NUMERICAL INVESTIGATION ON STEEL – CONCRETE COMPOSITE SLABS UNDER BLAST LOADING

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ABSTRACT

This paper discusses the numerical investigation on steel – concrete composite slabs under blast loading. The study was conducted using finite element software and the finite element model of the steel – concrete composite slabs was validated against a disparate test data. The model was used to investigate key parameter in particular; the diameter of mesh reinforcement used in the steel – concrete composite slabs. The validation results show that the computed model of steel – concrete composite slabs can almost replicate the result from the experimental. Thus, the model that have been computed was extended for blast simulation using CONWEP. CONWEP is a blast load function available in Abaqus FEA. The blast-profiles from the CONWEP was verified against the result obtained from a disparate field test. The results suggest the CONWEP is able to simulate the blast-pressure profiles with sufficient accuracy. By using CONWEP in Abaqus, the validate composite slabs were subjected to various blast loading cases. From the study, it was found that the pressure is affected by the stand-off distance and the weight of the mass explosive. Which the higher the explosive mass and the shorter standoff distance used will produce high impulse. High impulse load resulted a higher displacement on the steel – concrete composite slabs. Finally, from the parametric study, the limit diameter mesh reinforcement to use in steel – concrete composite slabs is 8 mm because increasing it more will not give significant resistance toward blast load.

ABSTRAK

Kertas kerja ini membincangkan tentang kaji selidik mengenai lantai komposit keluli – konkrit apabila terkena bebanan letupan. Kajian ini telah dijalankan menggunakan perisian komputer Abaqus. Model lantai koposit keluli – konkrit yang direka melalui perisian komputer ini telah disahkan melalui beberapa pengesahan data daripada ujian-ujian yang berbeza. Model yang sama juga telah digunakan untuk mengkaji parameter yang lain seperti kesan penukaran saiz diameter tulang kerangka yang digunakan dalam struktur lantai komposit ini. Hasil keputusan telah mengesahan bahawa model yang komputer yang direka mampu menghasilkan keputusan ujian yang hampir sama dengan hasil keputusan ujian daripada ujikasi ekperimen. Oleh itu, model ini akan dilanjutkan lagi untuk ujian simulasi letupan menggunakan fungsi “CONWEP” yang tersedia di dalam perisan Abaqus. Sebelum itu, satu pengesahan lain telah juga dilakukan, iaitu simulasi ujian letupan ke atas rasuk keluli yang berdasarkan dari kesusasteraan yang lain. Dari pengesahan itu, satu kesimpulan dibuat bahawa tekanan dari letupn dipengaruhi oleh jarak dan berat bahan letupan. Ini bermaknsa, lebih tinggi jisim bahan letupan dan jarak antara tempat letupan dan struktur pula adalah pendek, maka satu bebanan yang tinggi akan terhasil. Dari simulasi yang dilakukan, bebanan yang tinggi akan menyebabkan kerosakan yang tinggi. Akhir sekali, dari kajian parameter yang telah diadakan, saiz diameter maksima yang disyorkan untuk tulang kerangka untuk digunakan adalah 8 mm. Hal ini kerana, jika saiz diameter lebih tinggi digunakan, ianya tidak akan memberi kesan yang signifikan terhadap rintangan daripada bebanan letupan.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Steel – concrete composite slabs means that there are at least two components of the structure such as the steel deck and reinforced concrete floor that is bonding together by any mechanical techniques and act compositely to resist the tension and compression of the structure when subjected to any loads. Other than that, this type of structure can give advantages when comes to faster flooring construction, lighter floors and the rational use of construction materials (Marimuthu V., Seetharaman S., et al., 2006). Thus because of all that, this structure is becoming more popular in nowadays construction industry.

As it becomes common in buildings, researchers are interested to investigate the behaviour of the structures to blast loads because of the threats from terrorist attacks are ever increasing. Recently, Sri Lanka, had experienced three bombing incidents that resulted in more than 300 casualties and severe damages to buildings. Therefore, it is evident there is a need to investigate the response of the composite structure such as steel-concrete composite slabs to improve the understanding of the behaviour of the structure when subjected to blast loading.

Other evident is when Jintao Li and others (Jintao Li., Chao Huang, et al., 2018) conducted detailed finite element analysis of composite bridge deck to study the behaviour of structure under blast loading. The result suggested that the damage modes of the structure are depend to the type of the loading subjected which the high impacts loads are difference with blast loads. Thus, to ensure the safety of these structures especially for construction of blast-risk structures such as embassy buildings, it is important to design them which can withstand the expected design-based threat level.

