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BEHAVIORS OF THE COMPOSITE SLAB COMPOSED OF CORRUGATED STEEL SHEET AND CONCRETE TOPPING USING NONLINEAR FINITE ELEMENT ANALYSIS

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ABSTRACT

Behaviors under static loading of the composite slab composed of corrugated steel and concrete topping are studied in this work using Nonlinear Finite Element Analysis. The main parameters are mechanical shear connector, concrete strength, thickness of corrugated steel and additional steel rebar placed on the bottom of concrete topping. The software ABACUS® is utilized in the analysis. The analytical results are compared and calibrated to the experimental results performed by previous researchers. The verified finite element model is used to study the effects of the principle parameters, which cannot be practically performed by the experiment. The results show that slab without shear connecter failed in the brittle manner due to interface slip of concrete and corrugated steel after flexural cracking of concrete topping. The horizontal shear connectors used to prevent the interface slip are significantly increasing the load carrying capacity of composite slab. This is because concrete topping and corrugated steel are perform composite action. However, the low thickness and cross sectional area of corrugated steel, lead to the low flexural and load carrying capacity of the composite slab. It can be said that corrugated steel acts as a form of concrete topping. The most effective method to increase the flexural capacity of composite slab is by adding reinforcing bar at the bottom of concrete topping and shear connectors. The additional reinforcing bar can delay the abrupt failure of the composite slab after flexural cracking of concrete topping.

1. INTRODUCTION

Composite slab comprises of corrugated steel sheet and structural concrete topping is an optimum flooring system commonly used nowadays for the construction of buildings. This

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reduces the construction time and reduces the weight of the building, thus saving the cost of columns, foundations and overall construction. Laboratory tests reveal the actual behavior of the test specimens, but the interesting variables are limited and take a lot of time and resources. Finite element method (FEM) has been developed to analyze the behavior of test samples which reducing the cost, number of tests and time consuming. The finite element model verified by test results can be applied to analyze various problems which cannot be practically performed by the experiment. Nonlinear finite element models are developed to study behaviors of the composite slab composed of corrugated steel sheet and concrete topping. The key parameters are mechanical shear connector, concrete strength, thickness of corrugated steel and additional steel rebar placed on the bottom of concrete topping. The software ABACUS® is utilized in the analysis.

2. LITERATURE REVIEW

Sayed-Ahmed (2001) observed behavior of steel and (or) composite girders with corrugated steel webs, i.e. corrugated steel plates as webs and reinforced/prestressed concrete slabs as flanges for plate or box girders. The corrugated web increases the shear capacity.

Purse (1999) applied sheet metal pan or decking and sheet metal z-shaped closures sitting upon low profile open web steel joist providing a non-structural or structural concrete brake above the walls forming vibration damping and sound & fire barriers. The z-shaped closures have apertures formed through them which correspond to the end profiles of the joist shoes of the joists, and are fitted onto the joists before or after the joists are in place.

Anju (2015) studied behaviors of composite beam with shear connectors by 3D finite element modeling using ANSYS® software. The different types of shear connectors, stud, channel, tee, and perfobond connectors were the interesting parameters. The results revealed that the channel type shear connector has less displacement compared to the other types and the perfobond type connector shows maximum displacement for the given load.

Sundararooban (2017) used 3D finite element model utilized by ABAQUS® software to analyze the behavior of the composite slab under static load. Materials model, concrete damaged plasticity and elastic-perfectly plastic, are used for concrete and steel. The steel section was modelled using the shell element, S4R which is a 4-nodes doubly curved thin shell element that can be reduced the integration. C3D8R was a 8-node linear brick 3D solid element used in model of concrete. T3D2 was a 2-node linear 3D truss element used in model of steel rebar. Effects of sheet thickness and grade of concrete were used as the parameters. The results shown that the increase in thickness of steel deck sheet and characteristic compressive strength of concrete increased the load and moment carrying capacity of the slab.

Xinpei Liu (2015) analyzed the behavior of composite beams with shear connectors by finite element method and 3D modeling with ABAQUS® software. This model used the concrete damaged plasticity model and C3D8R element to simulate concrete and T3D2 elements to simulate reinforcing steel. The model was compared with results of Marshall et al. Considering the results from the finite element were consistent with experiment. Finite element can be efficiently used to analyze composite beams.

