JOURNAL OF MECHANICAL ENGINEERING AND SCIENCES (JMES)
ISSN: 2289-4659 e-ISSN: 2231-8380
VOL. 15, ISSUE 1, 7874 – 7884
DOI: https://doi.org/10.15282/jmes.15.1.2021.21.0621

ORIGINAL ARTICLE

Blast loaded steel-concrete composite slab

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ABSTRACT – This paper presented a numerical investigation of a steel-concrete composite slab subjected to blast loads. The finite element model of the composite slab was developed and validated against experimental results. The validated finite element model of the composite slab then subjected to blast loads using CONWEP function in ABAQUS. A validation investigation was performed on CONWEP function by comparing the blast-pressure profiles from CONWEP against experimental data. Both validation studies showed that the developed finite element model of the composite slab and CONWEP agree reasonably well with test results. The fully restrained composite slab was subjected to four different blast loads with different explosive weights and standoff distances. The transient deformation of the composite slab after subjected to blast loads was investigated where as predicted the deformation of the composite slab was influenced by the blast pressure, which is affected by the weight of explosive and standoff distance. This study also investigated the mode of failure where it was determined flexural failure at the midspan is the main mode of failure accompanied with concrete tensile failure at the supports. The thickness of the profiled deck and the coeffecient of friction influenced the dynamic response of the composite slabs. Increasing the thickness reduces the maximum displacement of the composite slabs. Increasing the coefficient of friction reduces the maximum dislacement but once the coefficient of friction reach its optimum value, no positive benefit is gained.

ARTICLE HISTORY
Received: 24th Feb 2020
Revised: 05th Mar 2021
Accepted: 15th Mar 2021

KEYWORDS
Numerical investigation;
steel-concrete composite slab;
finite element;
CONWEP

INTRODUCTION

The combination of steel and concrete creates steel-concrete composite structures where one of the main components is composite slab. Composite slabs mainly consist of reinforced concrete and profiled steel deck. The composite action in composite slab is contributed mainly by mechanical interlocking from shear connectors. The shear connectors for composite slabs come in the form of embossment, wires and holes [1]. The advantages of composite slabs are the profiled steel deck can be used as permanent formwork and can be considered in design as a tension reinforcement. Therefore, these advantages allow a faster construction time, reduced waste as less woods are used for formwork and lighter floors [1,2]. As a result, steel-concrete composite structural system has become a common construction method currently.

At the same time, the threat of terrorist attacks using explosive have increased in the past decades. Recently, in April 2019, more than 200 civilians were killed while nearly 500 people were injured in bombing attacks in Sri Lanka [3]. The targets were civilian buildings where the attackers have easy access to the buildings. Thus, the effects from these incidents have make people more concern on their safety and the ability of public buildings in protecting personnel and civilians in public buildings. Therefore, as steel-concrete composite structures have become a common construction method, it is essential to investigate their response when subjected to blast loads. In this study, the focus is on the composite slab, which is one of the components in a steel-concrete composite structural system. In blast protection design, there is no better protection than preventing the incidents from happening [4]. This ideal solution, however, is not part of this study, which the ultimate threat comes from explosive blasts is the focus of this study.

Most of the studies performed on steel-concrete composite structures subjected to blast loads were conducted using numerical analysis. For examples, Sadek et al. [5] and Alashker et al. [6] used finite element analysis to simulate blast events. The blast analysis, however, was performed using sudden column lost or column removal method rather than a direct blast load application. This column removal method is a threat-independent method, which means main blast parameters such as explosive weight and standoff distance are neglected. Furthermore, this method neglects the transient dynamic response of the structure just after the blast pressure impact on the structure. Other numerical investigation carried out by other researchers on other composite structures are by Fu [7] and Jeyarajan, Liew and Koh [8]. These studies, including ref [5] and [6], however investigated the global structural performance rather than a local or specific component in a structural system such as steel-concrete composite slab only. As such, there is a lack of information available in public domain on the behavior of steel-concrete composite slab subjected to blast loads.

The lack of information is not only limited to numerical investigations but also in experimental studies. This issue could be contributed by factors such as confidentiality, lack of proposedly built testing facilities and high cost [9]. However, Lan, Lok and Heng [10] have performed an extensive blast tests program on composite slabs and sandwich

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composite slabs. In the test program, the authors have tested 24 composite slabs with different thickness and reinforcement diameters. Although, the authors have had a successful blast tests program, the data presented for the tested composite slabs was limited. Only maximum displacements and experimental observations on the failure or damage of the composite slabs were presented for selected composite slabs. The amount of explosive used and the blast pressure profiles in the blast tests for the composite slabs were not reported in detailed. Nevertheless, the study has shown that the tested composite slabs have no debonding issues and the profiled steel deck has shown a great potential to provide an extra resistance in resisting blast loading. Liu, Yang and Kang [11] have performed experimental and numerical studies to simulate blast events on composite floors system. The study, however, was based on column removal method, which neglect the transient response of the composite floors after the blast load impact. Moreover, this study investigated the global structural performance rather than local structural elements.

