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Strengthening of Reinforced Concrete Slab by Concrete Overlay

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Abstract | This experimented work was used to learn flexural behaviors of reinforced concrete slabs strengthened by concrete overlay under static loading. Principal parameters included the thickness of concrete overlay and contact surface between slab and concrete overlay, with and without shear connector. The experimental results reveal that flexural stiffness and ultimate moment capacity of the slab with concrete overlay can be significantly improved above control specimen for all types of contact surface. Ductility of strengthening slab with shear connector is greater than that of the overlaid slab without shear connector. Also, it can observe brittle shear failure and debonding of contact surface due to high shear flow of the overlaid slab without shear connector and thick overlay concrete. This should be taken into account in the design consideration

Keywords | Composite action, Concrete overlay, shear connector.

Introduction | Reinforced concrete (RC) slab has been used in the construction of short to medium span length of bridges in Thailand. Deterioration of reinforced concrete slab can be caused by, overloading due to illegal traffic load, accidental fire damage, abrasion due to the traffic and corrosion of steel reinforcement due to concrete carbonation and chloride attack leading to the spalling of concrete cover. Figure1 shows the example of two types of deterioration of the RC deck slab, fire damage and abrasion. Performance of the slab, in terms of strength and stiffness, can be reduced with time. Maintenance should perform after the assessment of the slab type bridge. Degraded concrete on the top surface of the slab can be removed and can be overlaid by high-performance concrete. Flexural behaviors of RC slab strengthened by means of concrete overlay with various types of surface treatment between the slab and concrete overlay under static loading are studied in this work.

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Fig. 1: Surface deterioration of concrete bridge surface due to fire and abrasion. Source: Authors.

Literature Review

Many civil infrastructures have been under deterioration. Many researchers have applied externally bonded fiber reinforced polymer (FRP) sheets for reinforcement or strengthening of concrete structures.

Barros and Sena-Cruz (2001) conducted a simulation through a numerical model by using laminates of carbon fibre reinforced polymer (CFRP), layer of steel fibre reinforced concrete (SFRC) and the simultaneous use of CFRP laminates and SFRC overplayed for strengthening strategies as a way to increase the load bearing capacity of a concrete slab.

Mosallam and Mosalam (2003) presented an experimental and analytical investigation for evaluating the ultimate response of unreinforced and reinforced concrete slabs repaired and retrofitted with fiber reinforced polymer (FRP) composite laminates. For repair cases, test results of FRP systems were effective as the strength of the repaired slabs five times increased compared to that of the as-built slabs. For retrofitting applications, FRP systems can increase structural capacity of the as-built slabs up to 500% for unreinforced specimens and 200% for steel reinforced specimens.

Piyong et al. (2003) tested the flexural performance of a concrete slab strengthened with a three-stage prestressing system using CFRP sheets under a four-point static load test setup. The setup imposed a camber profile on the concrete slab such that upon release of the prestressing system initial stresses would develop in CFRP sheets. The test installed three glass FRP (GFRP) anchor spikes at each end of the prestressed FRP sheets, to prevent the debonding of the CFRP sheets. The GFRP anchor spikes were made by impregnating strands of glass fibers with resin. Their study found that flexural capacity of the slab strengthened with the three-stage prestressing system increased by 80%. The three-stage prestressing system with the GFRP anchor spikes can increase serviceability and capacity.

Buitelaar et al (2004) discussed reinforced high-performance concrete overlay system for rehabilitation and strengthening of orthotropic steel bridge decks. They described the development of the RHPC overlay, the properties of the RHPC overlay and the first application on an orthotropic bridge deck in the Netherlands.

Thanoon et al. (2005) presented a study on repair and structural performance of initially cracked one-way reinforced concrete slabs with five different techniques (cement grout, epoxy injection, ferrocement layer, carbon fiber strip and section enlargement). The slabs were loaded to failure stage and the structural response of each slab specimens have been predicted in terms of deflection, variation of strain in concrete and steel, collapse loads and the failure modes. All repair techniques were able to restore or enhance the structural capacity of cracked one-way concrete slabs.

Williams et al. (2006) present an experimental and numerical study conducted to investigate the performance in fire (standard ASTM E119 fire tests) of four different insulated FRP-strengthened concrete slabs. A numerical model was used to predict member behavior in fire. Model predictions showed satisfactory agreement with test data. The study indicated that appropriately designed and insulated FRP-strengthened concrete slabs are capable of achieving satisfactory fire endurances. Full-scale tests are needed to prove this.