From all previous studies, little information has been found regarding corrugated steel sheet and concrete composite in both experiment and analytical data. This work applies nonlinear finite element model to analyze flexural behaviors of corrugated steel sheet and concrete composite. The results are verified with experimental result performed by Na-Lampoon (2016). The verified model is used in parametric study.

3. THEORETICAL BACKGROUND

3.1 MATERIALS MODEL OF CONCRETE AND STEEL

The tensile behavior of concrete in terms of stress-strain relationship proposed by Wahalathantri (2011) as shown in Figure 1 is used in this work.

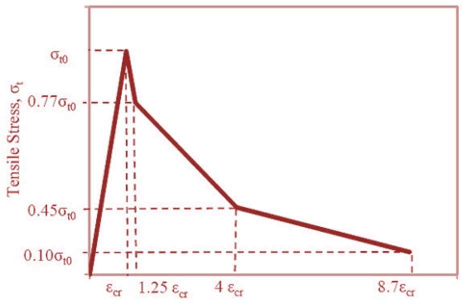


Figure 1: Tension Stiffening Model for Abaqus by Wahalathantri (2011).

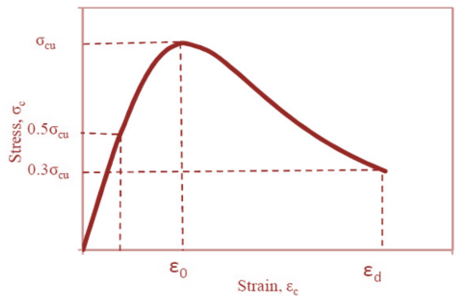


Figure 2: Compressive Stress-Strain Relationship for ABAQUS® by Hsu and Hsu (1994)

The stress - strain relationship of concrete in compression proposed by Hsu and Hsu (1994) is used and shown in Figure 2. This model can apply for concrete strength up to 62 MPa. Concrete behaves elastic for stress about 50% of ultimate compressive strength and then behave inelastic as shown in Figure3 that can be calculated by Equation (1)

$$\sigma_c = \left(\frac{\beta\left(\frac{\varepsilon_c}{\varepsilon_0}\right)}{\beta - 1 + \left(\frac{\varepsilon_c}{\varepsilon_0}\right)^{\beta}}\right)\sigma_{cu} \quad (1),$$

with parameters:

$$\beta = \frac{1}{1 - [\sigma_{cu}/(\varepsilon_0 E_0)]} \quad (2),$$

$$\varepsilon_0 = 8.9 \times 10^{-5}\sigma_{cu} + 2.114 \times 10^{-3} \quad (3),$$

$$E_0 = 1.2431 \times 10^2 \sigma_{cu} + 3.28312 \times 10^3 \quad (4).$$

Where σ_c refers to compressive stress, ε_c refers to compressive strain, σ_{cu} refers to ultimate compressive stress. Note: stress in the above equations is in kip/in^2 (1Mpa = 0.145037743 kip/in^2).

The stress-strain relationship of steel is assumed to be elastic-perfectly plastic without strain hardening as is shown in Figure 3.

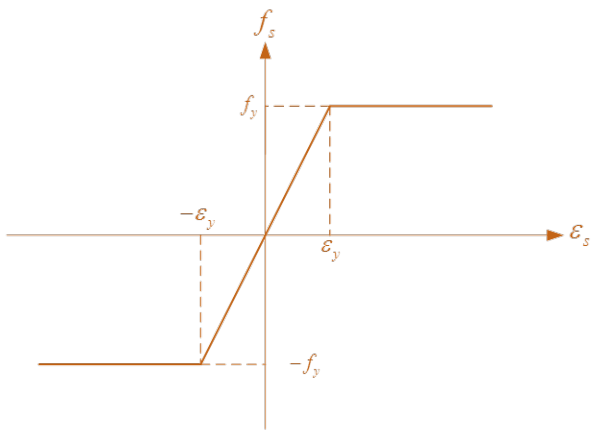
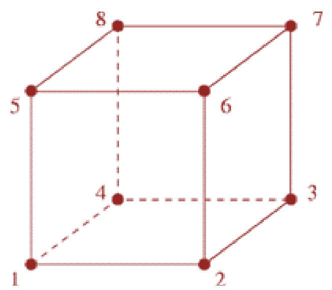


