclic	4.0	42
T4.0-G54-cyclic	4.0	54
T4.0-G102-cyclic	4.0	102

Table 3.7 Test cases for cyclic test

Gap (mm)	Thickness (mm)				Remark	Coupler Length (mm)
	3	3.5	4	4.5		
30			√		1.25D	78
42			√		1.75D	90
54			√		2.25D	102
102			√		4.25D	150
Total	4 Cases					

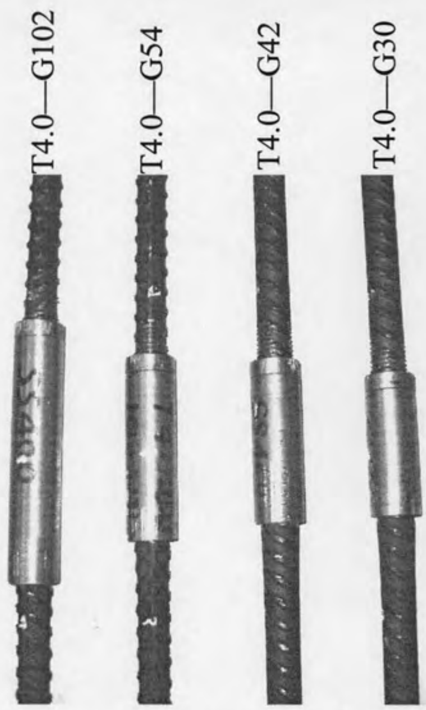
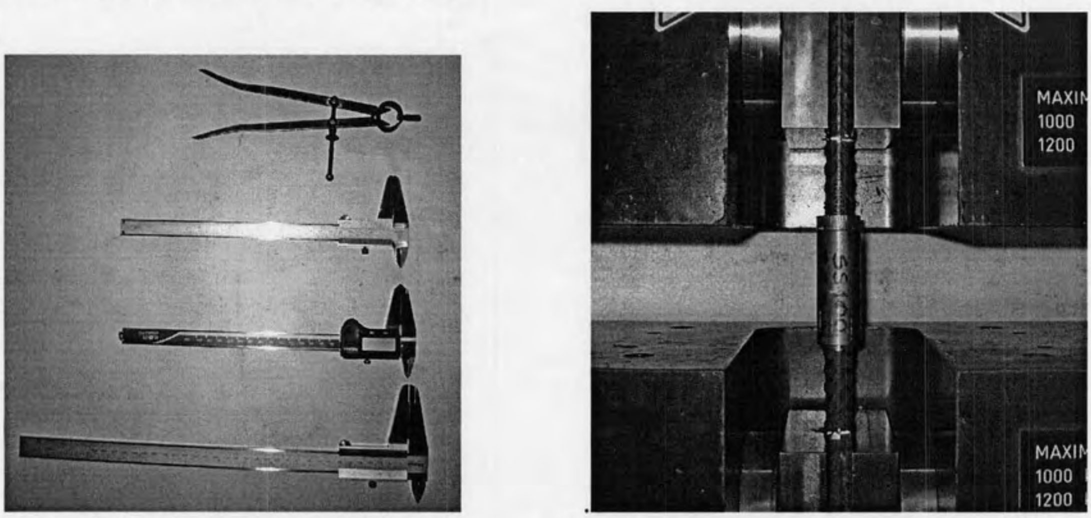


Figure 3.18 Sample of specimens subjected to cyclic test

3.5.2 Test set up

The deformations were measured by vernier caliper both before yielding and after yielding of the bar and coupler.



(a) Verniers and gauge (b) Mechanical splice specimen at actuator

Figure 3.19 Devices and test set up for cyclic test

3.5.3 Test Procedure

The cyclic test used the displacement control mode. A specimen was subjected in tension and compression $\pm 3\delta_{cy}$, $\pm 6\delta_{cy}$, $\pm 9\delta_{cy}$, and $\pm 12\delta_{cy}$ for two cycles per deformation. The value of deformation at yielding (δ_{cy}) is approximately 0.60 mm obtained from the tensile test of specimen T4.0-G102. The prescribed displacement was referred to the stroke of the actuator which is not the true displacement of a specimen. Because the displacement of the stroke includes the slip between the bar and grip as discussed earlier.