Therefore, this study investigated the transient response of a composite slab subjected to blast loads using finite element analysis. The blast loads were applied directly on the composite slabs and the displacement-time history of the slab was recorded for each blast load. The mode of failure and damage on the composite slab were observed from the numerical results and discussed in this paper. The influence of deck thickness and coefficient of friction are also investigated.

METHODOLOGY

This study was divided into two phases, which were quasi-static phase and blast simulations phase. The objective of the first stage was to validate the finite element models of composite slabs specifically for the mesh size, materials constitutive models and contact interactions. The validated finite element model was used in the second phase of this study. In this second phase, a validation study of blast loads simulation was performed to validate the blast pressure generated using CONWEP function in ABAQUS. The finite element model of the composite slab in this study was developed in accordance to a composite slab design used in an experimental program performed by Marimuthu et al. [1]. The reason for using the composite slab from Marimuthu et al. [1] is mainly because of the lack of experimental results for composite slabs with profiled steel decking subjected to blast load. The closest known blast test of similar type of composite slab was performed by Lan et al. [10]. However, there is a lack of information available in the report to develop the appropriate finite element models of the tested composite slabs. Therefore, this study has to improvise by using available composite slab testing. With a similar reason, the blast simulations were validated from disparate blast tests, which were from experiments conducted by Nassr et al. [12], with the main intention is to validate the CONWEP results. Thus, the results from the finite element analysis were compared against experimental results obtained in Marimuthu et al [1]. The blast pressures from the CONWEP function were compared against the blast pressure-profiles obtained from an experimental program conducted by Nassr et al. [12].

Validation of Finite Element Models

This section describes the development of the 3D finite element models of composite slabs using ABAQUS. The finite element model of the composite slab was developed in accordance to the design used in an experimental program performed by Marimuthu et al. [1]. The authors have conducted an experimental program to investigate the shear-bond characteristic of composite slabs for long and short shear spans. Each group, long and short spans, contain three tests with different shear spans. In this study, three composite slabs from the short span group were used for validation purposes and later to study the slabs behaviour when subjected to blast loads. The shear spans are as illustrated in Figure 1. The experiments were conducted by varying the shear spans (L_s), which were 320mm, 350mm and 380mm for the 3m (L) long composite slabs.

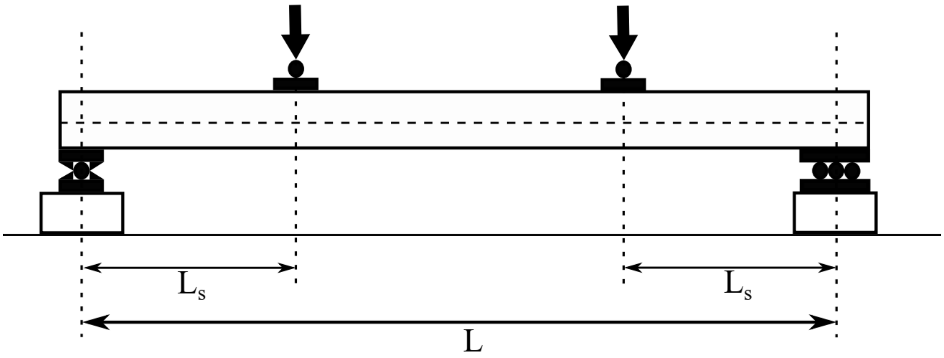


Figure 1. Schematic view of the experiment arrangement according to [1]

Finite element models

Three 3D finite element models of the composite slabs are developed using ABAQUS/CAE as presented in Figure 2. Eight-node linear brick elements with reduced integration (C3D8R) were used to model the concrete slab, all steel rollers and steel plates used at the supports and at the loading points. On the other hand, the profiled metal decks were modelled using three- and four-node reduced integration shell elements (S3R and S4R, respectively). The reinforcement mesh in the composite slabs was modelled using 2-node linear 3D truss elements (T3D2).

