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ANALYSIS OF HORIZONTAL SHEAR STRENGTH OF PRECAST PRESTRESSED CONCRETE SLAB AND CONCRETE TOPPING COMPOSITES

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ABSTRACT

This study aims to compare the horizontal shear strength at the interface between precast prestressed concrete slabs and concrete toppings under three different slab surface conditions: smooth or unintentionally roughened (Type 1), intentionally roughened by 3mm latitudinal indentations (Type 2), and intentionally roughened by 6mm latitudinal indentations (Type 3). The theoretical values for shear strengths for all types of the concrete slab-topping composites were compared to the experimental values calculated from vertical deflection and strain values which were obtained using the Three-Point Bending Test. The characteristics of the failures were also examined. The study shows that the horizontal shear strength and the deflection depend on the roughness of the surface of the concrete slabs. When compared to Type 1 concrete slabs under the load of 1,300kg, the concrete slabs with roughened surfaces showed stronger horizontal shear stress (by the factor of 0.898 for Type 3 and 0.953 for Type 2) and less deflection (by the factor of 1.113 for Type 3 and 1.053 for Type 2). The results highlight the importance of the roughened surface of the concrete slabs in enhancing the horizontal shear strength in the concrete slab-topping composites which could be of great benefit to engineering applications.

1. INTRODUCTION

The globally increasing demand in housing due to population growth has posed a concern for modern buildings to be constructed in a fast and cost-effective way [1]–[3]. One of many possible solutions is to establish housing estates in which each building is constructed using the same designs and materials. Using economical ready-made materials such as precast prestressed concrete slabs, also called concrete planks or concrete slabs, can save a considerable amount of time and materials used during the construction process [4]. In addition, factory-made precast concrete slabs can be manufactured to be higher quality and can tolerate heavier loads than in-situ concrete materials. Because of these benefits, concrete slabs have become widely-used for floor and bridge construction

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in modern architectures [5], [6]. After aligning concrete slabs on the floor, reinforcement steel bars are generally placed on top, followed by a layer of in-situ concrete in order to enhance the strength, increase the load capacity, and even out the weight distribution throughout the concrete slabs [7], [8]. There are two flat sides to the concrete slabs – one with a smooth surface and the other with a rough surface. In practice, in-situ concrete is poured on top of the rough sides of the concrete slabs. However, according to the ACI 318 Building Code and Commentary, the composite section designed for handling horizontal shear stress has to be clean and free of laitance and needs to have 6mm indentations on its rough side in order to maximize the horizontal shear strength [9]. In order for the precast prestressed concrete slabs to form a composite section with concrete toppings, the surfaces of the concrete slabs need to be sufficiently rough so that the horizontal shear force between the interfaces of the two materials can be effectively distributed [10]–[12]. However, in practice, the process of surface roughening is usually carried out when the newly-formed slabs begin to harden by brushing the top surface of the concrete slabs with a hard-bristle brush [13]. This gives an uneven texture on the surface, and the indentation pattern on the surface is generally less than 6mm. To highlight the importance of using concrete slabs with sufficiently roughened surfaces, this study aims to compare the horizontal shear strength achieved by different types of concrete slabs topped by in-situ concrete using Three-Point Bending Test. Three types of concrete slabs were studied: 1) concrete slabs with a smooth surface, 2) with a 3mm latitudinally indentation pattern, and 3) with a 6mm latitudinally indentation pattern.

2. MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 PRECAST PRESTRESSED CONCRETE SLABS

Precast prestressed concrete slabs (clean and free of laitance) have a compressive strength of $350kg/cm^2$ and are 5cm thick, 35cm wide, and 210cm long. Each concrete slab was reinforced with 4 PC-wires (4mm in diameter). The slabs were separated into three types according to their surface property. Three specimens of each type were used in this study.

Type 1: Unintentionally roughened concrete slabs

Type 2: Intentionally roughened concrete slabs (3mm latitudinally indented)

Type 3: Intentionally roughened concrete slabs (6mm latitudinally indented)

2.1.2 CONCRETE TOPPINGS

The 5cm-thick toppings have a compressive strength of $245kg/cm^2$. The same concrete toppings were used for all concrete slabs-topping composites.

2.2 CONCRETE SLAB-TOPPING COMPOSITES PREPARATION

2.2.1 PRECAST PRESTRESSED CONCRETE SLABS

In Type 1 precast prestressed concrete slabs, the surface of the slabs was smoothened using a trowel to give an unintentionally roughened finish. Type 2 and 3 carry the same materials and dimensions as Type 1. However, they were intentionally roughened by pressing metal frames on top of the concrete slabs during the moulding process to create a latitudinally raked pattern on their top surfaces. The metal frames were created using two long parallel round bars (12mm in diameter) as the outer frame attached to 31 latitudinally aligned round bars (6mm in diameter, each pair is 50mm separated when measured from center to center of the two bars). The indentations for the roughened surface were 3mm for Type 2 concrete slabs and 6mm for Type 3 concrete slabs. The pattern designs for Type 2 and Type 3 are shown in Figure 1A and Figure 1B.

