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Experimental Study of Two Way Half Slab Precast Using Triangular Rigid Connection of Precast Concrete Component

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Abstract

Precast concrete half slab system, which consists of precast concrete at the bottom part and cast-in-site concrete at the overtopping, is widely used as floor slab and commonly behave as a one-way slab. However, the problems occur when the precast half slab is designed as the two-way slab system. In this system, the connection of between precast concrete slabs should able to handle the two-way moment of the whole panel, without causing any significant damages. Hence, an innovative rigid connection between precast concrete slab components in two-way half slab system is presented in this paper. The objectives of this research are to conduct the experimental study for proposed connection between precast concrete slab components that behave as two-way half slab system. The 2200 mm × 2200 mm size of samples are performed using the triangular shape of the rigid connection between precast concrete slabs. The test is conducted using mid-span concentrated loading-unloading up to failure condition.

The test results are observed and verified with the response of monolith reinforced concrete slab system using the same loading pattern. The verification results show that proposed half slab system are able to withstand the two-way moment loading. Although the carrying capacity is still slightly lower than the monolith reinforced concrete slab system, the proposed half slab system is able to apply as the structural component.

Keyword: half slab, precast concrete, reinforced concrete, rigid connection, loading-unloading

INTRODUCTION

The precast concrete half slab is a structural slab system that consists of two different concrete type at the half bottom and the top part of the slab. The bottom part of the slab is made up of the precast concrete component, while the top part is contained of cast-in-site concrete material that so-called overtopping, as presented in Fig.1. Generally, precast concrete half slab system is acting limited as one-way slab only ($l_y/l_x > 2$), which is the primary moment loading is acting parallel to the connection between precast concrete components. Therefore, since such connection only resists the minor moment loading, the simple connection is commonly applied between the precast concrete components (as shown in Fig.2), as presented by Wijanto and Takim [1]. However, the problems occur when the precast half slab is designed as the two-way slab system. Since the moment loading act in both X and Y direction, the connection between the precast concrete components should be able to handle the acting moment in the corresponding direction. Otherwise, the crack damages will occur along the corresponding direction. The real case of port design that using the simple connection for two-way precast concrete half slab system is presented by Irawan et al [2]. Fig.3 shows the simple connection of the precast concrete slab component that applied in the port design. Furthermore, the crack that occurs in the bottom part of the slab due to the lacking capacity of the precast connection is depicted in Fig 4. Concrete crack only occurs parallel to the connection between precast concrete slabs.

This phenomenon indicates that the simple connection between precast concrete slabs cannot resist the moment loading to the corresponding direction. Hence, it is necessary to develop the rigid connection that applied in this connection system that can withstand the corresponding moment loading.

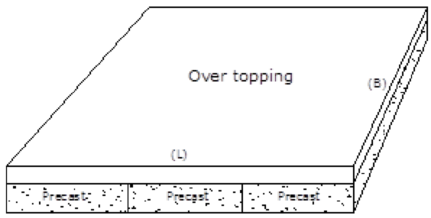

Figure 1. Half Slab Precast Concrete System

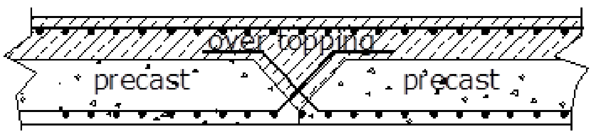

Figure 2. The simple connection is commonly applied between the precast concrete components

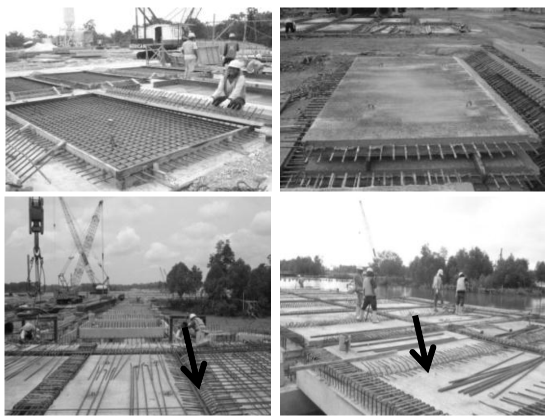

Figure 3. The simple connection at the bottom part of half slab precast

Many studies about the connection of precast concrete half slab have done previously by researchers. Hieber et al. [3] presented the interlocking connection that able to withstand the shear loading. Hence, the slab could be performed as diaphragm appropriately. Kim and Shim [4] investigated the performance of pre-tensioned half slab in the transverse direction and used the looping connection in the longitudinal direction. Kim and Shim [5] also investigated the crack width of half precast slab using looping connection between precast components. Using precast concrete also can reduce operation time substantially comparing to cast in situ concrete. Moreover, Yardim [6] proposed the connection for a precast thin panel that acts as composite slabs for the permanent framework in a residential building. Siswosukarto [7] proposed semi-precast slab as an alternative method to promote the green construction residential house project. Research about the flexure-shear behavior of precast concrete deck panels with cast-in-place concrete topping is also performed by Dowell. et al [8]. The failure prediction of the panel is analyzed using modified. However, this study only focused for the slab in one direction. Additionally, Santos and Julio, [9] has studied about horizontal friction between old and new concrete slab in half precast system. The load transfer mechanism at the concrete to the concrete interface is determined by several factors, such as cohesion behavior, friction coefficient, and dowel action. Lee at al [10] also studied about deflection of Reinforced Concrete Half Slab. Vakhsouri, [11] studied about the length of reinforcement adjacent to the crack where the compatibility of strain between the steel and concrete is not maintained because of partially bond breakdown and slip. However, most of those previous study is limited for one-way half slab precast system.