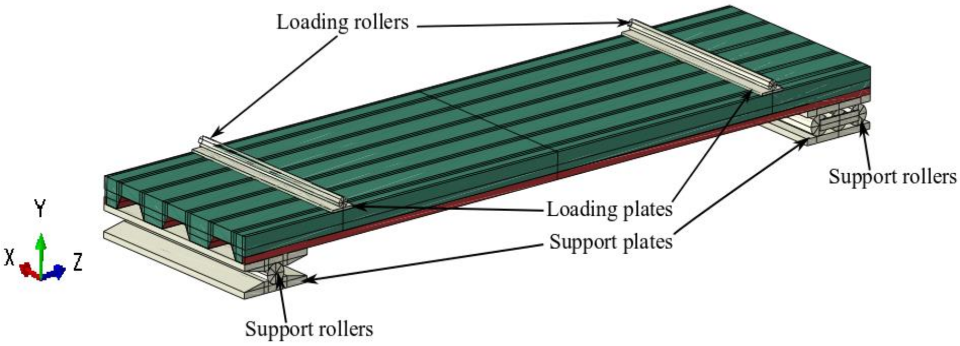


Figure 2. A finite element model of a composite slab under quasi-static tests

Materials constitutive models

The behaviour of concrete in compression and tension in the FE models was modelled using the Concrete Damage Plasticity (CDP) model according the formulation proposed by Kratzig and Polling [13]. This CDP model is suitable to be used for quasi-static and dynamic analysis [14]. In this study, the concrete density was taken as 2500 kg/m^3 and the Young's modulus was determined according to BS EN1992 (EC2) [15]. The plastic parameters required for the CDP models were taken as recommended in ABAQUS User's Manual [16]. The concrete ultimate compressive strength was taken as 20 MPa for all composite slabs [1]. The behavior of concrete in compression and tension is depicted in Figure 3(a). The damage of concrete in compression and tension was modelled by assigining damage parameters, DAMAGEC and DAMAGET, respectively. The damage parameters are in the range of 0 and 1, where 0 means no damage and 1 fully damage.

The rollers, plates and profiled steel deck are made from steel material. The density of these components was assumed as 7850 kg/m^3. The modulus of elasticity of all steel components was assumed as 200 GPa. The behaviour of steel deck and reinforcement mesh was assumed to be in a nonlinear fashion as illustrated in Figure 3(b). The steel deck and the reinforcement mesh were modelled as linear elastic materials until their respective yield limit. Once the yield limit is exceeded the deck and reinforcement behave plastically with hardening. The yield strength of the profiled steel deck was taken as 250 MPa [1] while the yield strength of the reinforcement mesh was assumed as 275 MPa. The performance of the steel rollers and plates is not the interest of this study. Therefore, the steel rollers and plates were assumed as linear elastic material. It is known that concrete and steel are two rate-sensitive materials where higher strain rates caused the strength of the concrete and steel to increase. This behaviour happens when the materials are subjected to a load in a very short time such as blast loading, which occur in milisecond. However, in this study the influence of strain rates on the strength of concrete and steel is neglected in the analysis of composite slabs subjected to blast loads.

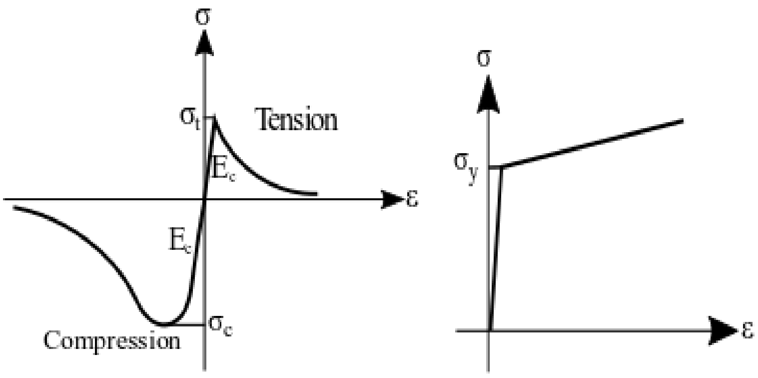


Figure 3. Uni-axial stress-strain curves of (a) concrete, (b) steel deck and reinforcement mesh

Contact interactions

Surface-to-surface contact interactions with finite sliding approach were assigned in the finite element models to model the contact interactions between concrete slab-profiled metal deck interfaces and steel-steel interfaces. The surface interactions were applied by specifying the normal and tangential interactions between interfaces. In normal direction, the interactions are defined as “HARD” contact pressure to minimise the penetration of the slave surfaces into the master surface. In the FE models, the master surfaces are the concrete surfaces and the profiled metal deck surfaces are the slave surfaces. The tangential interaction is assigned using the penalty-frictional formulation where appropriate coefficients of friction for respective contact interactions. The coefficients of friction used were 0.5 for concrete slab-profiled metal deck interfaces [17]. Qureshi et al. [17] assumed a frictionless contact between steel-steel interfaces in their study. However, in this study, a minimum coefficient of friction of 0.1 was assigned for all steel-steel interfaces. The reason for this is because it it impossible to achieve frictionless state between steel interfaces due to the present of surface roughness. Frictionless state could be possible if the steel interfaces were applied with lubricants. In the finite element models, the bond between the concrete slab and the reinforcement mesh was assumed as a perfect bond without any slips. Hence, an embedded constraint method is used to model the concrete slab-reinforcement mesh bond.

Boundary conditions

The bottom surfaces of the support plates at both ends of the composite slabs were restrained from moving and rotating in all directions. The loading plates were restrained from moving in X-direction only hence, free to move and rotate in other directions. On the other hand, the loading rollers were restrained from moving and rotating in all directions, except in Y-direction. In this study, an explicit dynamic procedure was used to obtain a quasi-static solution. Therefore, it is essential to minimise the effect of mass of the composite slabs by applying the load at a slow rate. The loading process was simulated using displacement-based loading scheme where a pre-determined displacement value was defined at the loading points to induce the load on the composite slab. A smooth amplitude function is used to increase the load slowly.