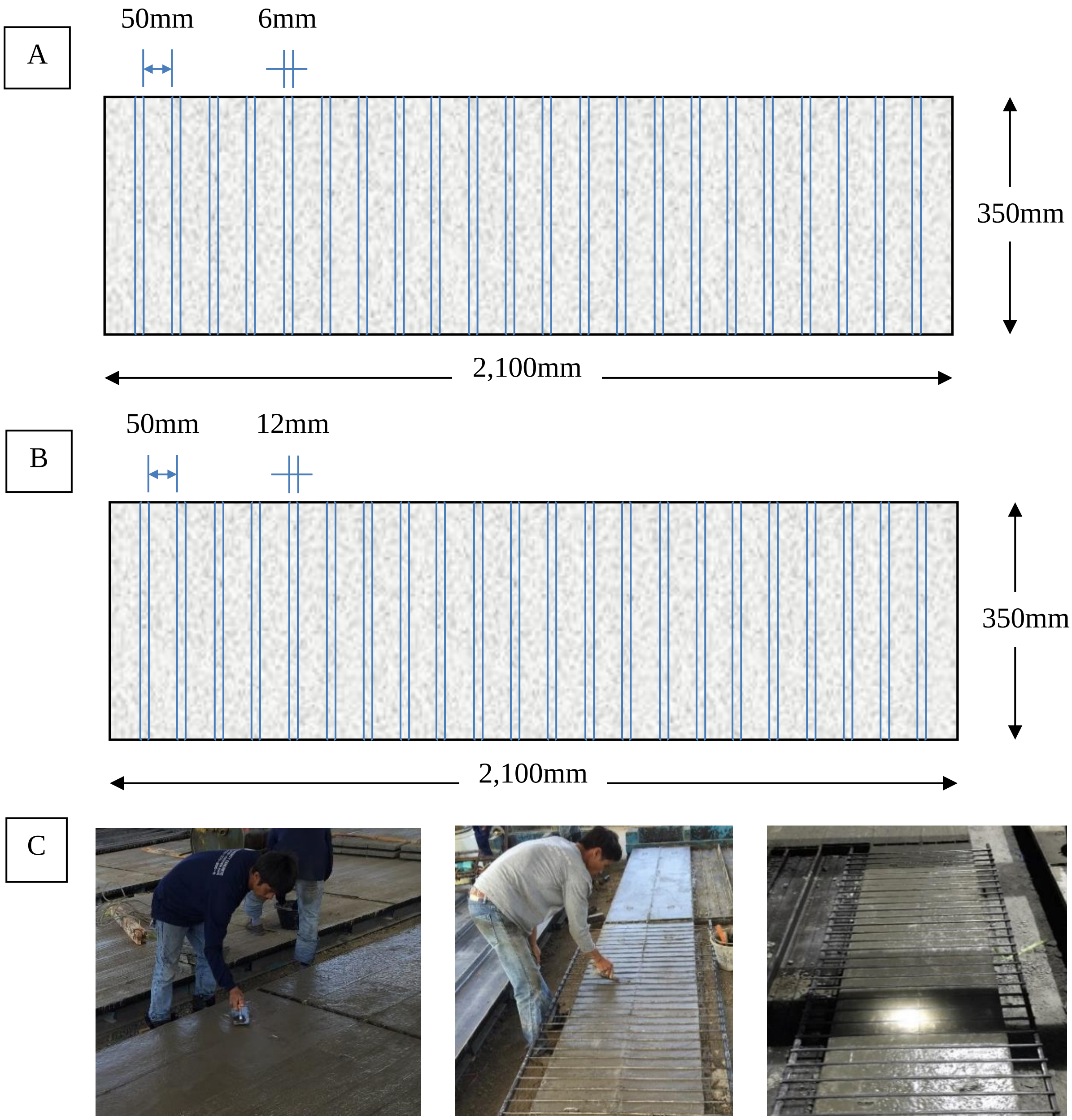

Figure 1: (A) Dimensions of concrete slabs with 3mm latitudinally indented surface, (B) with 6mm latitudinally indented surface (figures are not drawn to scale). (C) Concrete slabs in preparation (left: Type 1, centre: Type 2, right: Type 3)

2.2.2 STRAIN GAUGE ATTACHMENT

The concrete slabs were left dry for 24 hours in order for them to develop at least 75% of the desired strength. The metal frames were then removed and the outlines for attachment were drawn on the clean, polished surfaces of the concrete slabs. Seven strain gauges were then attached to the marked locations using cyanoacrylate adhesive (Figure 2A-B). Next, six electrical wires were connected to each end of the strain gauges. Each wire was tested for electrical voltages to ensure no faults or damages. A liquid coating material made of wax at a high temperature was applied on top of the strain gauges and the surrounding areas using a paint brush and left until dry (Figure 2C).