This work will present a different method for strengthening of reinforced concrete slab, through the use of the concrete overlay. This method is rarely found in the literature. The thickness of concrete overlay and contact surface between slab and concrete overlay, with and without shear connector, are used as parameters, with a focus on flexural stiffness and ultimate moment capacity of the slab.

Experimental study

Two series of test specimens are performed to study flexural behaviors under static loading of one-way slab with or without concrete overlay. The details of specimens are shown in Figures 2 and 3 and Table 1. Dimension and reinforcement of the reference concrete slab have been designed to be identical in all test series. In the 1st test series, the adequate shear connector between the slab and concrete overlay is provided and thickness of concrete overlay used in the strengthening of reference slab varies from 5, 10 and 15mm respectively. In 2nd test series, 2 reference slabs are overlaid by 10mm. thick concrete with and without shear connector. The average strength of materials used in the preparation of slab specimen is tabulated by Table 2.2. Adequate shear connector is designed and provided between the top fiber of RC slab and concrete overlay. Deform bars with 12mm diameter are used as shear connector. The top fiber of RC slab is drilled and nonshrink cement is poured into the hole before the insertion of the shear connector. Preparation of specimen can be expressed by Figure 4.

Slab specimen is loaded by the two-point load in the third point-bending test as shown in Figure 4. The load

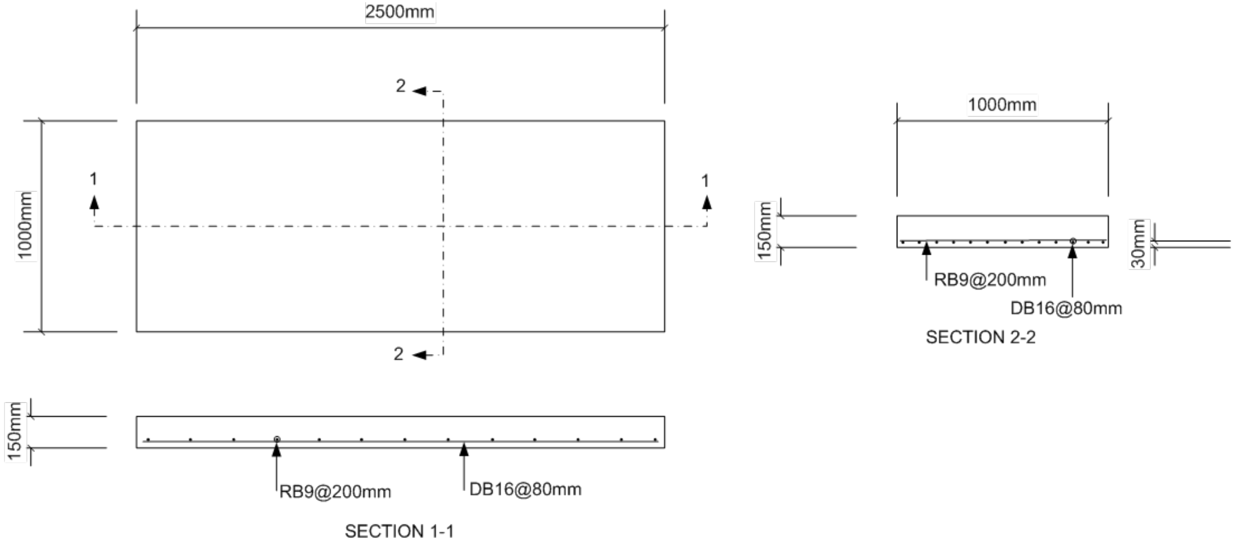

Fig. 2: Details of reference slab specimen. Source: Authors.