Mesh convergence study

A mesh convergence study was conducted before the results were compared against experimental data. From the convergence study, the optimum number of elements for the whole assembly of the developed finite element model is 37149 where the average mesh size was 20 mm for reinforcement mesh, concrete slab and profiled steel deck. According to this number of elements, the developed finite element models were compared against experimental results from Marimuthu et al. [1]. The failure load of the composite slabs from this numerical investigation and experimental study are tabulated in Table 1. The failure load from the experiment is denoted as F_{Exp} while F_{FEA} represented the failure load from the finite element analysis. The failure load is taken as the highest load just before a sudden load drop. The finite element analysis underestimates the failure load between 9% and 25%. The largest deviation is in specimen SS2 with 25% lower than experimental results. This large divergence could be contributed by the actual compressive strength of the concrete used in the experiment. In the experiment it was reported the concrete was designed as Grade 20 concrete, which has minimum compressive strength of 20 MPa. However, the study did not report the actual compressive strength of the concrete from compression test. Hence, there is a possibility the compressive strength of the concrete could be higher than 20 MPa. Nevertheless, the load-displacement curve of the composite slabs closely resembles the experimental load-displacement curve as presented in Figure 4.

Although the finite element analyses show that the FE models are stiffer, the failure of the composite slabs from the finite element analysis occurred almost at similar displacement level as the experiment. This stiffer response could be contributed to the The failure of the composite slabs is indicated by a sudden load drop as shown in the load-displacement curve in Figure 4. Moreover, the post-failure branch of the load-displacement curve showed similar trend as the experiment, except that the post-failure curves from the numerical investigation are higher than the experimental results. As a result, the final load, taken at the final measured displacement, for each composite slab is almost 2 times higher than the experiment. Nevertheless, the finite element models successfully simulate the response of the composite slab in the post-failure phase where the load starts to increase after a steep drop. The increase of load in this post-failure region could be contributed by the tensile membrane action provided by the profiled steel deck. At this stage, an uplift was observed between the two loading points. Hence, it might be reasonable to assume the composite slab has lost its composite action and the resistance of the slab is provided by the profiled steel deck thru the tensile membrane action.

Table 1. Experimental [1] and numerical results from the finite element analysis

Specimen	L_s (mm)	F_{Exp} (kN)	F_{FEA} (kN)	F_{FEA} /F_{Exp}
SS1	320	51.45	47.11	0.92
SS2	350	49.29	36.75	0.75
SS3	380	36.85	32.71	0.89

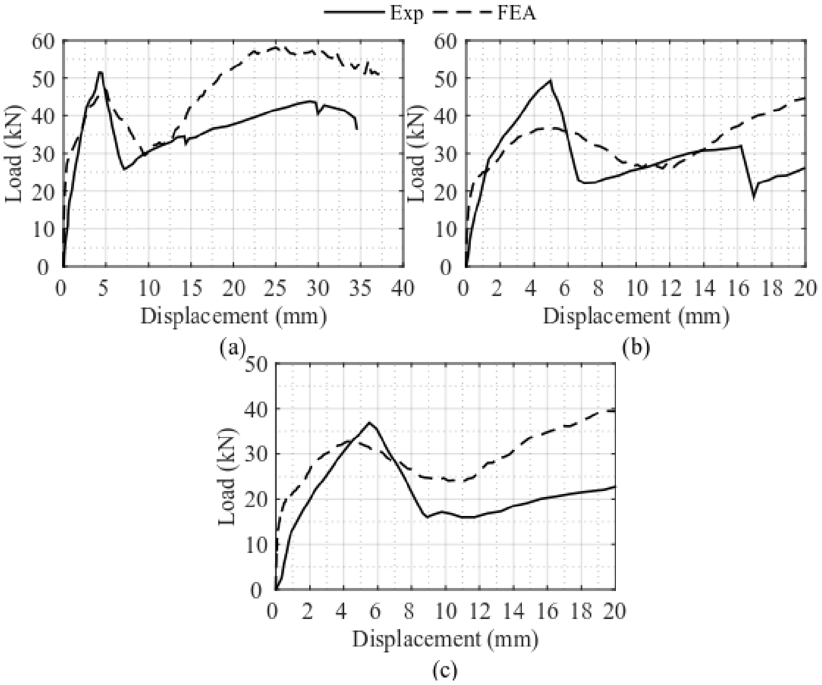


Figure 4. Load-displacement curves from experimental program [1] and finite element analysis for composite slab (a) SS1 and (b) SS2 and (c) SS3

Blast Simulations

In this study, the blast simulations were performed on the basis of the threat was from a luggage containing an amount of TNT explosive material detonated in a steel-concrete composite building. According to the available literature there is no specific guideline on the minimum amount of TNT and the minimum or maximum standoff distance that will cause a steel-concrete composite structural system to fail. On the other hand, according to FEMA 426 document [18], the amount of TNT that can cause a concrete column to fail is between 5.5kg and 45.5kg with standoff distance in the range of 3.4m and 5.4m. Therefore, this study used the blast parameters as suggested by FEMA 426 document, which are tabulated in Table 2.