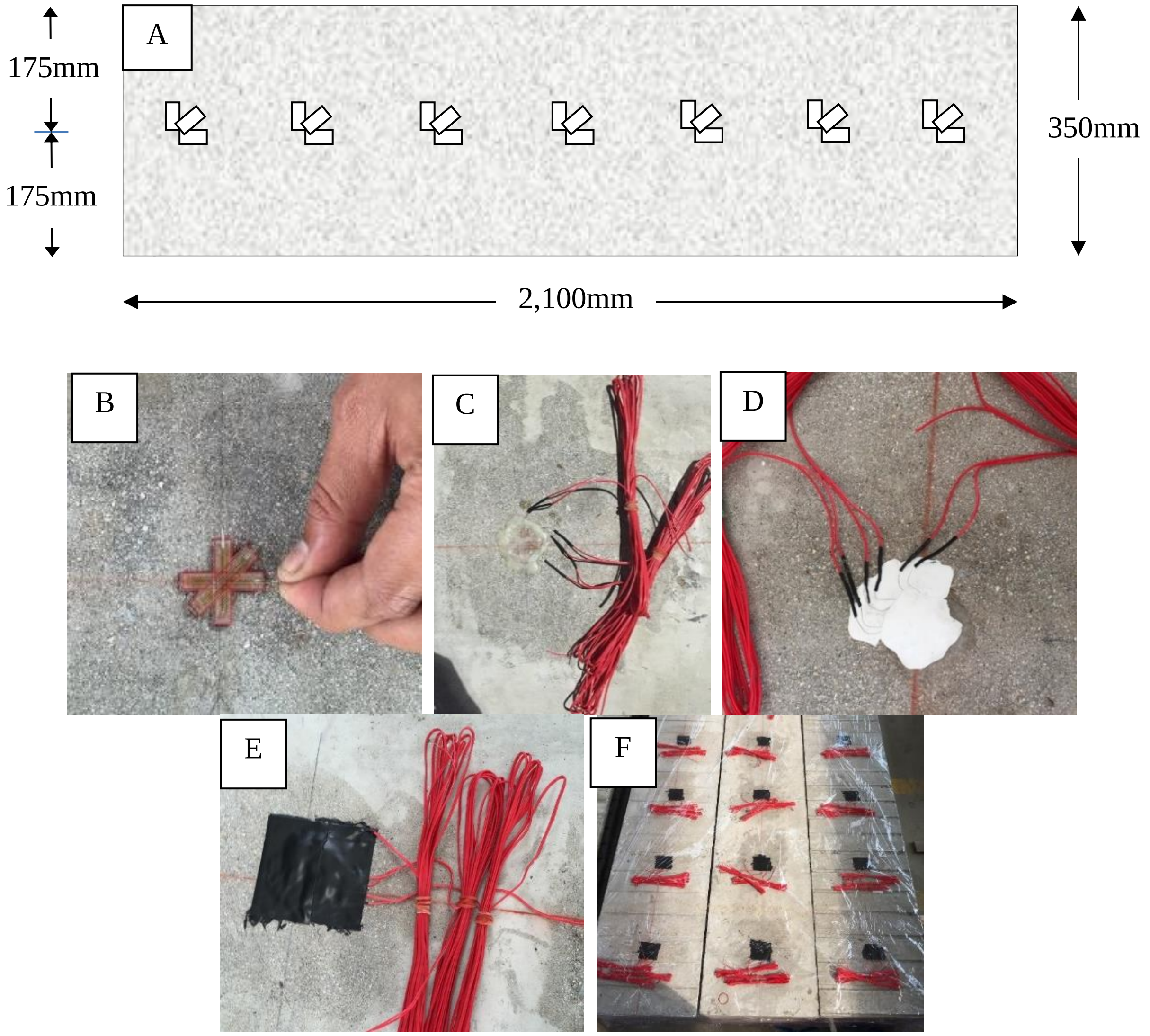

Figure 2: (A) The placement outline for strain gauges (not to scale). (B) strain gauges attached on to the cleaned and polished surface of a concrete slab. (C) Strain gauges after connected with electrical wires and coated with hot wax. (D) SB tape was placed underneath the six electrical wires extending from the strain gauges. (E) Strain gauges and wires were sealed with VM tape. (F) Concrete slabs with strain gauges attached were wrapped in plastic film to protect from dust (left: Type 2, center: Type 1, right: Type 3).

SB tape was then placed under the electrical wires. Each wire was separated and pressed to secure on the SB tape surface so that no pairs of electrical wires are in physical contact which can make short circuits (Figure 2D). Next, the devices were sealed with vinyl mastic tape (VM tape) to prevent water contained in the concrete topping from entering the devices (Figure 2E). The concrete slabs were then wrapped in plastic film to protect the materials from dust (Figure 2F).

2.2.3 CONCRETE TOPPINGS

Nine steel forms for pouring concrete topping were constructed using hollow rectangular tubes made of steel. The tube size was 2 inches wide and 4 inches long. Each formwork was drilled on its side to allow electrical wires to extend to the side through the holes. The nine concrete slabs (three types, each type has three specimens) were then assembled into each steel form and topped with in-situ concrete (Figure 3A). A concrete vibrator was employed to compress the concrete topping. The top surface of each concrete composite was smoothened using a trowel and a concrete float. Once the concrete toppings hardened, they were sprayed on top with a concrete curing compound and left for 24 hours. The concrete slab-topping composites were then removed from the steel formworks and rested for 28 days before being tested for horizontal shear strength (Figure 3B).

Figure 3: (A) In-situ concrete toppings were poured into each formwork. (B) The concrete slabs and toppings were left dry before being removed from the formworks.

2.3 TEST OF HORIZONTAL SHEAR STRENGTH

The Three-Point Bending Test (in accordance with ASTM Standards Building Codes [14]) was employed for the test (Figure 4). A 250-tonne universal testing machine was used for pressing the slabs through a 10-tonne load cell. A displacement transducer was placed at the center position of the machine. A concrete slab-topping composite, with strain gauges embedded, was then placed on top, supported by two steel legs at both ends. The values for 1) load pressure, 2) vertical displacement, and 3) horizontal shear strain were recorded using Portable Data Logger (Model: TDS-530) with Automatic Switching Box (Model: ASW-50B).

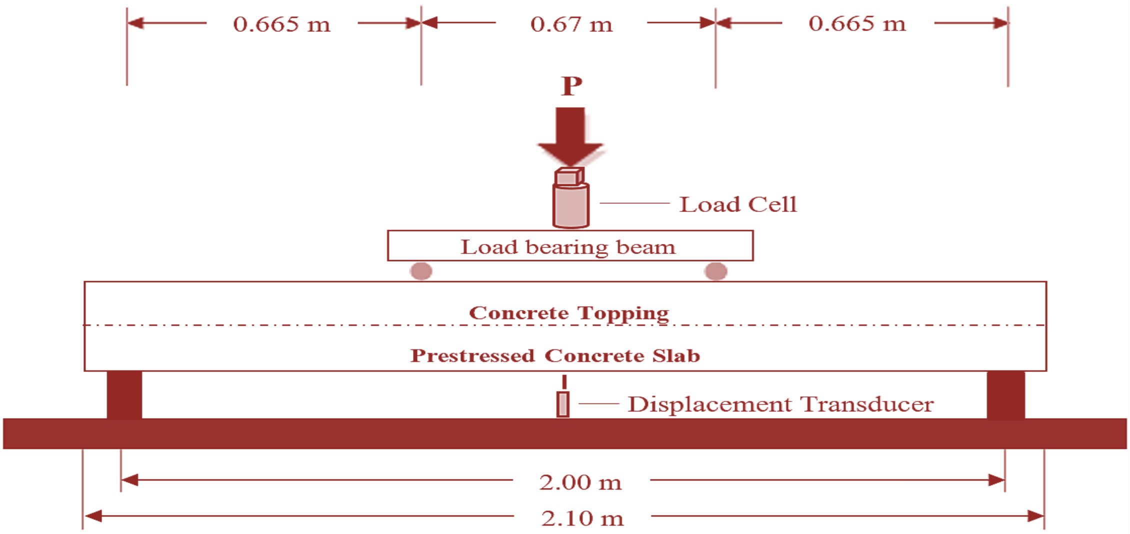

Figure 4: Test of horizontal shear strength of the concrete slab-topping composites using Three-Point Bending Test.

The pressure on the load bearing beam was gradually increased by 50kg until the first crack was observed. The characteristic of the crack on the concrete topping's surface was examined and the displacement transducer was then removed from the base of the machine. The experiment was repeated by further increasing the load by 50kg each time until failure. The characteristics of the concrete slab composite and the value for a load of failure were examined and recorded.

2.4 PARAMETERS AFFECTING HORIZONTAL SHEAR STRESS OF COMPOSITE SLABS

The horizontal shear stress on the interface between concrete slabs and concrete toppings (τ_{xy}) can be calculated according to the following pre-derived equation [15], Equation (1).

$$\tau_{xy} = \frac{\gamma_{xy} E}{2(1+\nu)} \qquad (1),$$

where γ_{xy}, E, and ν are the shear strain on the interface between the two concrete materials, the elastic modulus of the composite section, and the Poisson's ratio of the composite section, respectively.