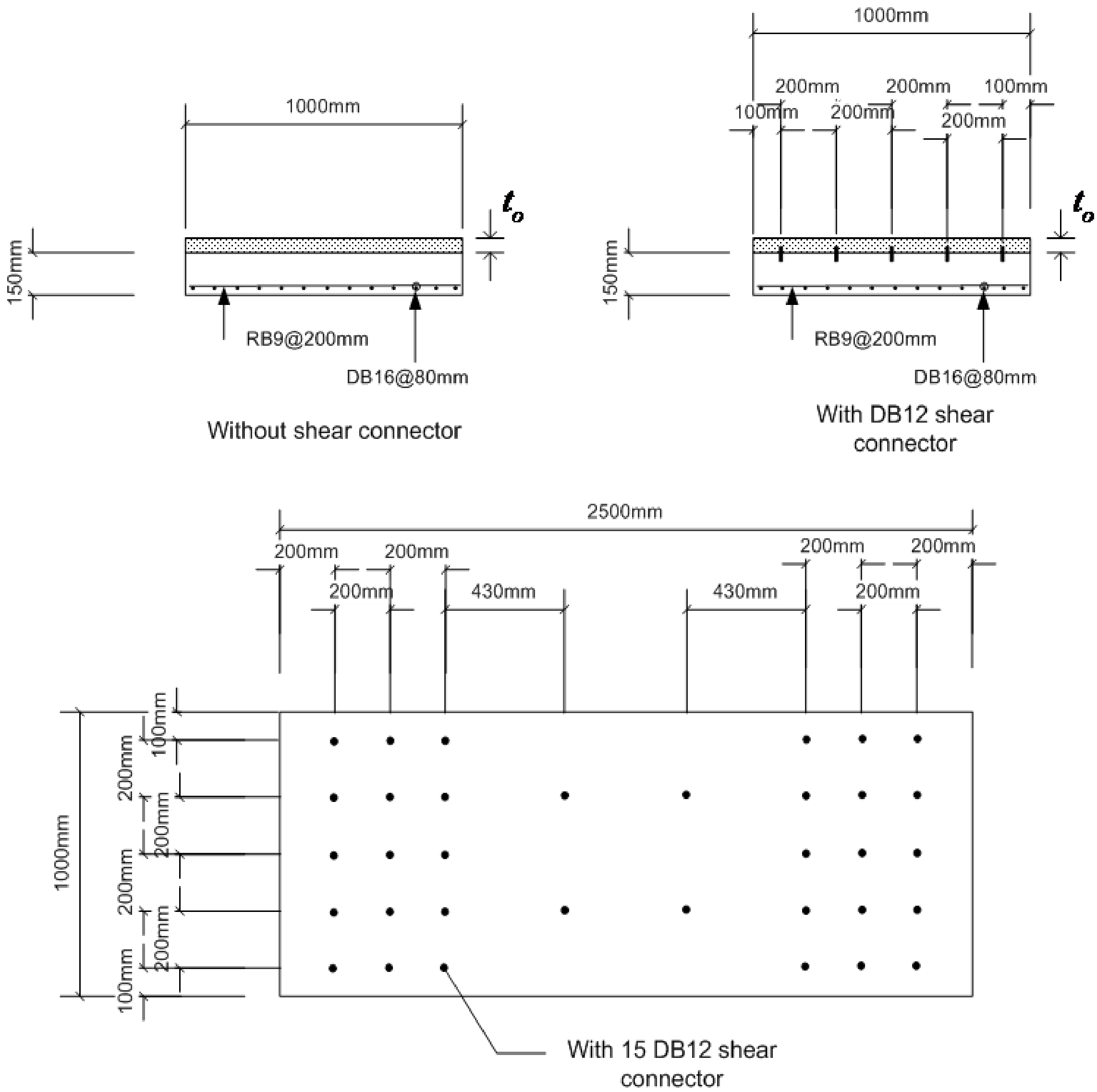

Fig. 3: Details of slab specimen with overlay and with or without shear connectors. Source: Authors.

is applied by hydraulic jack transfer to load cell that can be monitored by the data logger. Deformation, deflection at mid-span and strain (concrete and steel), are also monitored by the data logger. Load and deformation data can be recorded by the computer. The test set up of slab specimen can be expressed by

Fig. 4: Preparation of test specimen. Source: Authors.

Table 1: Specimen details. Source: Authors.

Remark	Thickness of concrete overlay (cm)	Name of speciman	Test series
Reference specimen	-	SR	1
With shear connector	5	SO-5-SC	
With shear connector	10	SO-10-SC	
With shear connector	15	SO-15-SC	
Reference specimen	-	SR	2
With shear connector	10	SO-10-SC	
Without shear connector	10	SO-10-NSC	

Table 2: Average material strength used in preparing of test specimen. Source: Authors.

concrete slab Fc(MPa)	concerete overlay Fc(MPa)	DB Steel Fy(MPa)	RB Steel Fy(MPa)
24.9	18.6	336.8	279.6

DB=Deform bar, RB= Round bar

Figure 4.

Results

Test results

Load-mid span relationship and failure mode of series I and II specimens are shown in Figures 6-9. Strength and stiffness of test specimen are summarized in Table 3.