When an explosion occurs in a building the blast pressure could be amplied due to the confinement and reflection effects. However, these effects are not considered in this study because of the methodology choose in the modelling of the blast simulations. As mentioned the blast simulations were conducted using CONWEP which neglect the influence of reflection and confinement effects. Moreover, this study utilise the simplicity of CONWEP which can be modelled in Lagrangian domain hence, reduces the computational cost. The confinement and reflection effects could be more suitable to be studied using more advanced method such as fluid-structure interactions in Eulerian-Lagrangian domain [19] but requires longer computational hours.

Table 2. Blast treats paramaters

Blast case	Standoff distance, S (m)	Explosive weight TNT, M (kg)	Scaled distance, Z (m/kg$^{1/3}$)
1	3.4	5.5	1.93
2	5.4	5.5	3.06
3	3.4	45.5	0.95
4	5.4	45.5	1.51

Validation of Finite Element Models

In this study, the blast simulations were conducted using CONWEP function in ABAQUS. To verify the blast pressure generated from CONWEP, a verification study was conducted. The verification study used blast test results from a disparate blast test. The blast pressure time-histories or profiles from CONWEP was verified against blast pressure profile obtained from the field test conducted by Nassr et al. [12]. Nassr et al. [12] has used ammonium nitrate-fuel oil (ANFO) mixture as the explosive material where the charges were place on the ground at standoff distances between 7 to 10.3 m. Table 3 shows the matrix of the experimental test of conducted by Nassr et al. [12]. However, only the results from Shot

1 and Shot 2 are used for comparison because the pressure-time history profiles from these two shots are available for comparison with the finite element results.

Table 3. Matrix of blast test from Nassr et al. [12]

Shot	Standoff distance, S (m)	Explosive weight ANFO, M (kg)	Scaled distance, Z (m/kg$^{1/3}$)
1	10.3	50	2.80
2	10.3	100	2.22
3	9	150	1.69
4	7	250	1.11
5	9.5	250	1.51

Figure 5 shows the blast pressure profiles from CONWEP and experiment obtained from pressure transducers P1 and P5 for Shot 1 and Shot 2, respectively. It should be noted CONWEP is trinitrotoluene (TNT)-based thus blast function therefore, the ANFO explosive weight was converted into TNT-equvalency by using 0.82 conversion factor [12]. The blast pressure profiles obtained from CONWEP showed close agreement with the experimental data in particular the maximum reflected blast pressure, P_r. CONWEP overestimates the reflected blast pressure for Shot 1 is 8% higher from the test data but underestimates the blast pressure in Shot 2 by 10%. In can be observed as well from Figure 5 that the time of arrival of the blast pressure from CONWEP is slightly later than the experimental data for both shots. Table 4 shows other blast parameters obtained from CONWEP and compared against experiment test results for selected blast pressure transducers, which are P1 and P5 transducers. Although CONWEP overestimates the positive phase duration, t_d in Shot 1 and Shot 2, the reflected blast impulse (area under the blast profile), I_r between CONWEP and experiment in average only differ around 7%. Hence, it can be concluded CONWEP can be used to simulate blast simulations.

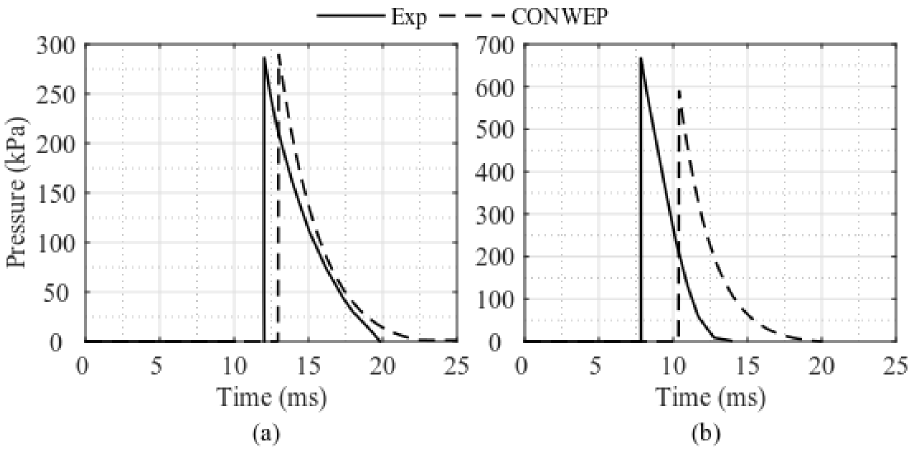


Figure 5. Experimental [12] and numerical blast pressure profiles comparison for (a) Shot 1 and (b) Shot 2

Table 4. Experimental [12] and numerical blast pressure parameters comparison

Transducer		P1			P5		
Shot	Method	$P_{r,max}$ (kPa)	I_r (kPa.ms)	t_d (ms)	$P_{r,max}$ (kPa)	I_r (kPa.ms)	t_d (ms)
1	Exp	267	770	7.9	311	721	6.8
	CONWEP	289	725	9.5	320	764	9.9
2	Exp	NC	NC	NC	662	1340	4.9
	CONWEP	543	1193	9.9	599	1248	9.7

*NC= not captured

RESULTS

Dynamic Response

The finite element model of composite slabs under quasi-static shear test and blast simulations using CONWEP developed in this study agree reasonably well with experimental test results. Therefore, the validated composite slab was used to study its dynamic behaviour when subjected to blast loads. The blast loads were applied directly on the composite slab using the CONWEP function. The maximum reflected blast pressure and impulse from CONWEP are tabulated in Table 5 while Figure 6 shows the blast pressure and impulse time-history from the respective blast load case. As predicted, the blast pressure from blast Case 3 is the highest as the standoff distance and the weight of explosive is higher and closer compared to other blast cases.