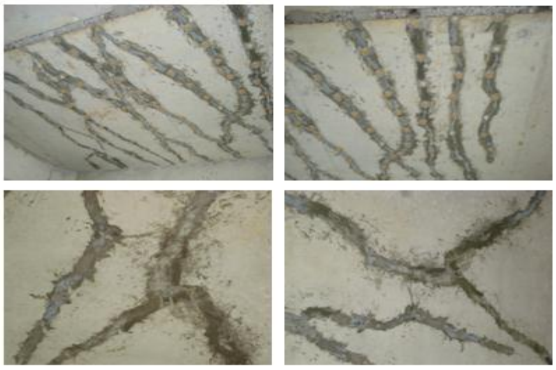

Figure 4. The crack that occurs at the bottom part of two ways half slab precast

Several types of research about two-way slab have already done by Tezuka [12] who examined experimentally about half - precast waffle slab for long spans. Moreover, Moldovan and Mathe [13] also have studied two-way waffle slab with post-tensioning pre-stressed. Furthermore, D. Fall et al [14] has studied analytically about two-way slab using steel fibers. Other studies of two-way slab also have done by Kim et al [15], who studied about flexure strengthening of the two-way slab by using CFRP. Gouverneur and Taerwe, [16] studied strain and crack development in continuous reinforced concrete slabs subjected to catenary action. However, all of those researchers only for the full-depth two-way slab. Whereas, for two-way half slab precast studies are still very limited perform by researchers. Based on those previous studies, preliminary experimental study about precast concrete half slab has performed by Irawan et al [2], which proposed the semi-rigid connection as shown in Fig.5a to 5c. The 800 mm × 5000 mm size of the precast concrete half slab was presented as a specimen. The total thickness of the slab was 500 mm, which is divided into 350 mm thickness of precast concrete and 150 mm of overtopping concrete. The specimen was set up as simply supported at two sides of the slab and subjected to the pure bending static loading along the corresponding direction of the connection. Hence, the slab specimen behaved as a one-way slab and the response of the connection that subjected to the bending loading along the corresponding direction can be obtained and observed.

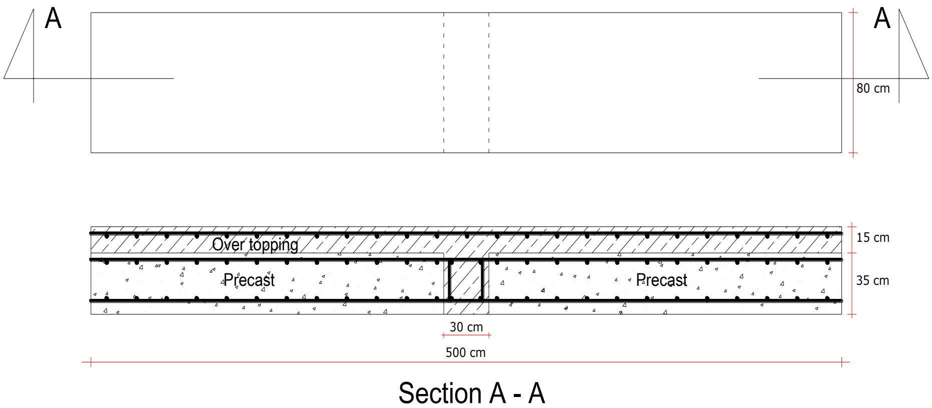

Figure 5a The half slab precast model of preliminary study

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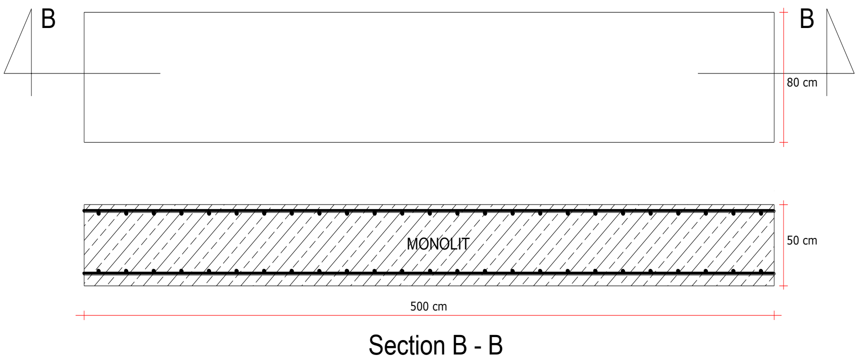

Figure 5b The monolithic slab model of preliminary Study

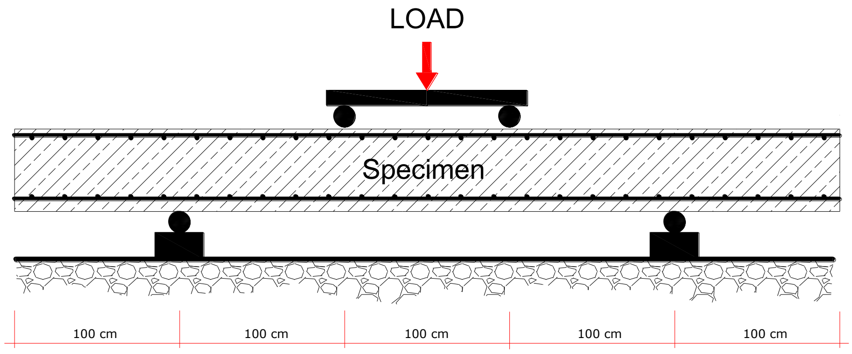

Figure 5c. Experimental set up of preliminary study

Based on the experimental result, which presented in Table 1, it was showed that the capacity of proposed precast concrete half slab to resist the cracking moment was 16% lower than monolith system. Therefore, to improve and increase the capacity of the precast concrete half slab, this paper present experimental study for proposed rigid connection between precast concrete slab components in two-way half slab system.

Table 1. Comparison P crack and M crack between monolithic slab and slab with connection

MODEL	P crack (Ton)	M crack (Ton-m)	REMARK
Slab with connection	15.2	7.72	Crack
Monolith slab	17.7	8.97	Crack

RESEARCH METHOD

This experimental study present 2200 mm × 2200 mm size of the specimen using the rectangular shape of the rigid connection between precast concrete slabs. The total thickness of the proposed concrete half slab is 200 mm, which is divided into 120 mm thickness of precast concrete and 80 mm of overtopping concrete. Moreover, in order to prevent slip between precast concrete and overtopping, several shear connectors are added to its interface. Furthermore, the simply supported at four sides of the precast concrete half slab are applied. The detail experimental setup is illustrated in Fig. 6a and 6b.