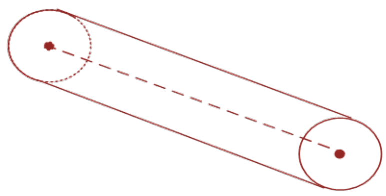
Figure 3: Elastic-perfectly plastic model of steel.

3.2 ELEMENT TYPE USED IN MODELING

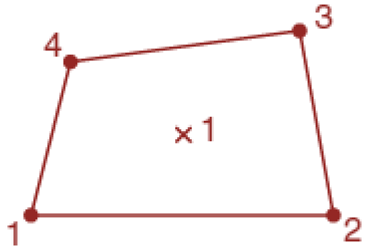
The concrete slab was modeled with 8-node linear brick, reduced integration elements C3D8R while the corrugated steel sheet was modeled with 4-node doubly curved general purpose shell, elements S4R. T3D2 element is used to simulate reinforcing steel. All elements used are shown in Figure 4.



(a) 8-node solid element (C3D8R) for concrete



(b) Truss element (T3D2) elements for reinforcing steel



(c) shell element (S4R) for steel sheet

Figure 4: Element used in the finite element model

4. FINITE ELEMENTS SIMULATIONS

This research uses the test samples of the composite slab that Tanatapong 2016 has performed. SN specimen is composite slabs composed of corrugated steel sheet with the dimension of 4000 mm (length) x 914 mm (width) x 76 mm (depth) overlaid by 125mm. thick concrete topping without shear connector and longitudinal steel rebar in concrete as shown in figure 5. The supports for the composite slabs are located 150 mm away from the span ends and test in the form of third point bending test. SSR specimen has the same configuration as the SN but L-bar shear connector and longitudinal steel rebar are added shown in Figure 6. Finite element model of SN and SSR are shown in Figures 7 and 8. SS specimen has the same configuration as the SN but only L-bar shear connectors are added without longitudinal steel rebar. Interface between steel and concrete is modeled by using contact properties, hard contact for normal behavior and penalty friction for tangential behavior.

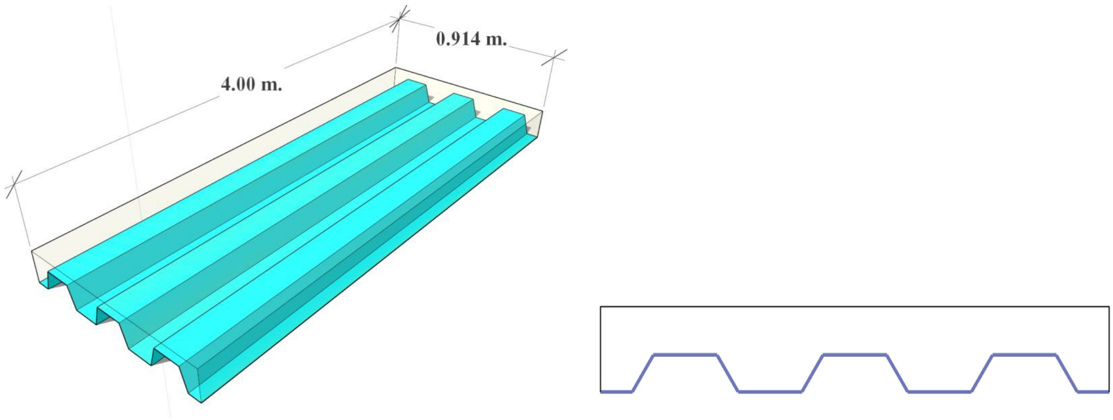


Figure 5: Details specimen SN of test performed by (Na-Lampoon, 2016)