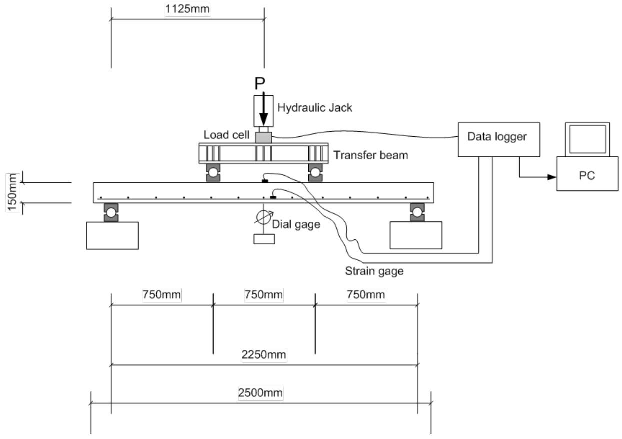

Fig. 5: Test set up of slab specimen

Discussions

First test series (slab with concrete overlay and shear connector)

It can be seen from Figure 6 and Table 3 that the strength and ductility of strengthening slab can be significantly increased by an additional concrete overlay. This is due to the increase of effective depth of the slab and moment arm

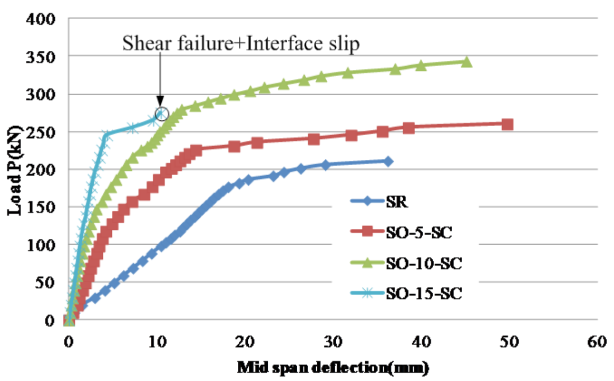

Fig. 6: Relationship between load and mid-span deflection of test series I. Source: Authors.

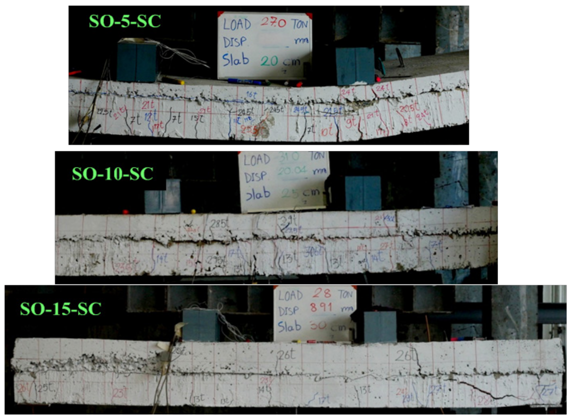

Fig. 7: Failure mode of the first test series.

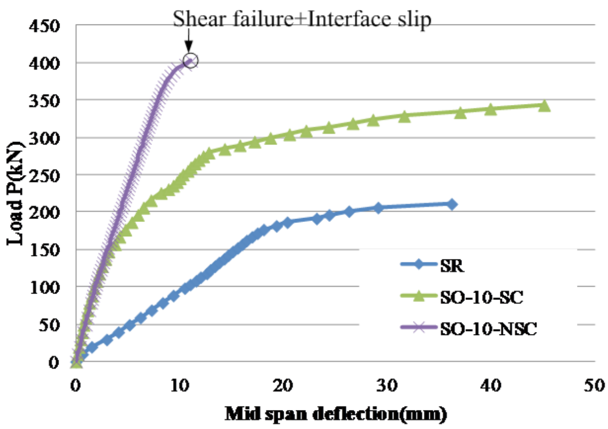

Fig. 8: Relationship between load and mid-span deflection of test series II. Source: Authors.

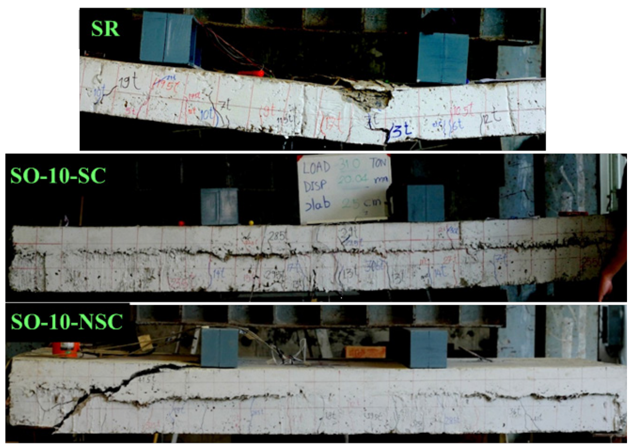

Fig. 9: Failure mode of the second test series. Source: Authors.