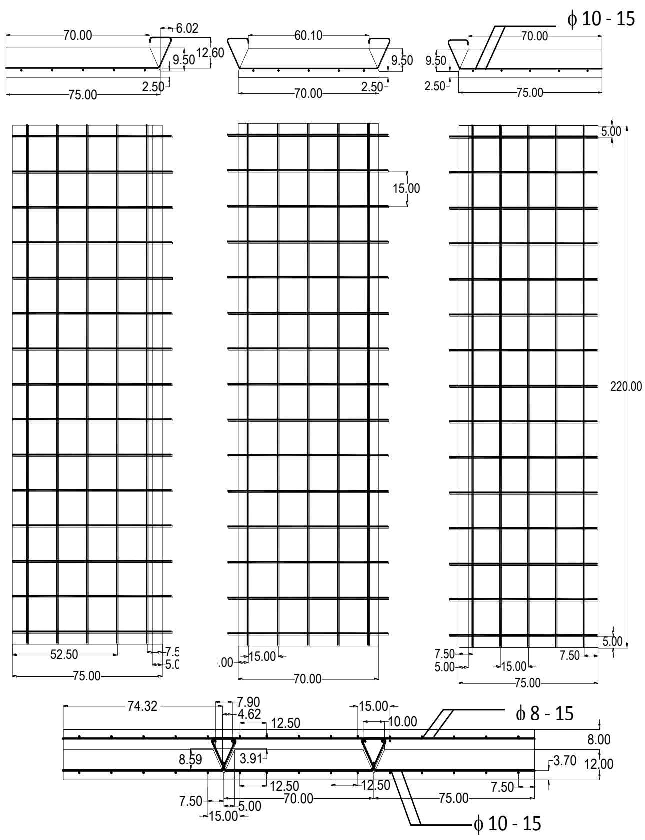

Figure 6a. Half slab precast model with triangular connection

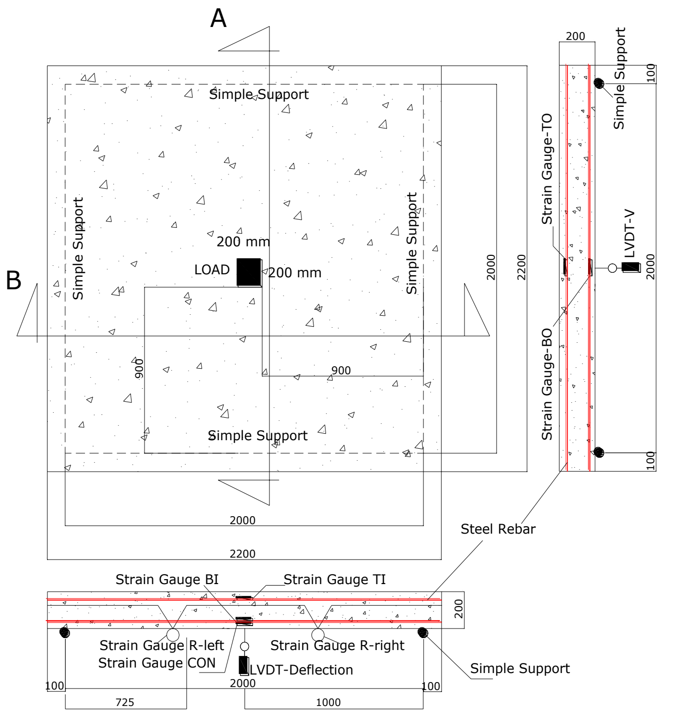

Figure 6b. Experimental setup of half-slab precast with triangular connection

Additionally, the test was conducted using mid-span concentrated loading-unloading up to failure condition, which is based on ACI 437R-03 [17] and presented in Fig. 7. The loading-unloading scheme is contained in three cycles, there are an elastic condition, concrete cracking, and plastic condition. Thus, the realistic behavior of two-way precast concrete half slab can be obtained and observed clearly. The results of the test are verified with the response of monolith reinforced concrete slab system (as shown in Fig. 8a and 8b), which also using the same loading pattern.

In addition, the material properties of the specimens are presented in Table 2.

Table 2 Material Properties

SLAB	COMPONENT	Compressive Strength fc' (Mpa)	
Monolithic Slab	Monolithic Slab	46.9	
Half Slab	Overtopping		46.9
	Precast		49.2

To observe the detail response such as strain and displacement, the specimen should equip by appropriate sensor component to measure the deformations. In this study, the sensor equipment that applied in the specimen is rebar and concrete strain gauge, an also LVDT that applied in both X, Y and Z direction. The detail location of the sensor equipment that applied in the specimen is presented in Fig. 9a to 9c.

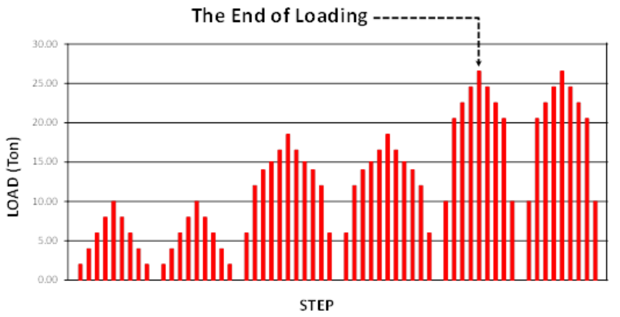

Figure 7. Experimental loading (Actual)