1.2 Statement of Problem

There is no literature can be found for the steel – concrete composite slabs subjected to the blast loading. Most of them, focussed on the experimental of the steel – concrete composite slabs under high impacts loading rather than the blast loading. For example, an experimental study has been carried out to investigate primarily the shear bond behaviour of the embossed composite deck slabs under simulated imposed loads, from paper by Marimuthu, Seetharaman, et al. (Marimuthu V., Seetharaman S., et al., 2006) and behaviour of headed shear stud in composite beams with profiled metal decking from paper by Qureshi and Lam (Qureshi J. and Lam D., 2012). This is because the experimental on the blast loading is too costly and high risk.

As the alternative to experimental methods, the numerical model can be performed using finite element software such as Abaqus FEA. This method can quantitatively stimulate the mechanical character of the steel – concrete composite slabs subjected to blast loading in more flexible and cheaper way. By utilise the finite element analysis, the understanding on the performance and response this structure under blast load can be enhance. Furthermore, parametric study can also perform to study the effect of that parameters to help improve the blast resistance design consideration for this structure in the future.

1.3 Objective of Study

In general, the objectives of the study are;

a) To model steel-concrete composite profiled slab using Abaqus FEA software and validate the model against test data.

b) To study behaviour of steel-concrete composite slabs under the blast loading.

c) To study the influence of reinforcement mesh diameters on the behaviour of the steel-concrete composite slabs subjected to blast load.

1.4 Significance of Study

This paper studies about the response behaviour of steel – concrete composite slabs under blast load. Thus, from that result and data from the numerical analysis of the structure, we can develop some awareness of the hazards and risks created by the blast loads. For future use, this paper can help in other researchers to implement the blast resistance design of the structure especially in steel – concrete composite slabs to prevent structure failure.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Structure

The composite structure is gaining wide acceptance in many countries as they provide a faster, lighter and economical construction in buildings. Because of that many researchers are eager to study the behaviour to this structure in order to enhance the understanding and provide a better solution to improve this structure in future to become more reliable and best option of the structure to use in flooring system in the construction.

Here some examples of the study conducted related to composite structure. First one from by Marimuthu, Seetharaman, et al (Marimuthu V., Seetharaman S., et al., 2006), which they conduct experimental studies on composite deck slabs to determine characteristic *(m-k)* values of the embossed profiled sheet. The experiment has been carried out to investigate primarily the shear bond behaviour of the embossed composite deck slab under simulated imposed loads and to evaluate the *m–k* values in the total of 18 composite slab specimens.

As the composite steel deck floor slab, it means that there a provide with a system that bond the steel deck and the concrete so that they can act compositely. The mechanical interlocking system is needed and it can be provided by many types of ‘shear transferring devices’ such as rolled embossments, transverse wires, hole etc. Example of composite steel deck floor system are shown in Figure 1. But the most efficient type to used is by embossments on the profiled steel sheeting. Thus, the shear bond characteristic of the embossed sheeting is rated by these two parameters ‘*m*’ and ‘*k*’. where ‘m’ represents the mechanical interlocking between steel and concrete and ‘k’ stands for friction between them.

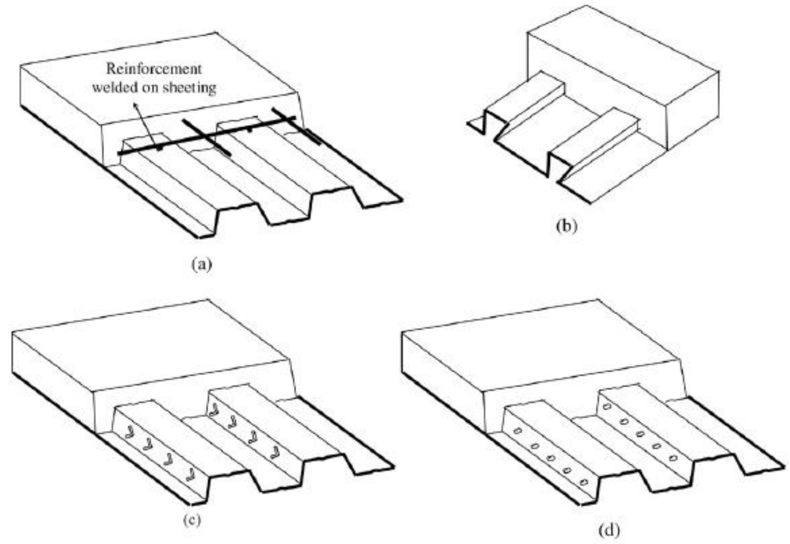


Figure 1: Composite Deck Slabs Using Different Types of Profiled Sheets

For experimental setup, the total 18 specimens were split into six sets of three specimens each in which three sets were tested for shorter shear span and the other three for longer shear span loading. Then all the specimens were tested to failure under static loads. The shear span is defined as a distance between the centre of support at either end to the point where the loading is applied. In the Figure 2, is shown the schematic setup of the static test for this structure and the location of the shear span.