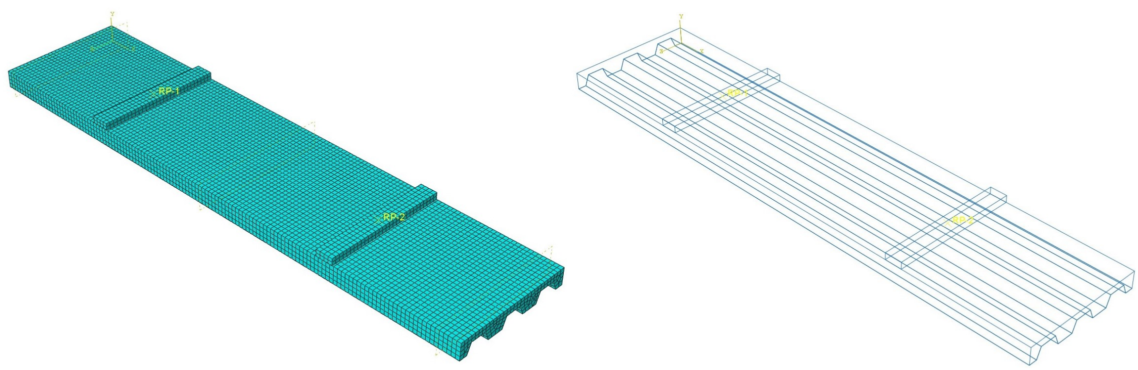


Figure 6: Finite element mesh of SN

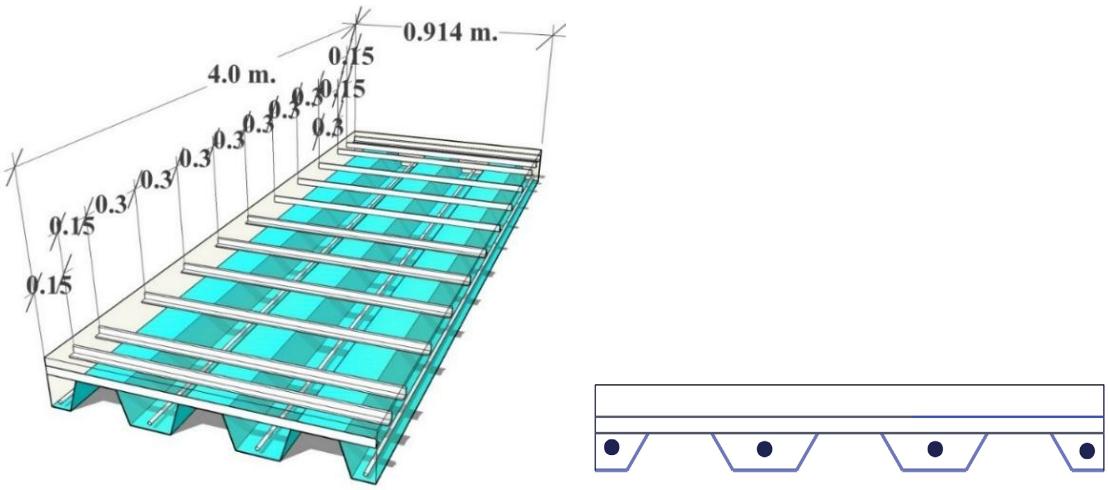


Figure 7: Details specimen SSR of test performed by (Na-Lampoon, 2016)