The transient response of the composite slab subjected to the blast loads is presented in Figure 7. As predicted, the composite slab in Case 3 experienced the largest displacement and the slab in Case 2 has the lowest displacement. These results are as predicted because the blast pressure and the impulse in Case 3 are higher compared to other blast cases as shown in Figure 7. In general, the displacement of the composite slabs increases as the blast pressure impacted on the composite slab increases. For example, with a reference to the blast pressure in Case 2, the blast pressure in Case 3 is almost 30 times higher. As a result, the maximum displacement of composite slab in Case 3 is almost 23 times higher than the composite slab in Case 2. According to the finite element results, the composite slab in Case 1 and 2 continues to vibrate after attained maximum displacement. If the analysis was performed longer, final displacement could be obtained. Nevertheless, it could be predicted that the final displacement will be close to the maximum displacement. Meanwhile in Case 3 and 4, the composite slab deformed and reached maximum displacement followed by a very slight spring-back response before immediately come to a rest. It can be observed the composite slab experienced permanent displacement in all blast load cases. Thus, this indicates the composite slab exceeded its yield limit.

Table 5. Predicted blast parameters from finite element analysis using CONWEP

Blast case	Reflected pressure, P_r (MPa)	Reflected impulse, Ir ($\times 10^{-3}$ MPa.s)	Positive phase duration, td (ms)
1	1.17	0.66	3.6
2	0.31	0.38	5.1
3	9.23	3.4	5.3
4	2.45	1.8	7.7