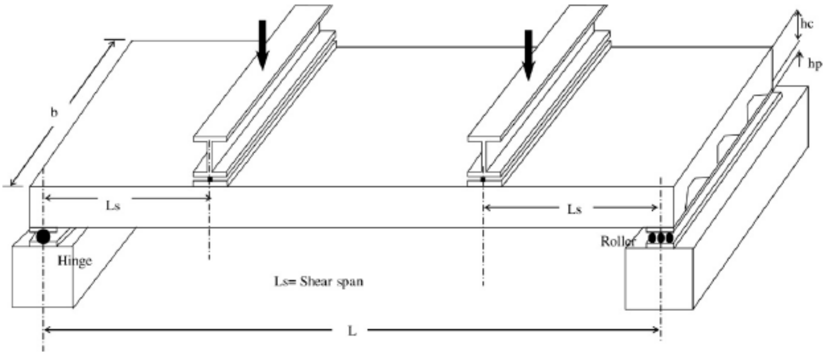


Figure 2: Schematic View of The Experimental Setup

Another research by Qureshi and Lam (Qureshi J. and Lam D., 2012), where they perform the numerical experiment to investigate the behaviour of the headed shear stud in composite beam with profiled metal decking. Same goes the composite slabs, the steel-concrete beams using profiled sheeting metal deck are becoming popular due to this structure being lightweight, strong and building services friendly. Plus, the composite action of the steel – concrete beam is ensured by mechanical action of headed shear connectors

In this paper, in order determine behaviour of the shear connector, the push test should be done. Thus, they used the finite element software Abaqus FEA to compute the push test and validate it with other experimental data. To model the steel – concrete composite beam, these components need to model first which are steel beam, concrete slab, trapezoidal profiled sheeting, steel wire mesh reinforcement and headed shear stud before assembled them all. Thus, the material properties of every components needed to identified through extensive literatures study.

One of the material properties needed to be understood is concrete damaged plasticity model (CDP). This model is commonly being used to model the material properties for concrete when analysis using dynamic function in Abaqus FEA. This model is primarily based on two main failure mechanisms namely tensile cracking and compressive crushing concrete. For the failure behaviour of this model is expressed as a softening stress – strain response.

Regarding to concrete damaged plasticity model (CDP), the paper from Polak, Aikaterini S. Genikomasu and Maria Anna (Polak, 2015), have done finite element analysis of punching shear of concrete slabs using damaged plasticity model in Abaqus. Even though that structure is different, but the material properties is the same and from this paper, all the informations regarding to CDP model have been discussed.

From the paper also, the concrete material parameter that ware used in the analyses are: the modulus of elasticity E_0, the Poisson's ratio υ and the compressive and tensile strengths of the selected slabs. The CDP model considers a constant value for the

Poisson’s ratio υ, which from analyses done, the value is υ = 0 was assumed. The dilation angle ψ was considered as 40^{o} and the eccentricity ε = 0.1.

Alashker, Tawil and Sadek (Alashker Y., El Tawil S., et al, 2010), discusses he progressive resistance of steel-concrete composite floors. The study is conducted using numerical analysis where they model the structure using finite element software and validated it through extensive comparisons to disparate tests data. Such extensive validation is necessary to lend credence to the model and provide reassurance that model results are reasonable.

Regarding to composite structure, another journal that related is from Jeyarajan and Richard Liew (S. Jeyarajan, 2015), where they are analysing of steel – concrete composite buildings for blast induced progressive collapse. The analyses are including several verification studies of the result from Abaqus with experimental data such as verifying the proposed joint model, composite slab under bending and flexural load. All these verifications are necessary before they undergo simulations of the robustness analysis of 3D composite frame subject to blast load.

Using the nonlinear dynamic analysis, there will be two – step process, first the dynamic analysis is carried out on 3D composite framework subjected to blast load based on the proposed simplified joint and composite slab models. Damaged members are then identified and removed. After the removal of damaged members, subsequent non – linear dynamic analysis is performed on the damaged building frame. This can reduce the computational time and less effort in modelling. The figure below shows general view result from the analysis.

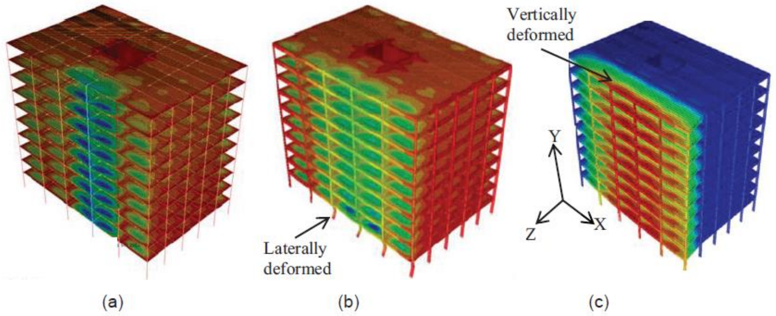


Figure 3: Deformed frame view for (a) one column loss analysis (b) non-linear dynamic analysis (c) five column loss analysis

2.2 Blast Waves and Blast Loading

From the information from "Blast and Ballistic Loading of Structures" book (Hetherington, 1994), the blast wave was form from the disturbance of pressure where the pressure moving outwards. This usually causes by the chemical or nuclear explosions produced large amounts of energy which heating the surrounding medium and produce high pressures and then disturbance to the pressures.