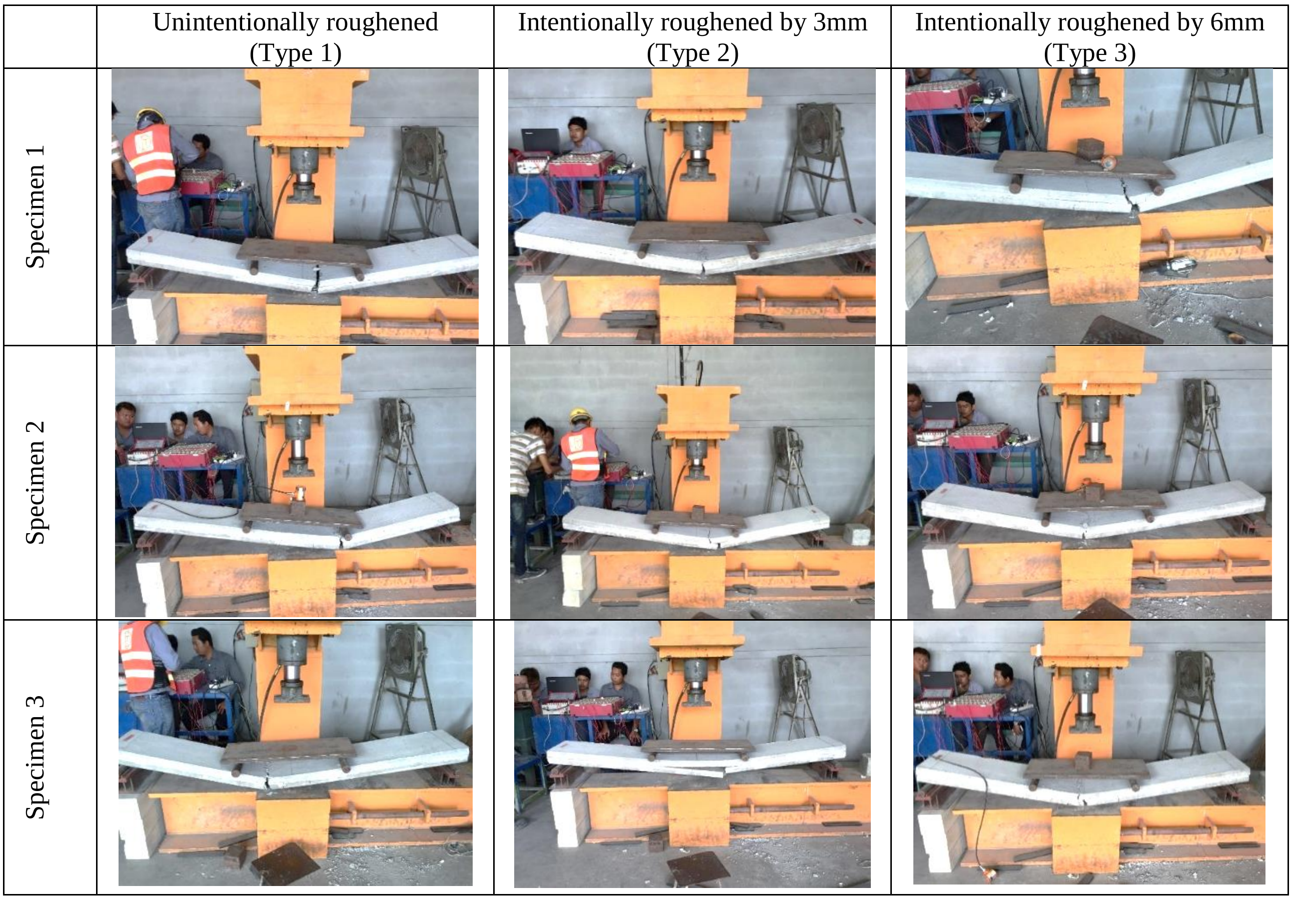

Figure 5: Characteristics of the concrete slab composites at their points of failure.

3. RESULTS AND DISCUSSION

Nine concrete slab-topping composite specimens were tested for horizontal shear strength using the three-point bending test method (Figure 5). In all cases, the crack lines were observed near the middle section of the specimens. These indicate that the vertical shear strength, as well as the horizontal shear strength between the concrete slabs and the concrete toppings, were not large enough to cause the failures due to shear stress. The failures of these specimens were caused by the bending moment. However, the loads at failure were the highest for the specimens made of 6mm intentionally roughened concrete slabs (Type 3), followed by the specimens made of 3mm intentionally roughened concrete slabs (Type 2) and then followed by the specimens made of unintentionally roughened concrete slabs (Type 1). On average, the load at failure of Type 3 and Type 2 concrete slabs were 1.035 and 1.020 times higher than that of Type 1.

Next, the deflections in nine concrete slab-topping composite specimens were measured and plotted in Figure 6. The points of the first crack varied from 1,320kg to 1,740kg, regardless of the types of concrete slabs. Therefore, it is inconclusive whether roughened surfaces of the concrete slabs could result in higher load required for the first crack to occur and further investigation concerning more variables and factors is needed. However, it can be observed from the figure that the slab-topping composite specimens from the same type tend to have broadly similar deflection characteristics, suggesting that the roughness on the surface of the concrete slabs affects the amount of the deflection when the concrete slab-topping composites were suppressed by the machine. When the deflection values of all specimens were closely examined under the same load of 1,300kg, Type 3 and Type 2 concrete slabs showed less average deflection by the factor of 0.898 and 0.950 when compared to Type1. In addition, when the same amount of deflection (2.80mm) was considered, Type 3 showed 1.078 times heavier load capacity, while Type 2 showed 1.034 times, compared to Type 1.

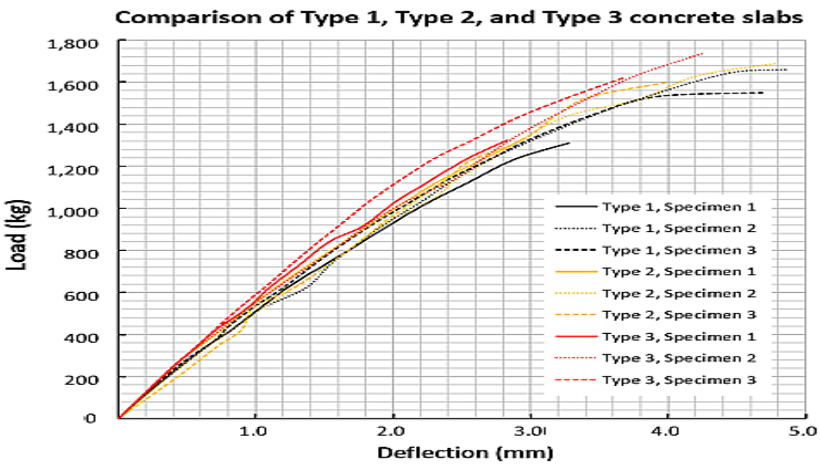

Figure 6: Comparison of the deflections of three types of concrete slab composites: with unintentionally roughened surface (Type 1, black lines), intentionally roughened by 3mm (Type 2, yellow lines), and intentionally roughened by 6mm (Type 3, red lines). Thick lines denote specimens no. 1 of each type. Dotted lines denote specimens no. 2, and dashed line, specimens no. 3. The top ends of each line denote the points where the first cracks appeared.