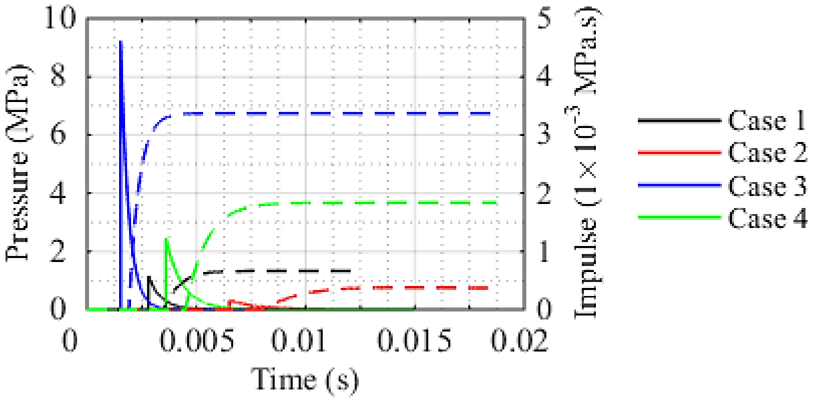


Figure 6. Predicted blast pressure profiles and reflected impulse

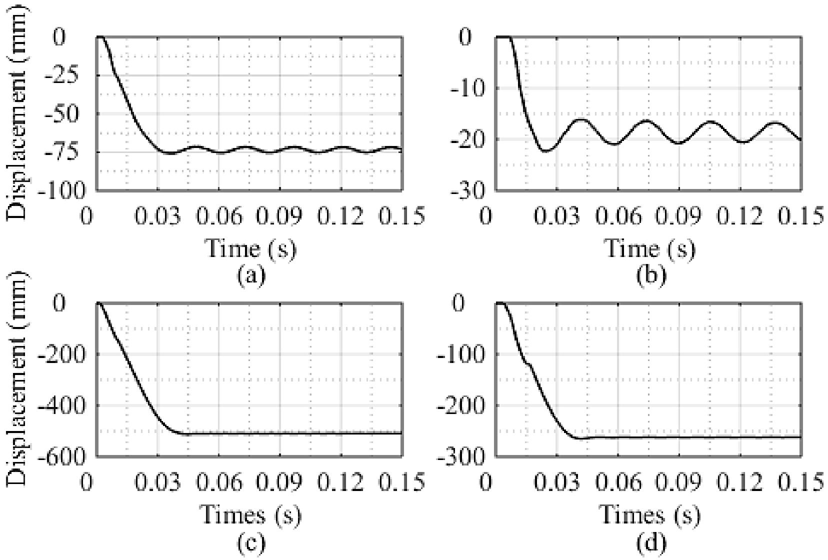


Figure 7. Predicted blast pressure profiles and reflected impulse

DISCUSSIONS

Mode of Failure

The mode of failure of the composite slab was investigated in this study. It was observed the composite slab experienced flexural failure at the midspan. Figure 8 shows the concentration of the tensional damage at the bottom section of the composite slab at the mid-span. The tensional damage is indicated using tensile damage parameter (DAMAGET). The tensile damage parameter is associated with the tensional damage in a material. The parameter ranges from zero to 0.99 where zero indicates no tensional damage while other than zero indicates tensional damage. Furthermore, the composite slab also experienced tensional damage in the concrete section at both supports as shown in Figure 9. This failure can be expected as both ends of the composite slab was restrained in translational and rotational degrees of freedom. Therefore, the concrete at the supports experienced tension force at the top section while at midspan the tension force in the concrete is concentrated at the bottom section of the concrete. According to the numerical observation, the severity of the damage in the concrete slab increases as the blast pressure increases. In Case 3, it was observed that the profiled steel deck at the supports stretched. This stretching could occur because of the excessive deflection experienced by the composite slab. No obvious delamination between the concrete and the profiled steel deck was observed in this numerical study as the concrete and the profiled deck move as a unit. Similar observation was observed by Lan, Lok and Heng [10] in their experimental program.

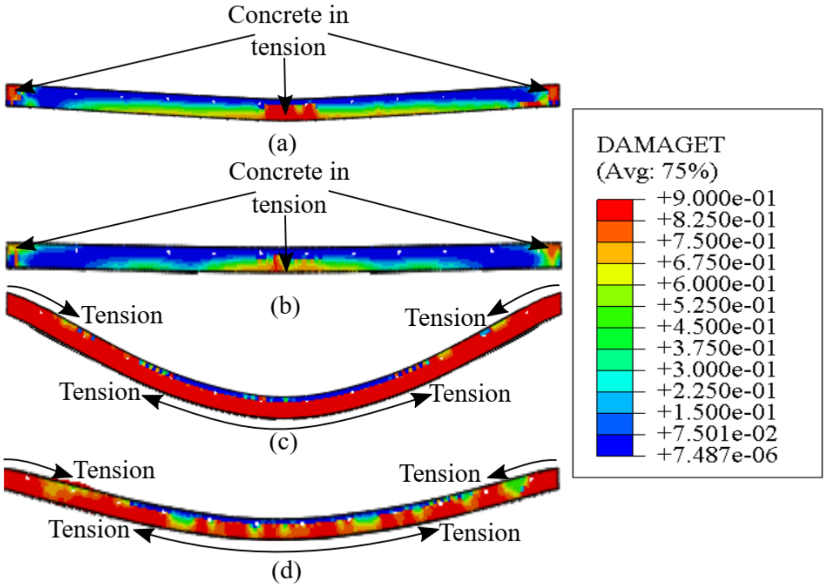
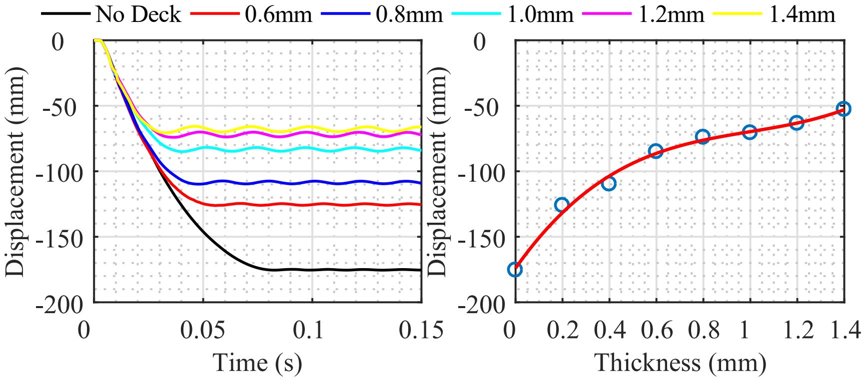


Figure 8. Composite slab in flexural mode for (a) Case 1, (b) Case 2, (c) Case 3 and (d) Case 4 at maximum displacement

The influence of profiled deck

Profiled steel deck is an assential part of steel-concrete composite slab were the deck could be designed as part of a tensile reinforcement. The most common thicknes for profiled steel deck is between 0.8 mm and 1.2 mm. In this study the influence of the deck thickness was investigated. The investigation was conducted by applying the blast load based on Case 1 as in Table 5. In one of the specimens, the steel deck was removed from the slab to simulate a ‘composite slab’ without a profiled steel deck or zero thickness deck. This specimen was a theoretical specimen only as it is impossible in the actual construction to have such kind of composite slab. Additionally, a number of theoretical steel deck thicknesses, which were 0.2 mm, 0.4 mm, 0.6 mm and 1.4 mm, were used in this study to obtain sufficient data and trends. These thicknesses were theoretical because the sizes are uncommon or not available in the market. Figure 9 shows dynamic behaviour of composite and the maximum displacement recorded from the finite element analyses for each deck thickenesess. In general, the maximum displacement of the slab decreases as the deck thicknes increases thus, improves the dynamic response of the composite slab. This study also shows the significant influence of steel deck in providing additonal resisance where the maximum displacement reduces around 30% when the deck is included in the composite slab. In general, this study shows that as the deck thickness increases the dyamic response of the composite improves significantly where the maximum displacement reduces more than 60% when compared between the thickest deck, which is 1.4 mm, and the slab without profiled deck or zero deck thickness. Hence, the profiled steel deck in the composite slab is important in providing additional strength and improve the dynamic response response of the composite slab when subjected to blast laods.