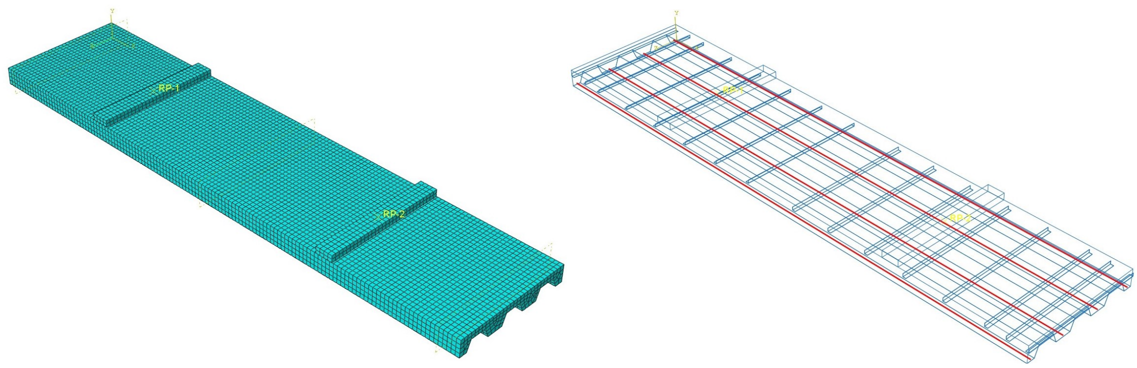


Figure 8: Finite element mesh of SSR

The material properties of concrete, steel rebar and corrugated steel sheet was referred to the results tested by Na-Lampoon (2016) as shown in Tables 1 and 2.

Table 1: Concrete properties.

Concrete Ultimate strength	28 MPa
Young's modulus	26,365 MPa
Poisson's ratio	0.2
Dilation angle	31
Eccentricity	0.1
Compression plastic strain ratio	1.16
Invariant stress ratio	0.667
Viscosity	0

Table 2: Properties of corrugated steel sheet , rebar and L-bar steel.

Yield Strength of Steelsheet	336 MPa
Yield Strength of RB9	436 MPa
Yield Strength of L-bar steel	240 MPa
Poisson's ratio	0.3
Young's modulus	210,000 MPa

Note: RB9 is round bar with 9mm diameter.

4.1 BOUNDARY CONDITION

The boundary conditions and prescribed transverse displacements of the composite slab are illustrated in Figure 9. The maximum out-of-plane deformation was applied along the depth of the slab with a linear prescribed displacement Uy to simulate the bending deformation of the composite associated with two-point loading. At the base of the corrugated steel sheet, for the left-end roller support two displacement degrees of freedom (Ux and Uy) were restrained, and for the right-end pin support three all of the three displacement degrees of freedom (Ux, Uy, Uz) were restrained.

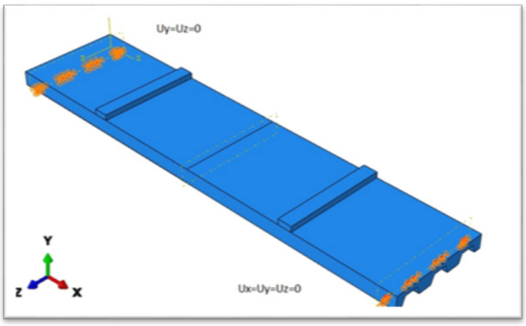


Figure 9: Boundary conditions of the slab

5. RESULT AND DISCUSSION

The FEM analytical results of the composite slab using ABAQUS® software shown an effect of mesh size or amount of the element on behavior under static loading of SN, SS and SSR are shown in Figure 10. Convergence of the solution is found to be 112,466, 60,000 and 65,996 elements for SN, SS and SSR respectively.