When explosive material detonates, almost 100% of the energy liberated is converted into blast energy. While it is nature of the blast, only 50% of energy produces blast and other converted into other form of thermal and other type of radiation. Which it is mean the explosion produced hot gases at pressures from 100 kilobars up to 300 kilobars and at temperature of 3000-4000^{o}C.

From "Structure to Resist the Effects of Accidental Explosions" book (Unified Facilities Criteria, 2008), the blast wave is described when it is expands in the air, any structure that located in the path of the blast travel will be engulfed by the shock wave. The magnitude and the distribution of the blast loads on the structure arising from these pressures are function of the following factors:

a) The type of explosive material, energy output and the weight of explosive

b) The stand-off distance which means the location of the detonation to the structure

c) The magnitude and reinforcement of the pressure by its interaction the ground barrier at the structure itself.

Talking about the blast loading. It is categories into two main groups based on the confinement of the explosive charge and can be divided into based on the blast loading produced within the donor structure or acting on acceptor structure which are unconfined explosion and confined explosion. For unconfined explosion, there free air burst explosion, burst explosion and surface burst explosion. While for confined explosion, there are fully vented explosion, partially confined explosion and fully confined explosions.

2.2.1 Important Blast Wave Parameters

According to the “Blast and Ballistic Loading of Structures” book (Hetherington, 1994), the significance blast wave parameter include t_o, the duration of the positive phase when the pressure is in excess of ambient pressure and i_s, the impulse of the wave which is the area beneath the pressure – time curve from arrival time at t_A to the end of the positive phase as given by

$$i_s = \int_{t_A}^{t_A + t_0} p(t)dt$$

A typical pressure – time profile for blast wave in free air is shown in Figure 3 where Δp_{min} is the greatest value of the pressure below ambient in the negative phase of the blast of duration T^-. This is the refraction component of the blast wave. Brode’s solution for Δp_{min} is

$$\Delta p_{min} = -\frac{0.35}{Z} \quad (Z > 1.6)$$

The negative phase duration is given by

$$T^{-} = 1.25W^{1/3}$$

and the associated specific impulse in the suction phase i^- is given by

$$i^{-} \approx i_s \left[1 - \frac{1}{2Z}\right]$$

Finally, λ_{rw}, the length of the refraction wave is given in metres for T^- in seconds by

$$\lambda_{rw} = 340T^{-}$$

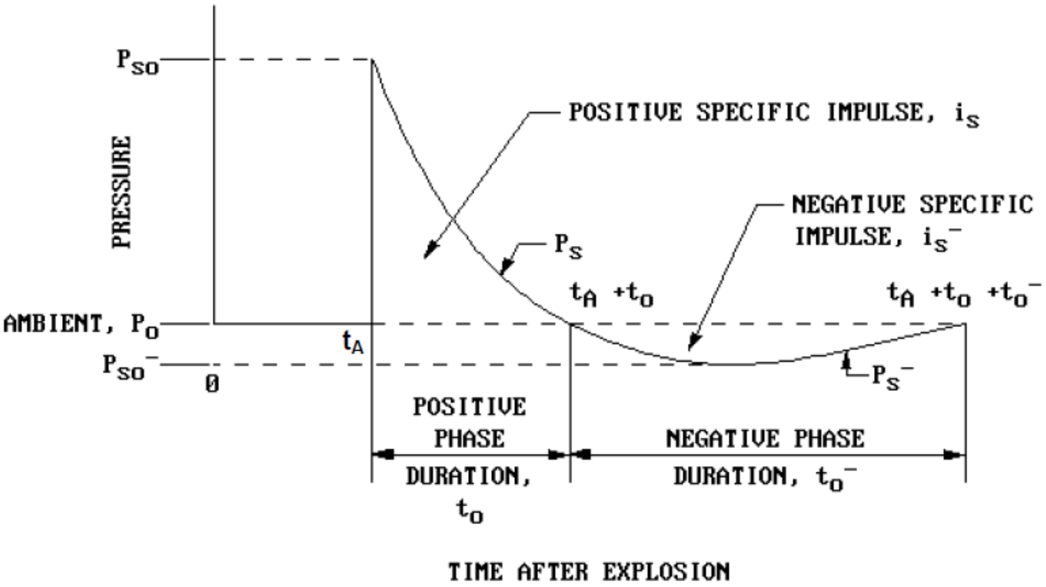


Figure 4: Blast Wave Pressure - Time Profile

A convenient way of representing significant blast wave parameter is to plot them against scaled distance as shown in Figure 4 from (Unified Facilities Criteria, 2008).