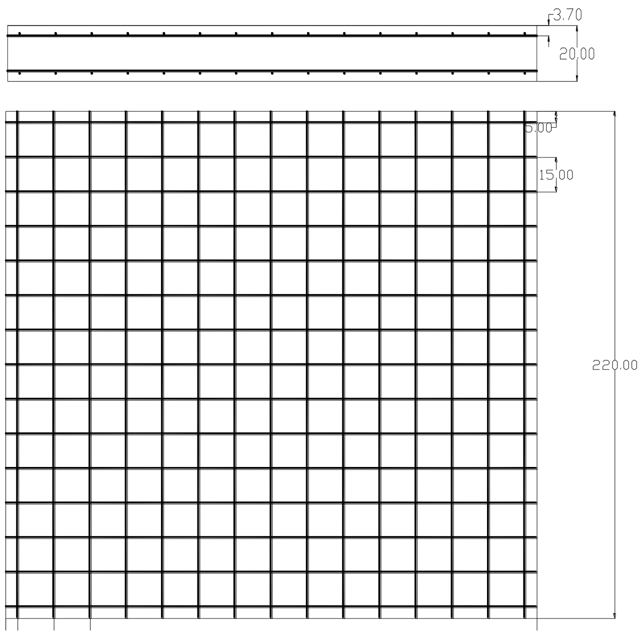

Figure 8a Monolithic model

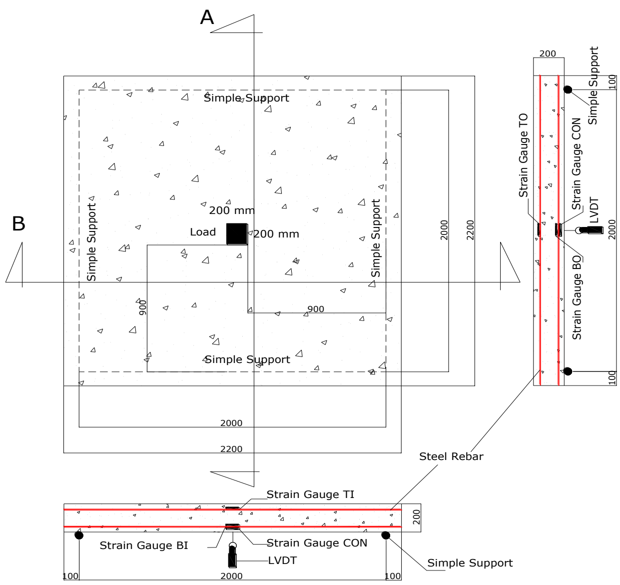

Figure 8b. Experimental setup of monolithic model

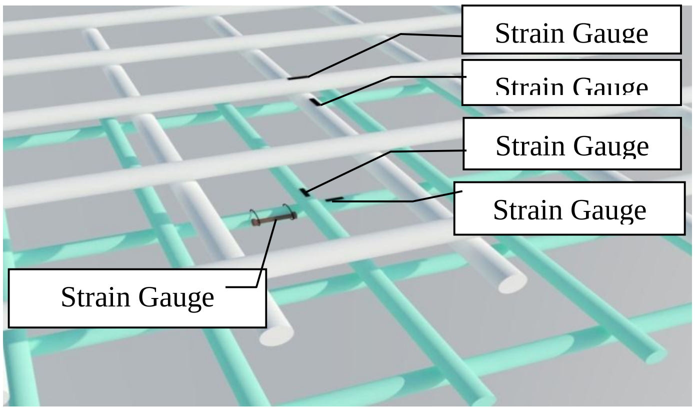

Figure 9a Strain gauge position in specimen

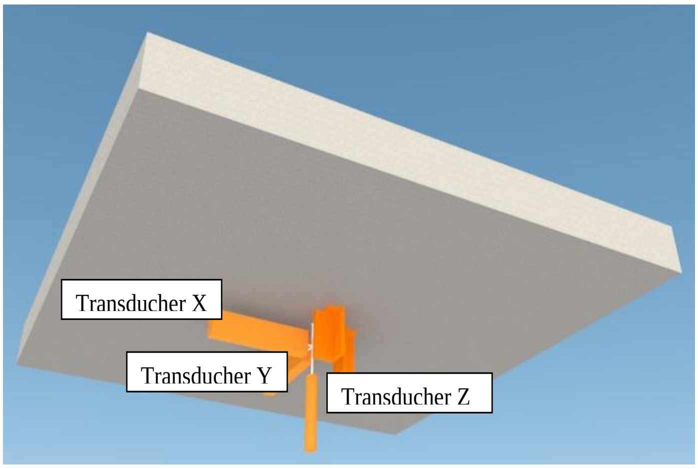

Figure 9b Transducer / LVDT position on monolithic model

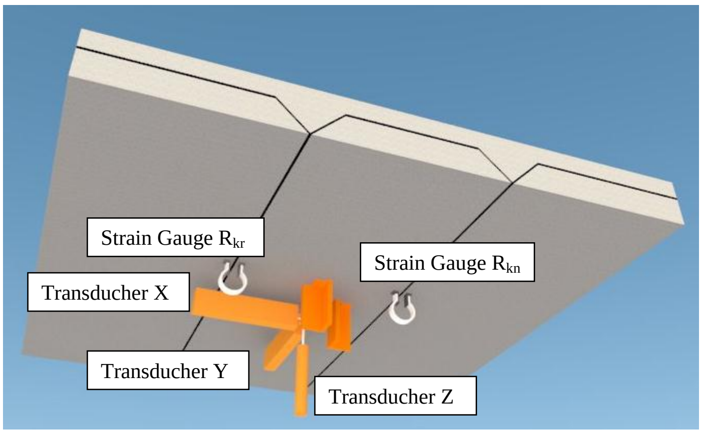

Figure 9c Transducer / LVDT position in half slab precast with triangular connection

RESULT AND DISCUSSION

The response of the specimen that observed this experimental study is consist of displacement both in X, Y, and Z direction; tension and compression strain of reinforcing steel bar width of concrete crack and also crack pattern. The detail observation results, as well as the discussion, is presented as follows.