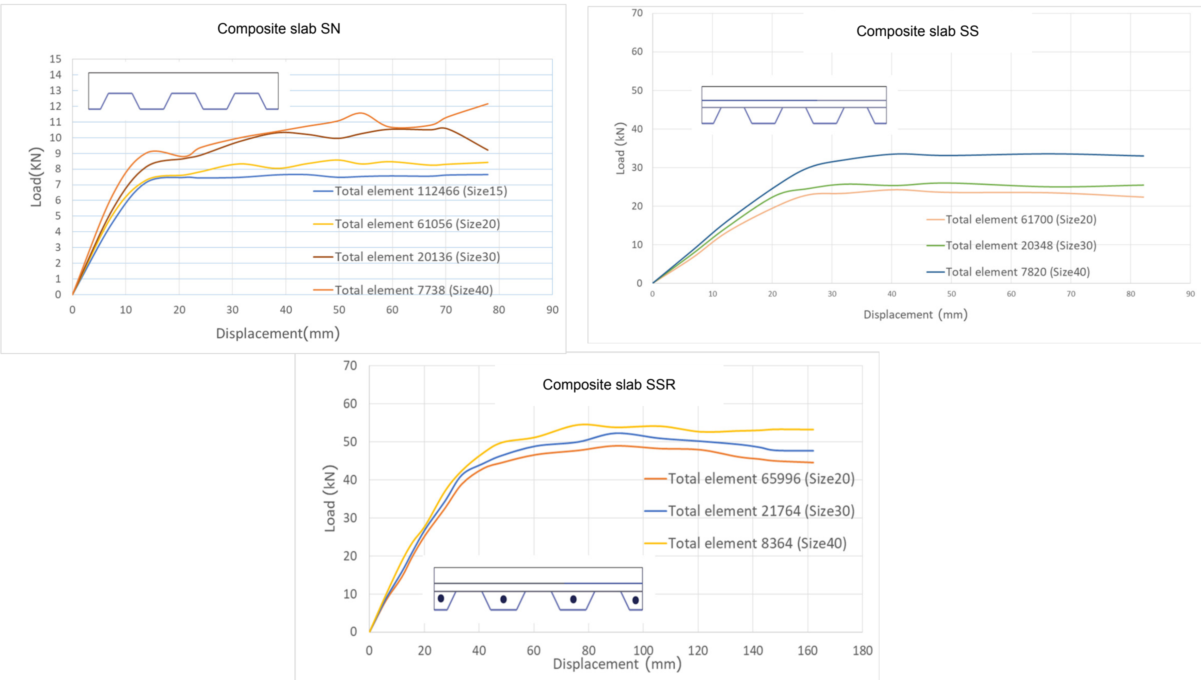


Figure 10: Mesh sensitivity on behavior under static loading of SN.

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The relationship between load and mid span deflection of the composite slab SN, SS and SSR compare with experimental results are shown in Figure 11. The convergence analytical results are found to be good correlation with experimental result in both linear and nonlinear range. Strength and deformation of the slab can be predicted accurately by nonlinear finite element model. It can be said that this model is reliable and can be used to perform a parametric study to consider the other involving parameters on the behaviors of composite slab.

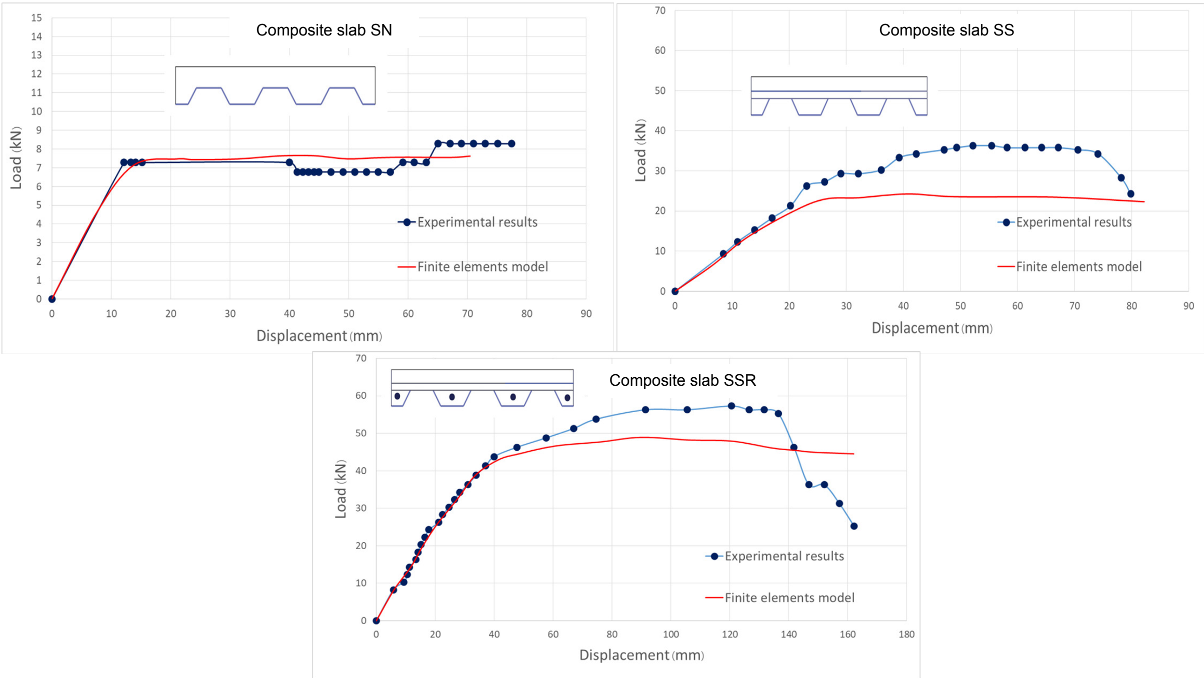

Figure 11: Comparisons of test and analytical results of composite slabs.