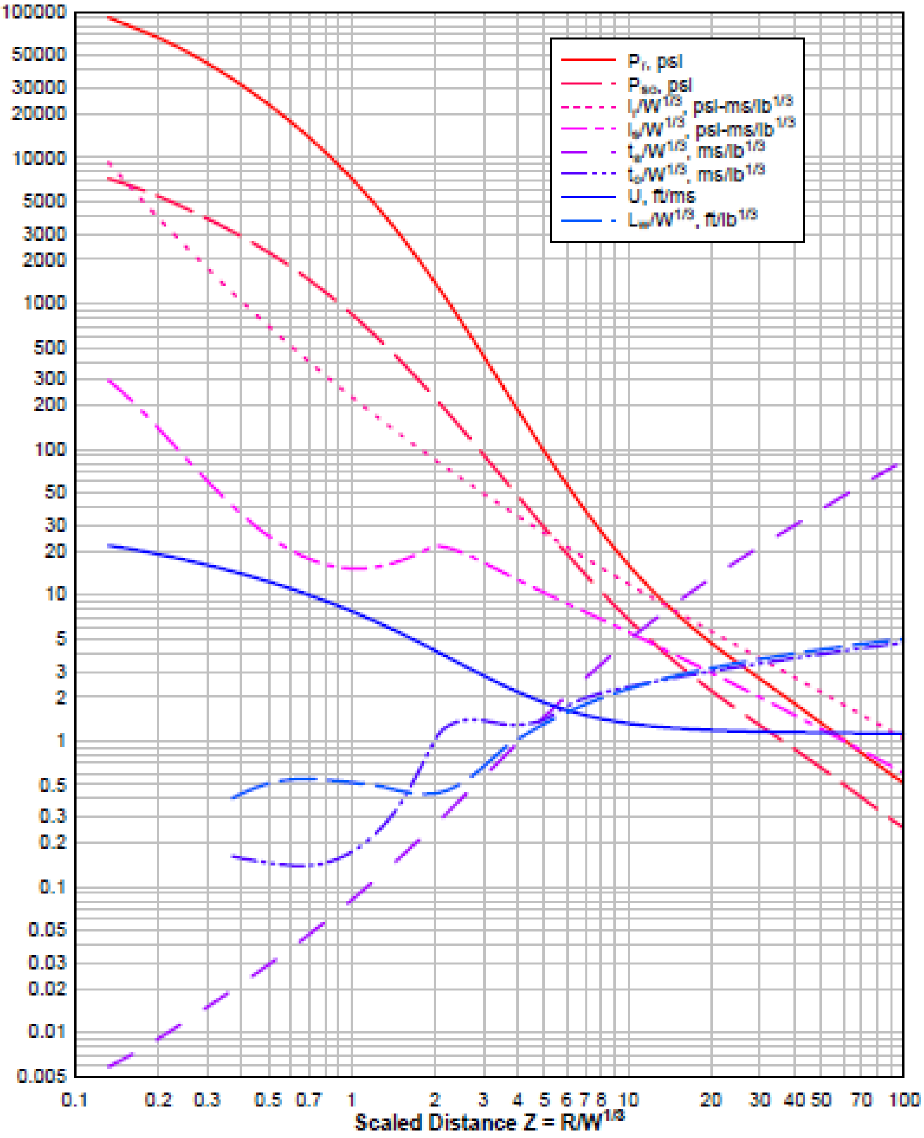


Figure 5: Blast Wave Parameters for Spherical Charge of TNT

2.2.2 Blast Wave External Loading on Structure

The discussion is focus on reflecting surfaces that are essentially infinite and do not allow the diffraction process when the system of waves is spread out to occur. In the case of finite target structures three classes of blast wave structure interaction can be identified. The first one, the interaction of large-scale blast wave such as might be produced by nuclear explosion such as nuclear engine. The target structure is engulfed and crushed by the blast wave and there are translational force moving the structure.

The second category is when a large-scale blast interacts with small structure. The target structure will likely be engulfed and crushed more like or less to be squash by the impacts from blast. Plus, the translational force also will significantly greater than previously category. Finally, the case of small blast wave produced by small explosion charge into substantial structure. Here the response of the individual structure elements needs to be analysed.

2.2.3 Blast Loading Analysis

There is some difficulty to find a paper related to the steel – concrete composite slabs subjected to blast load. But due to the fact that there will be validation needed for numerical blast load test result with the experimental test. Here are some paper that I found related with the study. First one, Nassr, Ghani Razaqpu, et al (Nassr A., 2012), have performed blast field test on the steel beams. From this paper full extensive experimental data is provided which can helps in data collection for modelling and validation for blast load test in Abaqus.