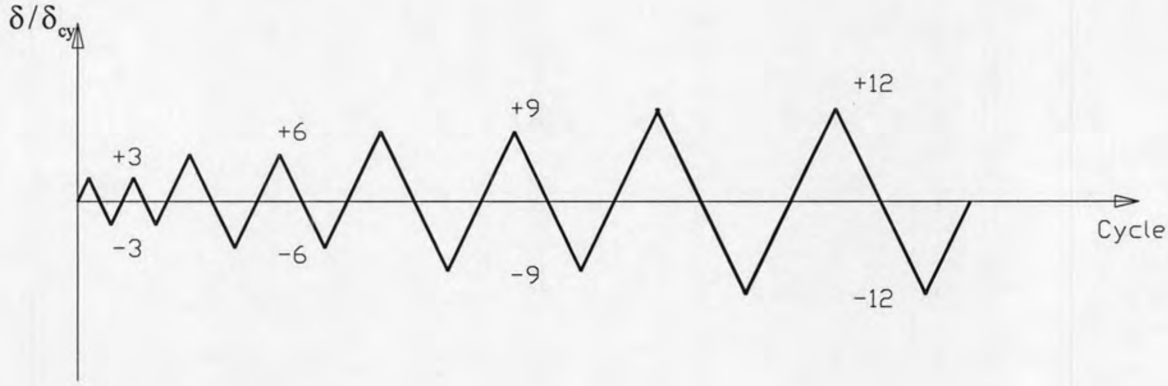


Figure 3.20 Schematic representation of cyclic test

3.6 Slip test

3.6.1 Specimen

The specimen in this test used a mechanical splice T4.0-G30.

3.6.2 Test set up

The slip was measured using the displacement transducer as shown in Figure 3.21

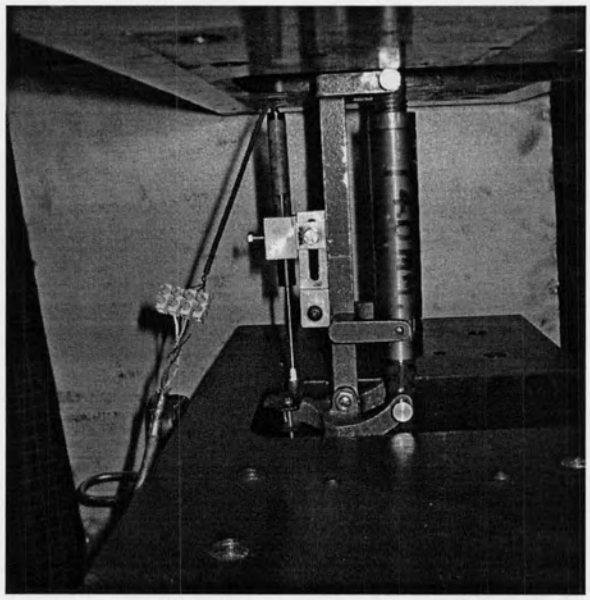


Figure 3.21 Displacement transducer installed at the deformometer to measure the slip between the coupler and thread bars

3.6.3 Test Procedure

The splice specimen was subjected to tensile cyclic test. The schematic of the test is shown in Figure 3.22. The slip is defined as the residual deformation of the difference of deformations in each cycle at stress 4 MPa.

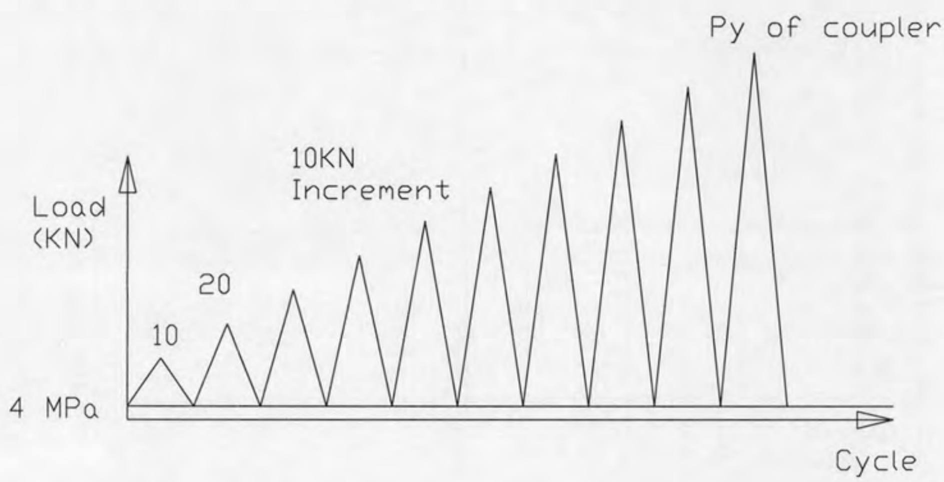


Figure 3.22 Loading schematic of slip test