a. Observation of Load – Displacement Relationship

Monitoring of displacement conducted using LVDT in both X, Y and Z direction which the result is presented in the data logger. Since the LVDT is installed and placed at the center of the span (Fig. 9b, and 9c), the displacement that observed in this study is only limited at the corresponding location. The relationship of load versus displacement curve that observed in this study is presented in Fig. 10 to Fig 15 for X, Y and Z direction, respectively. For the lateral displacement in X and Y direction, as shown in Fig. 10 to Fig 13, respectively, the value occur after the concrete crack has happened. Before concrete crack has occurred, the slab still remains in elastic condition. Which the slab still deflect simultaneously and satisfy the plain remain plain condition. The displacement curve at X direction of the proposed Half Slab Model with Triangular Connection showed as a tri-linear curve. The first change is happened due to the first crack of the concrete, and the second change is happened due to crack that occurred in the vertical interface between precast and cast-in-situ concrete. While for the monolithic concrete slab, the displacement curve in the X direction is still as a bilinear curve, which means the curve change is only due to the concrete crack that happened at the center of the span. For the displacement at Y direction, both Monolithic Monolithic and Half Slab Model with Triangular Connection has bi-linear displacement curve. This happened because in proposed Half Slab Model with Triangular Connection, the discontinuity between precast concrete only at X direction. Thus, the behavior at the Y direction of both Monolithic Model exactly the same. Furthermore, to obtain the cracking loading of the specimen it is also necessary to consider the deflection at Z direction. Since the loading is applied in the corresponding Z direction, the response in this direction is determined the capacity of the specimen. Based on the observation results, it is shown that the value of crack loading for each specimen, as seen in Fig 14 to 15, show that the proposed Half Slab Model with Triangular Connection has crack loading 17.9 % lower than the monolithic concrete slab. This happens because the proposed Half Slab Model with Triangular Connection has two different concrete components, such as precast concrete and cast in situ concrete. The interface between those components is becoming the discontinue part that will decrease the capacity of the concrete specimen.

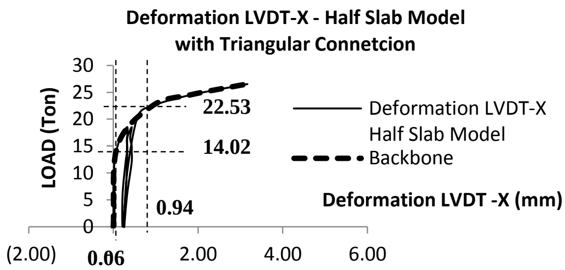

Figure 10. Deformation-X vs Load of monolithic model

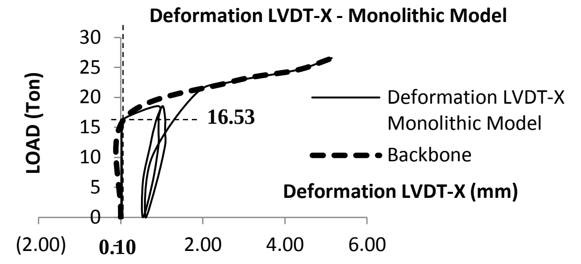

Figure 11. Deformation-X vs Load of half slab precast with triangular connection

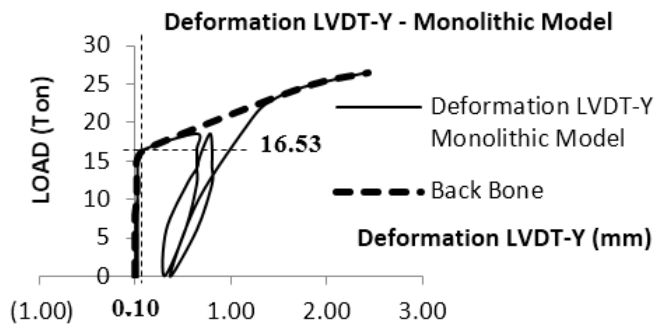

Figure 12. Deformation-Y vs Load of monolithic model

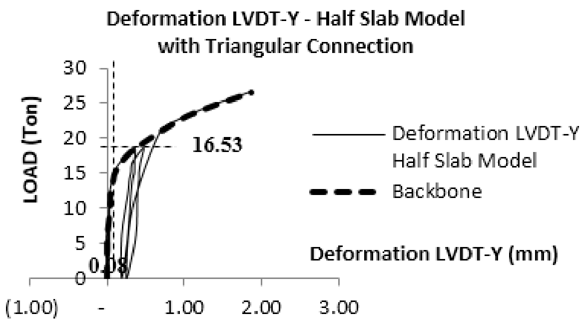

Figure 13. Deformation-Y vs Load of half slab precast with triangular connection

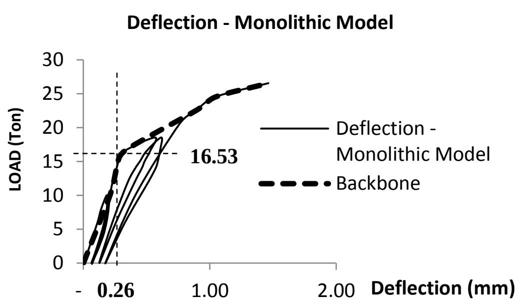

Figure 14 Deflection vs Load of monolithic model

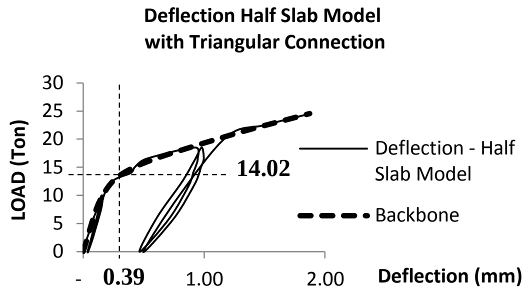

Figure 15. Deflection vs Load of half slab precast with triangular connection

b. Observation of Load – Rebar Stress Relationship

Monitoring of rebar strain conducted using strain gauge in both X and Y direction which the result is presented in the data logger. The strain gauge is installed and placed in both tension and compression reinforcing steel bar. The relationship of load versus stress curve for both tension and compression reinforcing steel bar that observed in this study is presented in Fig. 16 to Fig. 23, respectively. The response of the steel bar is similar with the concrete displacement.