Table 3: Test results of all test series. Source: Authors.

$\frac{T_o}{T_{SR}}$	a/d	P_u $(test)$ kN	P_u $(predicted)$ kN	$\frac{P_u}{P_u(SR)}$ (test)	$\frac{P_u(predicted}{P_u(test)}$	$\frac{EI}{EI_{SR}}$	Name of speciman	Test series	Failure mode
0.00	6.82	210.9	170.9	1.0	0.81	1.00	SR	1	flexural
0.33	4.69	260.0	269.5	1.2	1.04	3.03	SO-5-SC	1	flexural
0.67	3.57	343.4	368.1	1.6	1.07	5.81	SO-10-SC	1	flexural
1.00	2.88	274.7	466.7	1.3	1.70	8.23	SO-15-SC	1	shear+interface slip
0.00	6.82	210.9	170.9	1.0	0.81	1.00	SR	2	flexural
0.33	3.57	260.0	269.5	1.2	1.04	5.81	SO-10-SC	2	flexural
0.33	3.57	407.1	368.1	1.9	0.90	5.69	SO-10-NSC	2	shear+interface slip

of internal compression and the tensile force caused by bending. Ductility can be represented by the deformation capacity prior to failure. Improvement of ductility is caused by the increase of effective depth due to concrete overlay leading to the reduction of steel ratio ($\frac{A_s}{bd}$). Increased flexural strength is limited by the ratio of the thickness of overlay to a thickness of slab () and the ratio of shear span to effective depth ratio ($\frac{a}{d}$) as shown in Figures 9 and 10. This is due to that shear strength of the slab section without stirrup (in general) is limited leading to ultimate flexural strength cannot be developed. Brittle shear failure can be observed in the specimen with 15-cm. overlay thickness (SO-15-SC). Crack is initiated by diagonal tension near support of the existing slab and propagate to the interface between slab and concrete overlay as can be seen from Figure 6. According to the test data in this work, it can be proposed that the ratio of $\frac{T_o}{T_{SR}}$ should not exceed 0.67 and $\frac{a}{d}$ should not less than 3.57 otherwise shear reinforcement should be provided to prevent sudden failure due to shear. Vertical or inclined shear reinforcement can be installed in the slab before concrete overlay if shear reinforcement is required.

Flexural strength of the slab can be predicted well by a strain compatibility method using equivalent stress block proposed by ACI for compression internal force in the concrete section for reference slab and slab with overlay for $\frac{a}{d} \leq 3.57$ (Table 3). This is due to the imperfect bond between the interface of slab and concrete overlay, for a slab with a high $\frac{T_o}{T_{SR}}$ ratio, which is assumed perfectly bond in the calculation of flexural strength using strain compatibility method. Instead of a fully composite action slab with concrete overlay is said to be a partial composite action for high $\frac{T_o}{T_{SR}}$ ratio even if the shear connector is provided. This is due to high horizontal shear flow at the interface of slab and concrete overlay for a slab with high $\frac{T_o}{T_{SR}}$.

Flexural stiffness of slab specimens

Deflection of the slab can be reduced by an increase of flexural stiffness represented by the flexural rigidity (EI) at service loading condition. The average flexural rigidity of cracked flexural members is known as effective flexural rigidity (EI_e). This quantity can be calculated at each stage of the load before or after cracking by the following equation.

$$\Delta_{\max} = \frac{Pa}{24EI}\left(3L^2 - 4a^2\right)$$

L = Span length
a = Length of shear span
E = Modulus of elasticity of concrete
I = Moment of inertia of slab section
EI = Effective flexural rigidity

EI in this work is calculated at service load, which is defined as a half of ultimate load of reference specimen (SR). It can be seen from Table 3 and Figure 11 that significant improvement of flexural stiffness over the referenced slab can be observed for all strengthened slabs.