The horizontal shear stress can be obtained by substituting the measured experimental values (in the elastic range) into equation (1). The experimental values (τ_{xy}) were found to be in broad agreement with the theoretical values ($\tau_{xy,cal}$) (Tables 1-3). The horizontal shear stress was proportional to the vertical shear stress. Additionally, the horizontal shear stress was found to be highest at both ends of the load bearing beam and lowered proportionally towards the center of the beam. Under the load of 1,300kg and at position 0.10L, the average values for the horizontal shear stress for Type 3 and Type 2 concrete slabs were 1.148 times and 1.089 times stronger than that of Type 1. In general, the experimental horizontal shear stresses at other positions were also in broad agreement with the corresponding theoretical ones.

Table 1: Measured shear, shearing strain, and horizontal shear stress from the concrete composite specimens made of unintentionally roughened concrete slabs and concrete toppings (Type 1, top: specimen 1, middle: specimen 2, bottom: specimen 3).

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
179.67	0.76	0.75	1.10	154.47	0.72	0.71	0.95	129.27	0.69	0.68	0.79	104.07	-0.42	-0.42	0.64
279.62	1.42	1.41	1.72	254.42	1.36	1.35	1.56	229.22	1.30	1.29	1.41	204.02	-1.05	-1.04	1.25
323.67	1.76	1.75	1.99	298.47	1.48	1.46	1.83	273.27	1.45	1.44	1.68	248.07	-1.28	-1.27	1.52
381.27	2.32	2.30	2.34	356.07	1.68	1.66	2.18	330.87	2.13	2.12	2.03	305.67	-1.66	-1.65	1.88
432.09	2.60	2.58	2.65	406.89	2.26	2.24	2.50	381.69	2.13	2.11	2.34	356.49	-1.98	-1.97	2.19
481.22	2.71	2.68	2.95	456.02	2.48	2.46	2.80	430.82	2.38	2.36	2.64	405.62	-2.30	-2.28	2.49
526.96	2.88	2.86	3.23	501.76	2.77	2.75	3.08	476.56	2.71	2.69	2.92	451.36	-2.56	-2.54	2.77
579.48	3.32	3.29	3.56	554.28	2.84	2.82	3.40	529.08	2.75	2.73	3.25	503.88	-2.69	-2.67	3.09
626.91	3.73	3.70	3.85	601.71	3.60	3.57	3.69	576.51	3.48	3.45	3.54	551.31	-3.19	-3.16	3.38
676.04	3.89	3.86	4.15	650.84	3.86	3.83	3.99	625.64	3.79	3.76	3.84	600.44	-3.51	-3.48	3.68
730.25	4.22	4.19	4.48	705.05	4.20	4.17	4.33	679.85	4.06	4.03	4.17	654.65	-3.80	-3.77	4.02
784.46	4.67	4.63	4.81	759.26	4.56	4.52	4.66	734.06	4.40	4.36	4.50	708.86	-4.16	-4.13	4.35

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
228.80	1.24	1.23	1.40	203.60	1.12	1.11	1.25	178.40	1.09	1.09	1.09	153.20	-0.74	-0.73	0.94
286.40	1.38	1.37	1.76	261.20	1.35	1.34	1.60	236.00	1.32	1.31	1.45	210.80	-1.08	-1.07	1.29
323.67	1.61	1.59	1.99	298.47	1.50	1.49	1.83	273.27	1.49	1.48	1.68	248.07	-1.32	-1.31	1.52
376.19	2.21	2.19	2.31	350.99	1.93	1.92	2.15	325.79	1.81	1.80	2.00	300.59	-1.62	-1.61	1.84
425.31	2.24	2.22	2.61	400.11	2.19	2.17	2.45	374.91	1.89	1.87	2.30	349.71	-1.96	-1.94	2.15
476.14	2.67	2.65	2.92	450.94	2.45	2.43	2.77	425.74	2.45	2.43	2.61	400.54	-2.23	-2.22	2.46
526.96	2.86	2.84	3.23	501.76	2.82	2.80	3.08	476.56	2.77	2.75	2.92	451.36	-2.55	-2.53	2.77
577.78	3.10	3.08	3.54	552.58	3.02	3.00	3.39	527.38	2.99	2.96	3.24	502.18	-2.86	-2.84	3.08
630.30	3.58	3.55	3.87	605.10	3.47	3.45	3.71	579.90	3.43	3.40	3.56	554.70	-3.23	-3.20	3.40
682.82	3.90	3.87	4.19	657.62	3.79	3.76	4.03	632.42	3.66	3.63	3.88	607.22	-3.50	-3.48	3.73
731.95	4.28	4.24	4.49	706.75	4.23	4.20	4.34	681.55	4.11	4.08	4.18	656.35	-3.83	-3.80	4.03
775.99	4.61	4.58	4.76	750.79	4.36	4.33	4.61	725.59	4.30	4.26	4.45	700.39	-4.12	-4.09	4.30
831.90	5.02	4.98	5.10	806.70	4.65	4.62	4.95	781.50	4.53	4.50	4.79	756.30	-4.43	-4.40	4.64
882.72	5.07	5.03	5.42	857.52	4.97	4.93	5.26	832.32	4.79	4.75	5.11	807.12	-4.66	-4.62	4.95
935.24	5.39	5.34	5.74	910.04	5.31	5.27	5.58	884.84	5.30	5.25	5.43	859.64	-5.06	-5.02	5.27
969.12	5.64	5.59	5.95	943.92	5.45	5.40	5.79	918.72	5.29	5.36	5.64	893.52	-5.19	-5.15	5.48