Second, Rao, Agesh Markose and C. Lakshamana (Rao, 2016), had study about failure analysis of V-shaped plates under blast loading. The analysis has been done using numerical analysis software which is Abaqus FEA. What interesting about the analysis is the model for blast load is modelled by using the CONWEP blast loading function in Abaqus. CONWEP is an empirical equation used for directly applying the blast load on any structural geometry and CONWEP takes into account of;

a) the distance between the target and the charge,

b) the mass of the charge

c) the inclination of the target, for calculation of the blast pressures.

Although convenient, it is incapable of considering the effect of very near field loading and reflection from the nearby bodies. It helps to reduce the burden of explicitly simulating the progress of the shock wave and its interaction with structure. The pressure calculation using CONWEP function is based on experimental data and they can be used only by appropriately including the scaling parameters considering the actual explosion.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The analysis of the behaviour and response of the steel – concrete composite slabs under blast loading will be done using finite element analysis. To model the structure and apply it with the condition of blast load, the finite element software Abaqus FEA will be used to do the work. Before model the steel – concrete composite slabs subjected under blast loads, the computational model of the structure will be validated with experimental data that obtain from literatures. Its same goes to the validation for blast test that will have same process which there are extensive comparison with disparate test data. In order to lend credence to the model and provide reassurance that model result is reasonable.

3.2 Project Planning

In general, there are several steps have been planned in order to achieve the objectives of this research. First one is to model the computational model of the steel – concrete composite slabs using Abaqus software. For this step, the experimental model from Marimuthu, Setharaman, et al.'s research (Marimuthu V., Seetharaman S., et al., 2006) will be refer to model the computational model. Then the model computed will be test under static test and the result will be compare with the experiment data from the same paper to validate the model to have some insurance that computed model can behave same with real live structure.

Second step, is to applied the blast load to the computed model of composite deck slab. But unfortunately, there are no literature can give the experiment data or result of blast field test on the composite deck slabs. Thus, the validation through comparison to disparate test data is applied for solving this problem. This resulted that, the paper from

Nassr, Ghani Razaqpu, et al. (Nassr A., 2012), which they perform a field blast test on steel beams will be used to replicate the same test using Abaqus and compare it with the experimental result from the paper.

Such extensive validation is necessary to lend credence to the model and provide reassurance that the responses of the blast impact can also be replicate using Abaqus and also can be applied to the computed composite deck slabs model. This led to step three, which the blast load be applied to the computed composite deck slabs model using the case study provided from the "Structure to Resist the Effects of Accidental Explosions" book (Unified Facilities Criteria, 2008).

Finally, the result from the simulation of blast load test on the computed composite deck slabs model will be recorded and discuss. Then, the parameter study will be test which the diameter of mesh reinforcement of the composite deck slabs will be change will several diameters in order to find out its responses regarding to the matter.

3.3 Data Collection

Here are the lists of the literatures that used with the contributions of data that will be used for disparate test data of this research

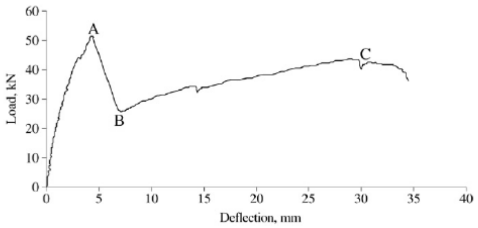
3.3.1 Static Test

For static test, the computational model of steel – concrete composite slabs will be computed according to the model of structure from Marimuthu, Seetharaman, et al. (Marimuthu V., Seetharaman S., et al., 2006). From this paper, they provide all the necessary data about static test on the composite deck slabs which include the dimensions of the structure, the applied load, the schematic design of the experiment and the result of the experiment.

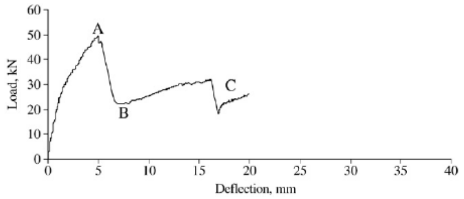
In the paper, the total of 18 specimens were split into six sets of three specimens each in which three sets were tested for shorter shear span and the other three for longer shear span loading. The sets of shorter shear span only will be chosen to model in the Abaqus. The length of shear span chosen are shown in Table 1 below.