The rebar that located in the X direction of the proposed Half Slab Model with Triangular Connection has a tri-linear curve. Again, this happened due to the discontinuity between precast concrete components. The first change of the tri-linear curve is happened due to the first crack of the concrete slab, and the second change is happened due to crack that occurred in the vertical interface between precast and cast-in-situ concrete.

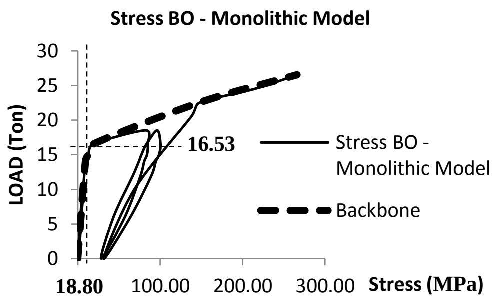

Figure 16 Stress-BO vs Load of monolithic model

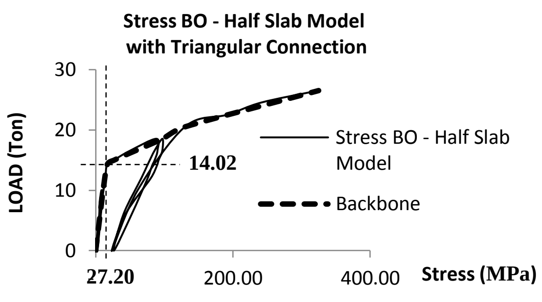

Figure 17 Stress-BO vs Load of half slab precast with triangular connection

Fig. 16 and Fig. 17 show the relationship between load and stress that occurred in the BO strain gauge. BO strain gauge installed on the bottom concrete reinforcement outer layer, indicating that the stress of bottom reinforcing steel of Monolithic Model and B. The relationship curve of load versus stress is linear-shaped before cracked. After the concrete has cracked, the movement of the backbone of the stress curve still linear but the slope of the curve has already changed. BO stress value for the Monolithic Model at the beginning of the crack is 18.80 Mpa and Half Slab Model with Triangular Connection is 16.20 Mpa. Furthermore, for BI strain gauge, which installed on the bottom concrete reinforcement inner layer, has a trend similar to the BO strain gauge, but the value is smaller than of BO stress.

The value of BI stress at the beginning of the crack is equal to 16.60 Mpa at 16.53 ton load for Monolithic Model and 11.87 Mpa at 14.02 ton load for Half Slab Model with Triangular Connection. The relationship of load versus the value of BI stress can be seen in Fig. 18 to 19.

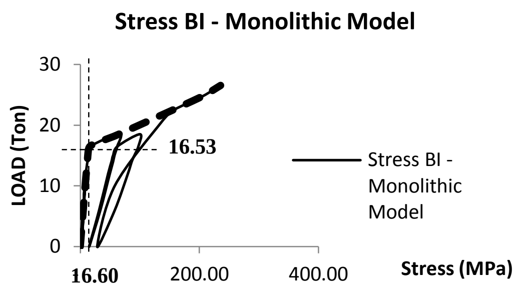

Figure 18 Stress-BI vs Load of monolithic model

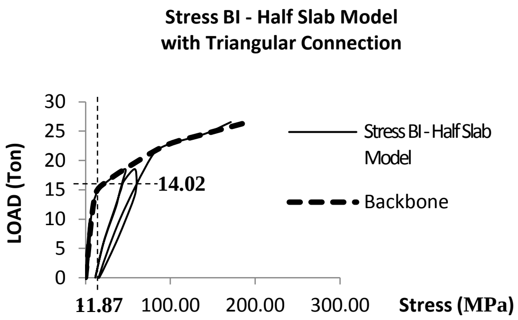

Figure 19 Stress-BI vs Load of half slab precast with triangular connection

The relationship of load versus stress value of TO and TI can be seen in Fig. 20 to Fig. 23. TO strain gauge which is installed on the upper concrete reinforcement outer layer, indicating that the stress of upper reinforcing steel of Monolithic and half slab model. Stress that occurs in reinforcement is the compression stress. At the beginning of the crack, the stress of reinforcement in Monolithic Model is -16.45 Mpa and for Half Slab Model with Triangular Connection is -10.52 Mpa. The value of stress will continue to increase if the load is increased. But at the certain load, acceleration of the increasing stress will decrease. This happens due to the shifting position of the neutral axis is getting to the top fiber. Furthermore, TI strain gauge has a trend similar to the TO strain gauge, but the value is smaller than of TO stress. TI stress value at the beginning of the crack is equal to -16.45 Mpa at 16.53 ton load for Monolithic Model and -8.40 Mpa at 14.02 ton load for Half Slab Model with Triangular Connection.