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
238.01	1.36	1.34	1.46	212.81	1.20	1.19	1.31	187.61	0.95	0.95	1.15	162.41	-0.76	-0.76	1.00
296.56	1.66	1.65	1.82	271.36	1.32	1.31	1.66	246.16	1.47	1.46	1.51	220.96	-1.12	-1.12	1.36
335.53	1.92	1.90	2.06	310.33	1.71	1.70	1.90	285.13	1.65	1.63	1.75	259.93	-1.38	-1.37	1.59
377.88	2.02	2.01	2.32	352.68	1.99	1.98	2.16	327.48	1.74	1.73	2.01	302.28	-1.64	-1.63	1.85
425.31	2.38	2.36	2.61	400.11	2.34	2.32	2.45	374.91	2.17	2.15	2.30	349.71	-1.92	-1.90	2.15
479.53	2.77	2.75	2.94	454.33	2.60	2.58	2.79	429.13	2.42	2.40	2.63	403.93	-2.24	-2.23	2.48
528.65	3.05	3.03	3.24	503.45	2.93	2.91	3.09	478.25	2.79	2.77	2.93	453.05	-2.57	-2.55	2.78
586.25	3.26	3.23	3.60	561.05	3.17	3.15	3.44	535.85	2.97	2.95	3.29	510.65	-2.94	-2.92	3.13
633.69	3.37	3.34	3.89	608.49	3.47	3.44	3.73	583.29	3.41	3.38	3.58	558.09	-3.21	-3.18	3.42
684.51	3.97	3.94	4.20	659.31	3.89	3.86	4.05	634.11	3.75	3.72	3.89	608.91	-3.56	-3.53	3.74
726.86	4.28	4.24	4.46	701.66	4.07	4.04	4.30	676.46	3.99	3.96	4.15	651.26	-3.82	-3.79	4.00
775.99	4.59	4.55	4.76	750.79	4.46	4.42	4.61	725.59	4.04	4.01	4.45	700.39	-3.98	-3.95	4.30
835.29	4.82	4.78	5.12	810.09	4.63	4.60	4.97	784.89	4.59	4.55	4.82	759.69	-4.48	-4.45	4.66
879.33	5.12	5.08	5.39	854.13	4.82	4.78	5.24	828.93	4.75	4.71	5.09	803.73	-4.76	-4.72	4.93
930.16	5.42	5.37	5.71	904.96	5.31	5.26	5.55	879.76	5.28	5.24	5.40	854.56	-5.07	-5.03	5.24

Table 2: Measured shear, shearing strain, and horizontal shear stress from the concrete composite specimens made of 3mm intentionally roughened concrete slabs and concrete toppings (Type 2, top: specimen 1, middle: specimen 2, bottom: specimen 3).

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
227.10	1.33	1.32	1.39	201.90	1.22	1.21	1.24	176.70	0.96	0.95	1.08	151.50	-0.73	-0.73	0.93
274.54	1.65	1.64	1.68	249.34	1.60	1.59	1.53	224.14	1.33	1.32	1.38	198.94	-1.09	-1.08	1.22
323.67	1.86	1.85	1.99	298.47	1.84	1.82	1.83	273.27	1.61	1.60	1.68	248.07	-1.43	-1.42	1.52
377.88	2.32	2.30	2.32	352.68	2.13	2.11	2.16	327.48	2.10	2.08	2.01	302.28	-1.83	-1.82	1.85
428.70	2.48	2.46	2.63	403.50	2.37	2.35	2.48	378.30	2.31	2.29	2.32	353.10	-2.16	-2.14	2.17
476.14	2.93	2.91	2.92	450.94	2.84	2.82	2.77	425.74	2.65	2.63	2.61	400.54	-2.56	-2.54	2.46
526.96	3.19	3.16	3.23	501.76	3.00	2.98	3.08	476.56	2.90	2.88	2.92	451.36	-2.83	-2.81	2.77
579.48	3.45	3.42	3.56	554.28	3.42	3.39	3.40	529.08	3.37	3.34	3.25	503.88	-3.14	-3.11	3.09
630.30	3.82	3.79	3.87	605.10	3.69	3.66	3.71	579.90	3.68	3.65	3.56	554.70	-3.47	-3.44	3.40
677.74	4.19	4.15	4.16	652.54	3.99	3.96	4.00	627.34	3.82	3.79	3.85	602.14	-3.76	-3.73	3.69
725.17	4.33	4.30	4.45	699.97	4.30	4.27	4.29	674.77	4.19	4.15	4.14	649.57	-4.11	-4.08	3.99
775.99	4.83	4.79	4.76	750.79	4.65	4.61	4.61	725.59	4.38	4.35	4.45	700.39	-4.32	-4.29	4.30
830.20	5.08	5.04	5.09	805.00	5.00	4.96	4.94	779.80	5.04	5.00	4.78	754.60	-4.76	-4.72	4.63
875.95	5.32	5.28	5.37	850.75	5.21	5.17	5.22	825.55	5.19	5.15	5.06	800.35	-5.11	-5.07	4.91
928.46	5.71	5.67	5.70	903.26	5.65	5.60	5.54	878.06	5.52	5.47	5.39	852.86	-5.47	-5.42	5.23
975.90	5.97	5.92	5.99	950.70	5.91	5.87	5.83	925.50	5.86	5.82	5.68	900.30	-5.75	-5.70	5.52