Table 1: Details of Shorter Shear Span Loading and Its Behaviour

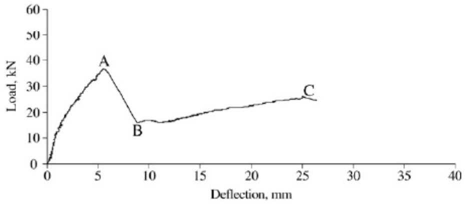
No.	Shear span L_s (mm)	Failure load (kN)	Behaviour
1	320	55.625	First stage: Shear cracks were formed near the loading point and sudden drop in the capacity. Region A–B in Figure 5
2	350	52.191	Second stage: Carried additional load by reinforcement mesh provided at the mid-depth of the concrete. Also, flexural cracks were formed in between the loading points. Region B–C in Figure 5
3	380	47.340	Slip: Slip was observed from the early stage of loading and the rate of slip was higher after first stage.



(a) Shear span $L_s = 320$ mm.



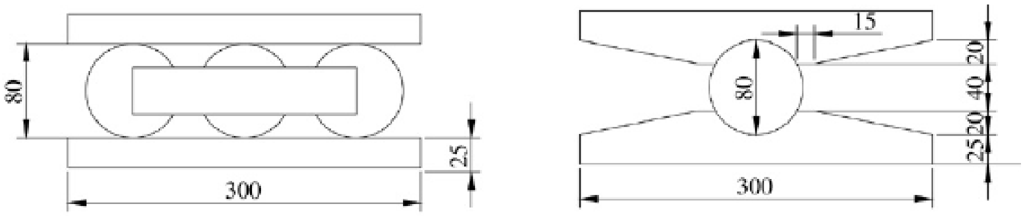
(b) Shear span $L_s = 350$ mm.



(c) Shear span $L_s = 380$ mm.

Figure 6: Load Vs Central Deflection for Shorter Shear Span Specimens.

For the setup of the experiment, it was setup followed a schematic view of the experiment as shown in Figure 2. The composite deck slabs will be applied the load was using a computer controlled servo-hydraulic 25-ton MTS actuator under displacement control. The specimens will be placed on the roller and hinge supports that were specially fabricated for the experiments as shown in Figure 6 below.



Roller support

Hinged support

Figure 7: Schematic View of The Supporting Arrangements.

3.3.2 Blast Test

The only literature about blast test experiment that have full and completed result is from Nassr and others paper (Nassr A., 2012). They have performed experimental performance of steel under blast loading. They used a total of 13 beams to this field test using live explosives. Plus, the blast wave characteristics, including incident and reflected pressures, were recorded. Same also time-dependent displacements, acceleration, and strains at different location the steel were measured.

There are two different section sizes used in the experiment which are W150 X 24 and W200 X71 and the length of the beam is 2413 mm. The member of each section size was obtained from the same production batch to minimize variation in material properties. The yield stress and ultimate strength of the W150 X 24 section were 393 and 537 MPa, respectively, and those of the W200 X 71 section were 362 and 474 MPa, respectively. The cross section of the test specimens is shown the Figure 7 below.

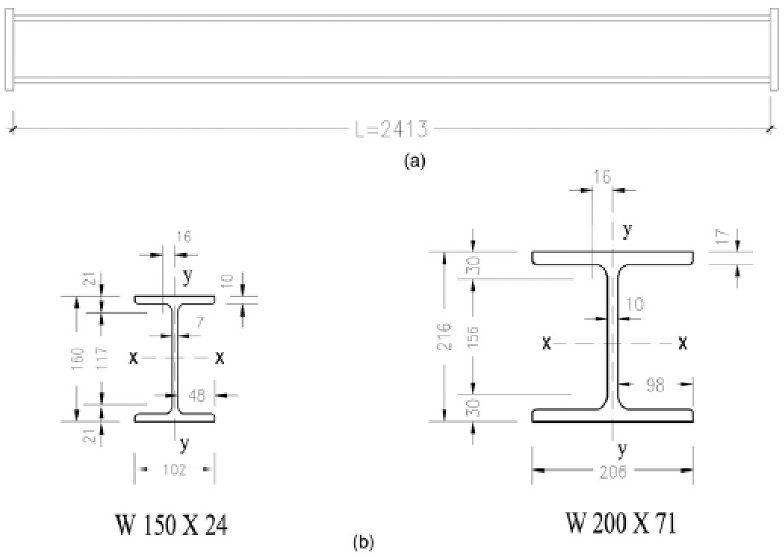


Figure 8: Cross Section of The Test Specimens (dimensions are in milimeters)

The test was setup using a reinforced concrete as a supporting frame with clear opening of 2.36 X 2.81 m in order to support the steel beams during the blast test. The Schematic view of charge location is shown in Figure 8 and the dimensions of the test frame and the reflecting surface is shown in Figure 9.