(a) (b)

Figure 9. (a) Dynamic response and (b) maximum displacements of composite slabs subjected to blast load Case 1 (50 kg of ANFO at a standoff distance of 10.3m with different deck thickness

The influence of coefficient of friction

The composite interaction between concrete slab and profiled steel deck is developed from the shear bond and the mechanical interlock between concrete and profiled deck. The embossment on the deck and the re-entrant geometry and shape of the profiled deck provide composite interaction. However, in finite element modelling, the re-entrant gometry could be possible to be modelled but the embossment is quite complex to be modelled and might requires a very fine mesh to obtain a decent mesh shape and to avoid any possible numerical errors due to mesh ratio during analysis. Therefore, researchers have instead used different method such as by assigning a coefficient of friction to model the composite interaction between the concrete and the profile steel deck in their finite element model [14 & 20]. Their finite element results using this approach are comparable to their experimental results which suggest this friction based method is succesful in simulating the composite interaction between concrete slab and profiled steel deck. Similar apporach is used in this study thus, the influence of coefficient of friction to the dynamic response of the blast loaded composite slabs need to be studied.

In this investigation, the composite slab is subjected to a blast load equivalent to 50 kg of ANFO at 10.3 m standoff distance with different coefficient of friction. The selected coefficient of frictions were 0 (frictionless), 0.25, 0.50, 0.75 and 1. The dynamic behaviour of the composite slab from the finite element analysis is depicted in Figure 10. The slope of the dislacement-time history of the composite slab with frictionless interaction, as illustrated in Figure 10(a), suggests that the frictionless contact interaction slightly change the slabs behviour at the intial stage which could be caused by the sudden movement of the slab to equilibrate any inequilibrium occured during the transient movement of the slab. On the other hand, slab with other coeffecients of friction show no changes to the slope of the displacement-time history at early stage of the transient response. Moreover, it seems that the composite slabs with coeffecient of friction indicate slightly lower stiffness compared to the frictionless composite slab. The frictionless composite slab shows slightly higher stiffess just after the sudden change of the slope which suggests that could be affected by the sudden movement of the concrete slab and the profled steel deck.

The results in Figure shows that the coefficient of friction greatly affect the dynamic response of the compsote slab. Interestingly, the finite element results in Figure 10(b) suggest increasing the coefficent of friction may not always improve the dynamic reponse of the composite slabs by reducing the maximum displacement. Once the coefficient of friction reach its optimum value, increasing the coefficient of friction has no benefit. In this study, the optimum value of coefficient of friction is 0.5. This suggest that the initial assumption to use 0.5 as the coefficent of friction as mentioned in previous section is appropriate.

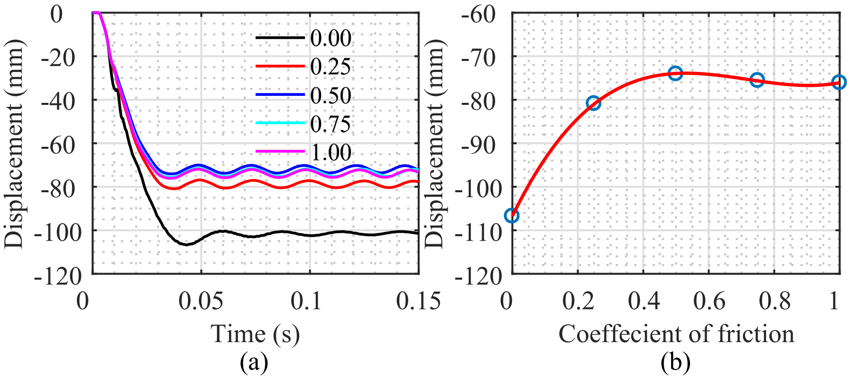


Figure 10. (a) Dynamic response and (b) maximum displacements of composite slabs subjected to blast load Case 1 (50 kg of ANFO at a standoff distance of 10.3m with different coefficients of friction

CONCLUSIONS

The dynamic behaviour of steel-concrete composite slab subjected to blast loads has been investigated. The results are summarized below:

1) The dynamic response of the composite slab is influenced by the weight of explosive and stand-off distances.
2) The composite slab responses could be categorized as spring-back responses and permanent deformation or a very light spring back response and permanent deformation depending on the blast pressure.
3) The main mode of failure is flexural mode at the midspan with stretching of profiled deck at the support when the slab deformed excessively.
4) Profiled deck thickness has great influence on the dynamic response of the composite slab. Increasing the thickness of the profiled deck reduces the maximum displacement of the book.
5) Increasing the coefficient of friction between concrete and steel deck improves the dynamic response by reducing the maximum displacement. However, when the value of the coefficient of friction exceeds its optimum value, no positive benefit is gained by the composite slab to improve its dynamic response. In this study, the optimum coefficient of friction was found to be 0.5.

ACKNOWLEDGMENTS

The authors would like to acknowledge Universiti Malaysia Pahang for research grants and funding (RDU1803153).

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