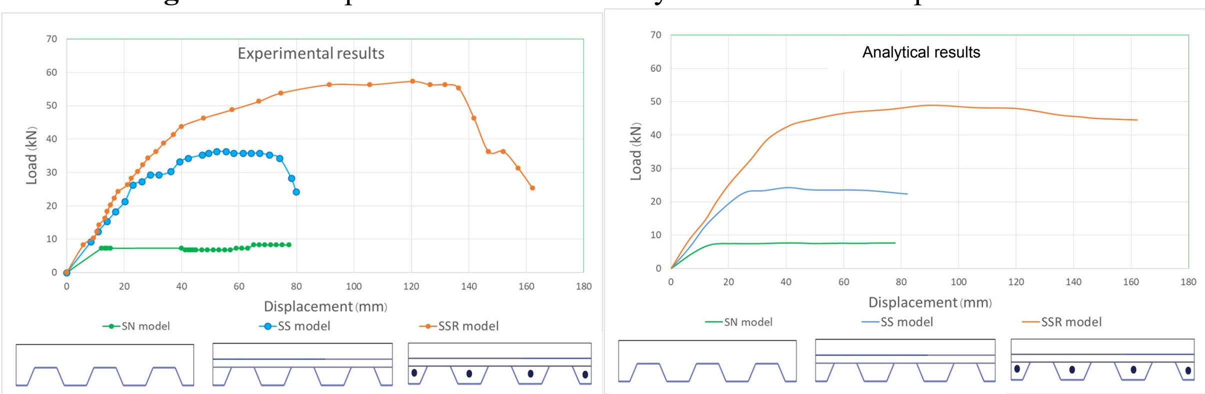

Figure 12: Test and analytical results of composite slabs.

Considering the experimental and analytical results in Figure 12, it is found that composite slab composed of corrugated steel sheet and concrete topping without shear connector (SN) can carry low load and fail in brittle mode due to the slip of the interface of steel and concrete. This is because after the flexural crack of concrete topping applied load is redistributed to corrugate steel sheet which cannot support the increasing load due to the low thickness, 0.75mm, and area of the corrugated steel sheet. Composite action of slab SN cannot be performed. Corrugated steel sheet acts as the form of concrete topping slab in this case. Providing L shape steel shear connector can significantly improve stiffness and load carrying capacity of the composite slab (SS). This can be said that composite action can be performed in SS slab. Strength, stiffness and ductility can be significantly improved in SSR slab composed of corrugated steel sheets, L shape steel shear connector and longitudinal steel reinforcement. This is due to the delay of concrete flexural cracking caused by the action of the added longitudinal steel rebar.

6. CONCLUSION

The nonlinear analysis of composite slabs composed of corrugated steel sheet and concrete topping have been carried out with the Finite Element Analysis using software ABAQUS®. Elements C3D8R is used for concrete, shell element S4R for corrugated steel sheet and truss elements T3D2 for longitudinal reinforcement. Materials model proposed by Wahalathantri (2011) and Hsu and Hsu (1994) are used for concrete in tension and compression respectively. The interface between steel and concrete is modeled by using contact properties, hard contact for normal behavior and penalty friction for tangential behavior gives satisfactory results. The results from finite element analysis of SN, SS and SSR provide consistent solutions with the results of laboratory tests. Finite element methods using ABAQUS® can be reliably used to analysis the behavior of composite slab. Shear connector and longitudinal steel reinforcement should be provided on corrugated steel sheet before poring of concrete topping to give the most efficient composite action, stiffness, strength and ductility of composite slab.

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