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
215.25	1.25	1.24	1.32	190.05	1.23	1.23	1.17	164.85	1.21	1.20	1.01	139.65	-0.64	-0.64	0.86
276.23	1.77	1.76	1.69	251.03	1.63	1.62	1.54	225.83	1.44	1.43	1.39	200.63	-1.14	-1.13	1.23
325.36	2.05	2.04	2.00	300.16	1.82	1.81	1.84	274.96	1.72	1.71	1.69	249.76	-1.47	-1.46	1.53
377.88	2.43	2.41	2.32	352.68	2.21	2.19	2.16	327.48	2.12	2.10	2.01	302.28	-1.84	-1.82	1.85
428.70	2.70	2.68	2.63	403.50	2.52	2.50	2.48	378.30	2.46	2.44	2.32	353.10	-2.17	-2.15	2.17
482.91	3.01	2.98	2.96	457.71	2.82	2.80	2.81	432.51	2.69	2.67	2.65	407.31	-2.57	-2.54	2.50
532.04	3.28	3.25	3.26	506.84	3.00	2.98	3.11	481.64	2.99	2.96	2.95	456.44	-2.88	-2.86	2.80
577.78	3.64	3.61	3.54	552.58	3.41	3.38	3.39	527.38	3.25	3.23	3.24	502.18	-3.20	-3.18	3.08
635.38	3.94	3.91	3.90	610.18	3.84	3.81	3.74	584.98	3.66	3.63	3.59	559.78	-3.60	-3.57	3.43
679.43	4.43	4.39	4.17	654.23	4.04	4.01	4.01	629.03	3.94	3.91	3.86	603.83	-3.89	-3.86	3.70
725.17	4.57	4.54	4.45	699.97	4.41	4.37	4.29	674.77	4.03	4.00	4.14	649.57	-3.81	-3.78	3.99
779.38	4.80	4.77	4.78	754.18	4.52	4.49	4.63	728.98	4.48	4.45	4.47	703.78	-4.20	-4.17	4.32
835.29	5.12	5.08	5.12	810.09	5.12	5.08	4.97	784.89	4.78	4.74	4.82	759.69	-4.58	-4.54	4.66
874.25	5.43	5.39	5.36	849.05	5.30	5.26	5.21	823.85	5.22	5.18	5.05	798.65	-4.81	-4.77	4.90
928.46	5.76	5.71	5.70	903.26	5.74	5.70	5.54	878.06	5.47	5.42	5.39	852.86	-5.20	-5.15	5.23

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
215.25	1.30	1.29	1.32	190.05	1.18	1.17	1.17	164.85	0.94	0.94	1.01	139.65	-0.65	-0.64	0.86
283.01	1.75	1.73	1.74	257.81	1.70	1.68	1.58	232.61	1.52	1.51	1.43	207.41	-1.17	-1.16	1.27
325.36	2.00	1.99	2.00	300.16	1.80	1.79	1.84	274.96	1.77	1.75	1.69	249.76	-1.53	-1.51	1.53
376.19	2.37	2.35	2.31	350.99	2.24	2.22	2.15	325.79	2.07	2.06	2.00	300.59	-1.88	-1.87	1.84
430.40	2.73	2.71	2.64	405.20	2.45	2.43	2.49	380.00	2.28	2.26	2.33	354.80	-2.22	-2.20	2.18
476.14	3.07	3.05	2.92	450.94	2.91	2.89	2.77	425.74	2.77	2.75	2.61	400.54	-2.51	-2.49	2.46
525.27	3.23	3.20	3.22	500.07	2.95	2.93	3.07	474.87	2.82	2.80	2.91	449.67	-2.76	-2.74	2.76
582.87	3.54	3.51	3.58	557.67	3.47	3.45	3.42	532.47	3.19	3.17	3.27	507.27	-3.13	-3.10	3.11
626.91	3.93	3.90	3.85	601.71	3.78	3.75	3.69	576.51	3.72	3.69	3.54	551.31	-3.46	-3.43	3.38
682.82	4.18	4.15	4.19	657.62	4.06	4.03	4.03	632.42	3.94	3.91	3.88	607.22	-3.70	-3.67	3.73
728.56	4.58	4.54	4.47	703.36	4.42	4.39	4.32	678.16	4.41	4.37	4.16	652.96	-3.82	-3.79	4.01
775.99	4.97	4.93	4.76	750.79	4.76	4.73	4.61	725.59	4.61	4.58	4.45	700.39	-4.11	-4.08	4.30
840.37	5.14	5.10	5.16	815.17	5.06	5.02	5.00	789.97	4.84	4.80	4.85	764.77	-4.52	-4.48	4.69
879.33	5.52	5.48	5.39	854.13	5.41	5.37	5.24	828.93	5.23	5.18	5.09	803.73	-4.76	-4.73	4.93
931.85	5.78	5.73	5.72	906.65	5.71	5.66	5.56	881.45	5.47	5.42	5.41	856.25	-5.06	-5.02	5.25

Table 3: Measured shear, shearing strain, and horizontal shear stress from the concrete composite specimens made of 6mm intentionally roughened concrete slabs and concrete toppings (Type 3, top: specimen 1, middle: specimen 2, bottom: specimen 3).

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
234.37	1.64	1.63	1.44	209.17	1.44	1.43	1.28	183.97	1.29	1.28	1.13	158.77	-1.04	-1.04	0.97
276.23	1.98	1.96	1.69	251.03	1.90	1.88	1.54	225.83	1.56	1.55	1.39	200.63	-1.36	-1.35	1.23
327.06	2.20	2.18	2.01	301.86	2.01	1.99	1.85	276.66	1.80	1.79	1.70	251.46	-1.72	-1.71	1.54
379.57	2.47	2.45	2.33	354.37	2.28	2.26	2.17	329.17	2.26	2.25	2.02	303.97	-2.14	-2.12	1.86
425.31	2.83	2.81	2.61	400.11	2.64	2.62	2.45	374.91	2.55	2.53	2.30	349.71	-2.44	-2.43	2.15
479.53	3.14	3.11	2.94	454.33	3.00	2.98	2.79	429.13	2.87	2.84	2.63	403.93	-2.79	-2.77	2.48
535.43	3.51	3.49	3.28	510.23	3.47	3.45	3.13	485.03	3.16	3.14	2.98	459.83	-3.15	-3.12	2.82
571.01	3.75	3.72	3.50	545.81	3.49	3.46	3.35	520.61	3.31	3.29	3.19	495.41	-3.25	-3.22	3.04
625.22	4.08	4.04	3.84	600.02	3.96	3.93	3.68	574.82	3.79	3.76	3.53	549.62	-3.49	-3.47	3.37
677.74	4.34	4.31	4.16	652.54	4.31	4.27	4.00	627.34	4.07	4.04	3.85	602.14	-3.88	-3.85	3.69
731.95	4.68	4.64	4.49	706.75	4.54	4.50	4.34	681.55	4.39	4.36	4.18	656.35	-4.25	-4.22	4.03
775.99	4.86	4.82	4.76	750.79	4.83	4.79	4.61	725.59	4.75	4.71	4.45	700.39	-4.56	-4.53	4.30
826.82	5.25	5.21	5.07	801.62	5.19	5.15	4.92	776.42	5.06	5.02	4.76	751.22	-4.78	-4.74	4.61
881.03	5.57	5.52	5.41	855.83	5.45	5.40	5.25	830.63	5.33	5.29	5.10	805.43	-5.15	-5.11	4.94
921.69	5.98	5.94	5.65	896.49	5.78	5.74	5.50	871.29	5.62	5.58	5.35	846.09	-5.57	-5.53	5.19
975.90	6.12	6.08	5.99	950.70	6.02	5.97	5.83	925.50	5.81	5.76	5.68	900.30	-5.73	-5.69	5.52