Second test series (Overlaid slab without shear connector)

In this test series, two slabs are overlaid by 10mm thick concrete with and without shear connector between the contact surface are tested up to failure. It can be observed from Figure 8 and Table 3 that significant increase of the flexural capacity of strengthening slab above reference specimen. Flexural capacity of

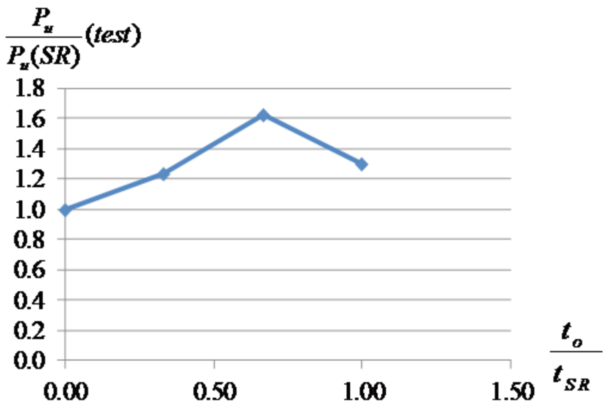

Fig. 10: Effect of overlay thickness on flexural strength of slab specimen (series I). Source: Authors.

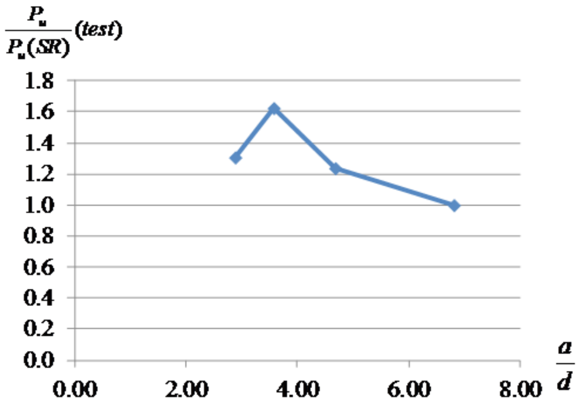

Fig. 11: Effect of shear span to effective depth ratio on flexural strength of slab specimen (Series I). Source: Authors.

the specimen with shear connector is slightly lower than that of the specimen without shear connector but ductility is larger. This is due to the action of shear connector, which prevents the slip of the contact surface of the slab, and concrete overlay leading to performing a composite action. Brittle shear failure can be observed in specimens without shear connector. Crack is initiated by diagonal tension caused by shear adjacent to support of the reference slab and propagates to contact surface of the top slab and concrete overlay.
It should be noticed that perfect bond between the slab and concrete overlay in the overlaid specimen without shear connector (SO-10-NSC) lead to flexural capacity is slightly higher than the specimen with shear connector (SO-10-SC) as can be observed by Figure 3 but failure mode is brittle, shear and interface slip. Slippage of the contact surface of SO-10-SC is resisted by shear connector lead to more ductile than SO-10-NSC and SR.

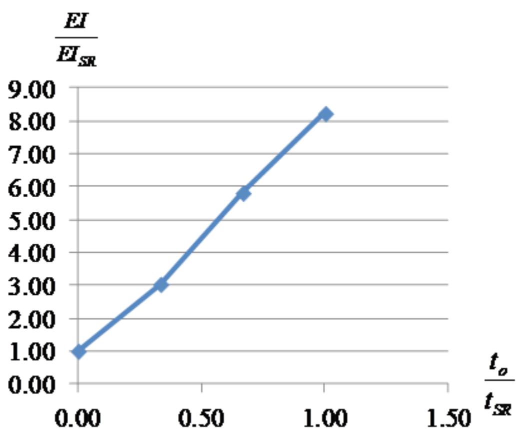

Fig. 12: Effect of overlay thickness on flexural stiffness. Source: Authors.

Conclusion

Flexural behaviors of slab strengthened by concrete overlay are done by experiment. The thickness of overlay and mechanical shear connector between the top slab and concrete overlay are used as principal parameters. The following conclusion can be made.
Composite action between the top slab and concrete overlay can be achieved by mechanical shear connector lead to the increase of flexural strength, stiffness, and ductility of strengthening slabs. According to the test data in this work it can be proposed that the ratio of overlay thickness to the thickness of existing slab should not exceed 0.67 and the ratio of shear span to effective depth ratio should not less than 3.57 otherwise shear reinforcement should be provided to prevent sudden failure due to shear. Vertical or inclined shear reinforcement can be installed in the slab before concrete overlay if shear reinforcement is required.
Slab strengthened by concrete overlay without shear connectors can be done to increase flexural strength and stiffness, but the failure mode might be a brittle failure due to shear. Further studies are needed to be clearly understood about the effect of overlay thickness on flexural behaviors of strengthening slab without shear connectors.

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