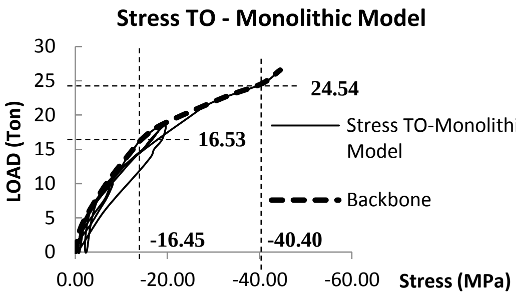

Figure 20 Stress-TO vs Load of monolithic model

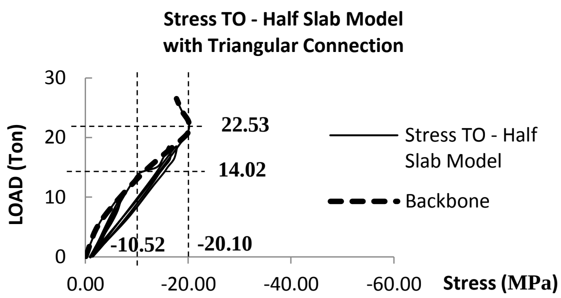

Figure 21 Stress-TO vs Load of half slab precast with triangular connection

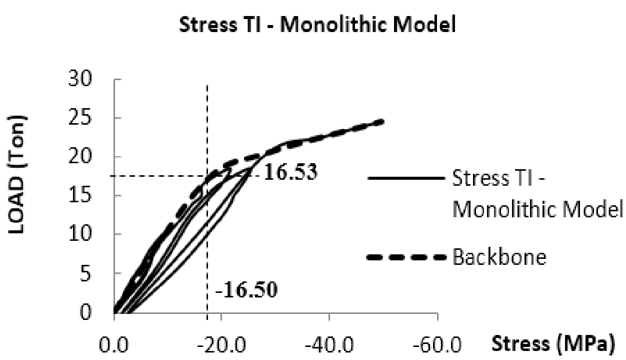

Figure 22 Stress-TI vs Load of monolithic model

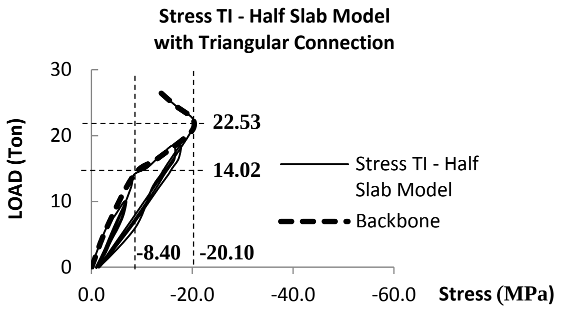

Figure 23 Stress-TI vs Load of half slab precast with triangular connection

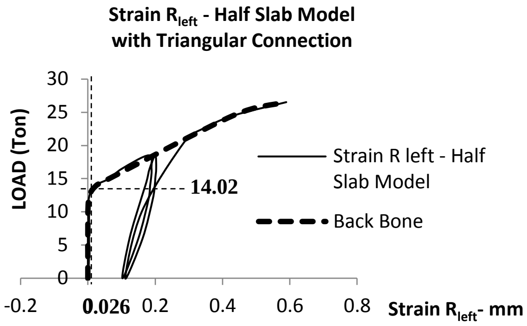

Figure 25 Strain-R_{left} vs Load of half slab precast with triangular connection

c. Observation of Load – Concrete Strain Relationship

Strain gauge CON embedded at the mid-span in the bottom of concrete X direction shows the strain that occurs in concrete. The shape of the curve backbone strain and load relationship changes two times as the backbone of the curve BI stress and load relationship shown in Fig. 19. The changing of the curve at first, when the first crack occurs at the mid-span of concrete and then the second time when the connection between precast components have cracked. The relationship of load versus strain of concrete can be seen in Fig. 24.

Additionally, Rr_{ight} and R_{left} strain gauges that installed on the interface of the joints between precast components at the right and left locations, show the movement of cracks that occur in these locations. Based on the monitoring results show that the strain occurring strain began to occur after the concrete has been cracked. This happens because the strain gauge installed at the concrete surface. So before the concrete cracked, strain gauge has no response. But after the first crack occurs at the connection between precast components, the strain's value has begun to be read. The relationship of load versus strain of R_{left} strain gauges can be seen in Fig. 25. But the relationship of load versus strain of R_{right} strain gauges could not be obtained, because there was a damage in the strain gauge.

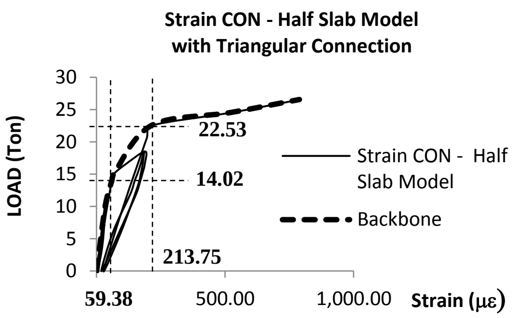

Figure 24 Strain-CON vs Load of half slab precast with triangular connection

d. Observation of Crack Pattern

Based on the experimental observation that the crack pattern of monolithic slab Monolithic Model due to loading – unloading, the crack pattern from elastic condition until the ultimate condition has diagonal direction. But at the beginning loading, half slab precast Half Slab Model with Triangular Connection has a crack pattern at mid span and perpendicular to the direction of the joints between the precast components.

The next cracking occurs at the connection between the precast components that have begun to be separated. After that, the next crack propagation started in a diagonal direction. So it can be concluded that the half slab of precast initially still behaves as a one-way slab, but after reinforcement at the connection between precast components has been tightened, half slab precast can behave as a two-way slab. The crack propagation of monolithic slab and half slab precast with a triangular connection can be seen in Fig. 27 to Fig. 30.