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
252.52	1.77	1.76	1.55	227.32	1.68	1.66	1.39	202.12	1.52	1.51	1.24	176.92	-1.17	-1.16	1.09
271.15	1.92	1.90	1.66	245.95	1.79	1.78	1.51	220.75	1.65	1.64	1.35	195.55	-1.32	-1.31	1.20
327.06	2.23	2.22	2.01	301.86	2.01	1.99	1.85	276.66	1.82	1.81	1.70	251.46	-1.78	-1.77	1.54
374.49	2.57	2.55	2.30	349.29	2.32	2.30	2.14	324.09	2.24	2.22	1.99	298.89	-2.05	-2.04	1.83
423.62	2.92	2.89	2.60	398.42	2.71	2.69	2.44	373.22	2.54	2.52	2.29	348.02	-2.35	-2.33	2.14
476.14	3.10	3.08	2.92	450.94	2.99	2.96	2.77	425.74	2.84	2.82	2.61	400.54	-2.66	-2.64	2.46
525.27	3.55	3.52	3.22	500.07	3.32	3.29	3.07	474.87	3.12	3.09	2.91	449.67	-2.98	-2.96	2.76
577.78	3.83	3.80	3.54	552.58	3.57	3.54	3.39	527.38	3.44	3.41	3.24	502.18	-3.30	-3.27	3.08
626.91	4.11	4.08	3.85	601.71	3.90	3.87	3.69	576.51	3.74	3.71	3.54	551.31	-3.56	-3.53	3.38
677.74	4.48	4.44	4.16	652.54	4.35	4.32	4.00	627.34	4.03	3.99	3.85	602.14	-3.89	-3.86	3.69
726.86	4.82	4.78	4.46	701.66	4.57	4.54	4.30	676.46	4.38	4.35	4.15	651.26	-4.23	-4.19	4.00
781.08	5.18	5.14	4.79	755.88	4.93	4.89	4.64	730.68	4.73	4.69	4.48	705.48	-4.55	-4.52	4.33
831.90	5.37	5.32	5.10	806.70	5.20	5.16	4.95	781.50	5.04	5.00	4.79	756.30	-4.82	-4.78	4.64
881.03	5.62	5.57	5.41	855.83	5.52	5.48	5.25	830.63	5.34	5.29	5.10	805.43	-5.15	-5.11	4.94
930.16	5.98	5.93	5.71	904.96	5.70	5.65	5.55	879.76	5.55	5.51	5.40	854.56	-5.48	-5.43	5.24
980.98	6.16	6.12	6.02	955.78	5.98	5.93	5.86	930.58	5.77	5.72	5.71	905.38	-5.67	-5.62	5.55

0.10L				0.40L				0.70L				CL			
Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$	Shear	γ_{xy}	τ_{xy}	$\tau_{xy,cal}$
113.60	0.00	0.00	0.70	88.40	0.00	0.00	0.54	63.20	0.00	0.00	0.39	38.00	0.00	0.00	0.23
238.96	1.63	1.62	1.47	213.76	1.60	1.59	1.31	188.56	1.39	1.38	1.16	163.36	-1.19	-1.18	1.00
271.15	1.90	1.88	1.66	245.95	1.80	1.78	1.51	220.75	1.59	1.58	1.35	195.55	-1.49	-1.47	1.20
333.83	2.29	2.27	2.05	308.63	2.03	2.02	1.89	283.43	1.92	1.90	1.74	258.23	-1.63	-1.62	1.58
379.57	2.51	2.49	2.33	354.37	2.33	2.32	2.17	329.17	2.24	2.22	2.02	303.97	-2.03	-2.01	1.86
427.01	2.82	2.80	2.62	401.81	2.66	2.64	2.47	376.61	2.49	2.47	2.31	351.41	-2.37	-2.35	2.16
477.83	3.13	3.11	2.93	452.63	2.93	2.91	2.78	427.43	2.77	2.75	2.62	402.23	-2.70	-2.68	2.47
526.96	3.45	3.43	3.23	501.76	3.28	3.25	3.08	476.56	3.07	3.05	2.92	451.36	-3.01	-2.98	2.77
576.09	3.76	3.73	3.53	550.89	3.53	3.51	3.38	525.69	3.29	3.26	3.23	500.49	-3.25	-3.23	3.07
628.61	4.17	4.14	3.86	603.41	3.85	3.82	3.70	578.21	3.76	3.73	3.55	553.01	-3.55	-3.52	3.39
676.04	4.51	4.47	4.15	650.84	4.22	4.19	3.99	625.64	3.96	3.93	3.84	600.44	-3.88	-3.85	3.68
730.25	4.81	4.77	4.48	705.05	4.53	4.49	4.33	679.85	4.33	4.30	4.17	654.65	-4.25	-4.22	4.02
775.99	4.93	4.89	4.76	750.79	4.89	4.85	4.61	725.59	4.67	4.63	4.45	700.39	-4.58	-4.54	4.30
828.51	5.37	5.33	5.08	803.31	5.21	5.17	4.93	778.11	5.05	5.01	4.77	752.91	-4.90	-4.86	4.62
877.64	5.67	5.62	5.38	852.44	5.44	5.40	5.23	827.24	5.35	5.31	5.08	802.04	-5.23	-5.19	4.92
925.07	5.79	5.74	5.68	899.87	5.67	5.62	5.52	874.67	5.47	5.42	5.37	849.47	-5.41	-5.36	5.21
977.59	6.22	6.17	6.00	952.39	6.00	5.96	5.84	927.19	5.78	5.74	5.69	901.99	-5.63	-5.59	5.53

4. CONCLUSION

The results of this study showed that the increase in roughness on the surface of the concrete slabs directly affects the horizontal shear strength. Under the same load, the 6mm intentionally roughened concrete slabs had the greatest horizontal shear strength, the heaviest load capacity, and the smallest deflection, followed by the 3mm intentionally roughened concrete slabs, and then the unintentionally roughened concrete slabs, respectively. All the failures of the composite slabs were due to the bending moment and the bending moments, causing the failures to occur near the middle of the specimens and no slips separating the concrete slabs and the concrete toppings were detected. The results highlight the key role of roughened surfaces of the concrete slabs and suggest that 6mm indentations should be used in order to achieve the maximum horizontal shear strength of the concrete slab-topping composites.

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