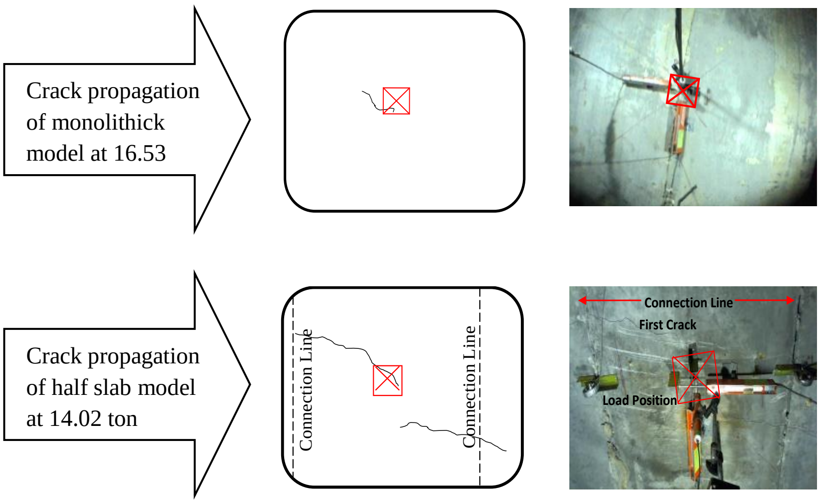

Figure 27 Initial crack of Monolithic and Half Slab Model at crack load

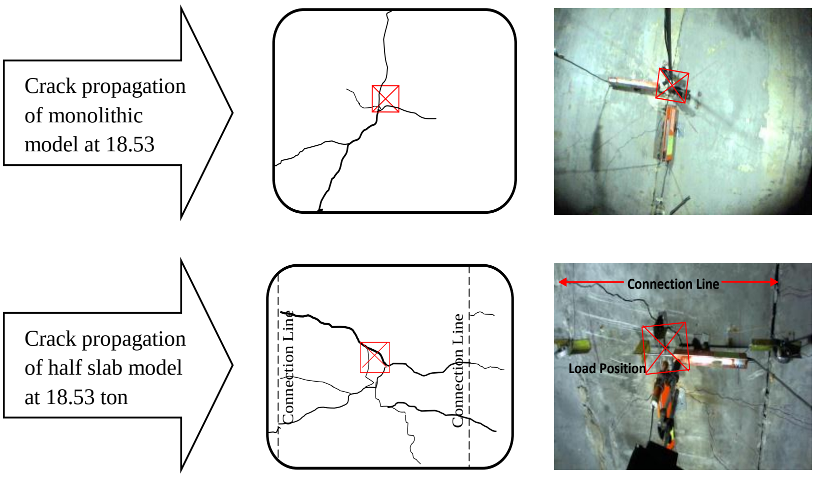

Figure 28 Initial crack of Monolithic and Half Slab Model at crack load

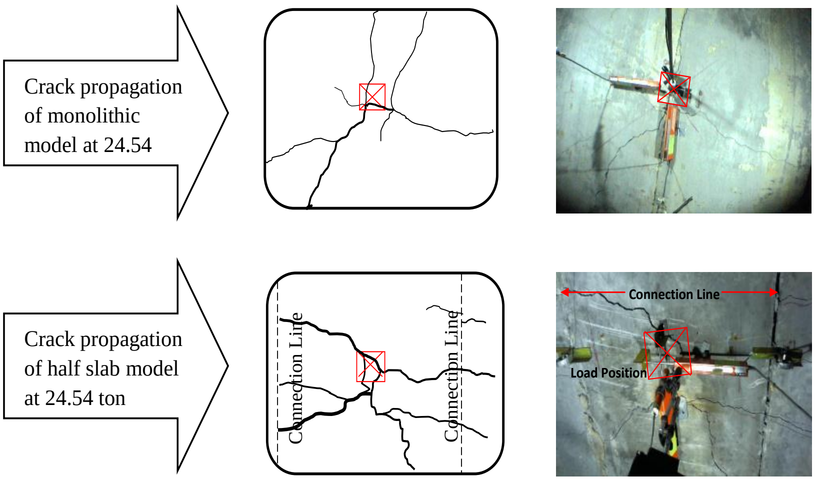

Figure 29 Crack propagation of slab model A and B at 24.54 ton load

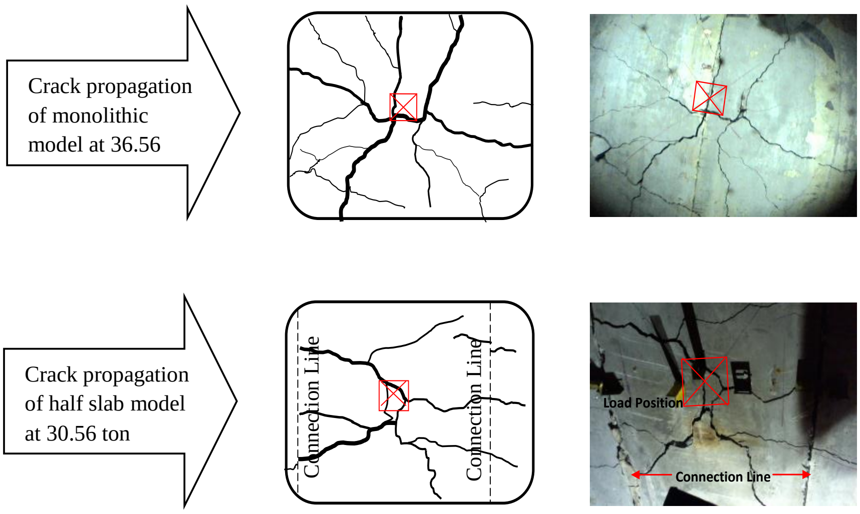

Figure 29 Crack propagation of slab model A and B at 24.54 ton load

CONCLUSION

Base on experimental results, the two-way half slab precast with a triangular connection has a deflection is higher than the monolithic slab. The differences is reached 12%. The crack load of two-way half slab precast with Triangular Connection has a crack load smaller than a crack load of the monolithic slab, but not less than 18%.

The reduction of crack load shows not many differences compared with the model proposed in the preliminary study. The differences reach 16.5%. However, half slab precast with triangular connection does not require formwork to be installed underneath between precast components as required in the model preliminary study.

The strain of monolithic slab at mid-span X direction has a strain's value higher than half slab precast. This happens because in the half slab precast has a connection between a precast component in the X direction. So it can be made reducing the strain in concrete.

The propagation of half slab of precast initially still behaves as a one-way slab, but after reinforcement at the connection between precast components has been tightened, half slab precast can behave as a two-way slab.

The tension reinforcement of half slab precast in X direction will increase after the initial crack and will increase again after the connection between precast components has begun to be separated. So the backbone of the curve that shows relationship load versus reinforcement stress has three linear shape as shown in Fig. 19. Because of in Y direction there is no connection, then the backbone of the curve has a bi-linear shape as shown in Fig. 17.

The value of stress in compression reinforcement will continue to increase if the load is increased. But at the certain load, acceleration of the increasing stress will decrease. This happens due to the shifting position of the neutral axis is getting to the top.

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