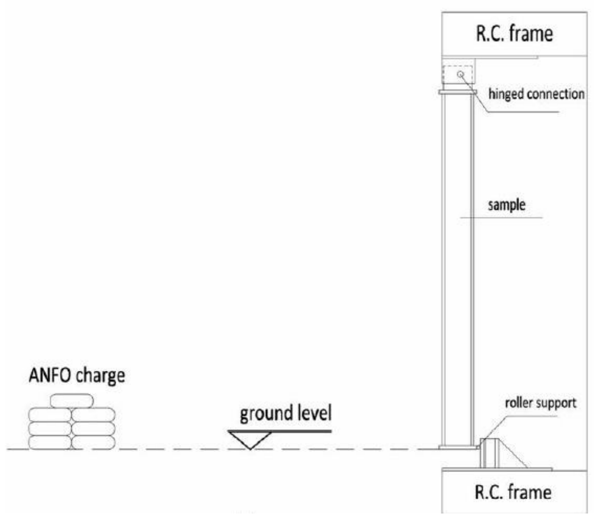


Figure 9: The Schematic View of Charge Location

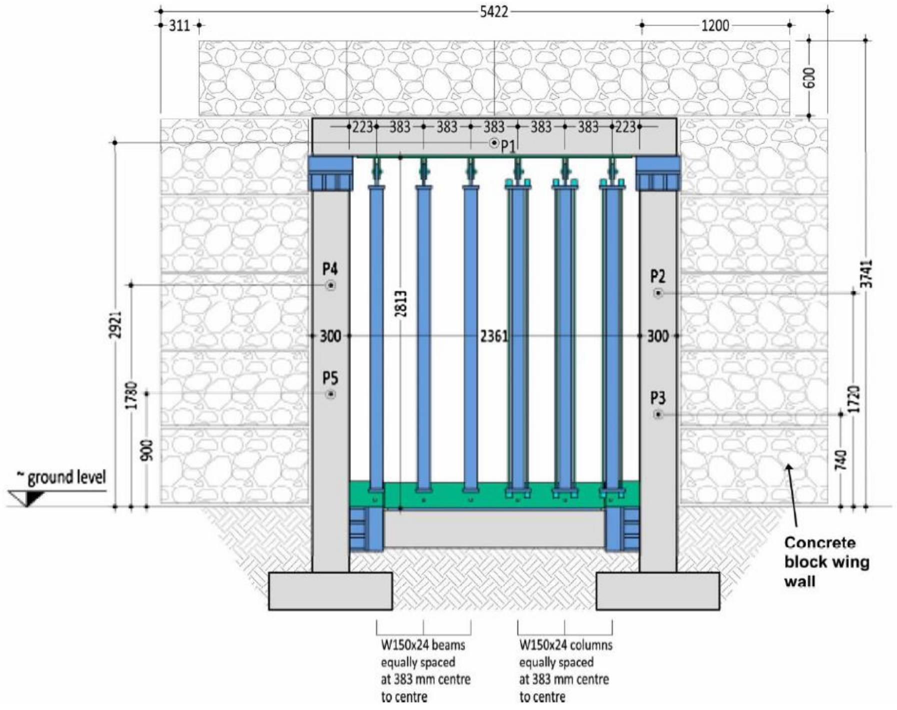


Figure 10: The Dimensions of The Test Frame and The Reflecting Surface

Each beam was subjected to one of the five blast shots generated by different combinations of stand -off and charge weight as shown in Table 2. As shown before, the beams were tested in the vertical and it is simple supported for convenience. They were subjected mainly to bending caused by the blast pressure because the axial stress caused by self-weight was negligible. During the blast tests, incident and reflected pressure were measured using transducers location from the centre of charged as follow is Table 3.

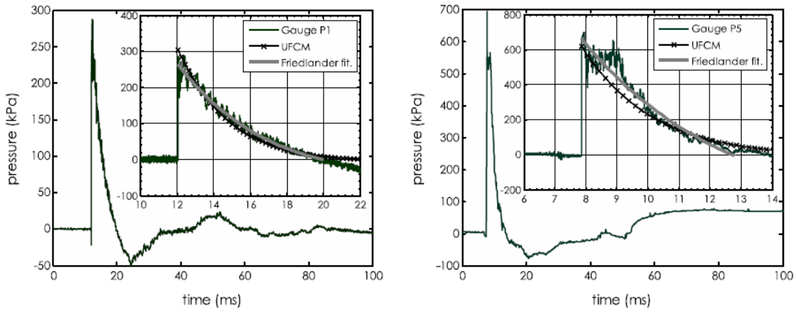
Table 2: Different Combinations of Stand -Off and Charge Weight

Shot	Section designation	Charge mass (kg)	Stand-off distance (m)	Scaled distance (m/kg$^{1/3}$)	Axis of bending	Test beams
1	W150 × 24	50	10.30	2.80	x-x	1B1, 1B2, 1B3
2	W150 × 24	100	10.30	2.22	y-y	2B1, 2B2, 2B3
3	W150 × 24	150	9.00	1.69	x-x	3B1, 3B2, 3B3
4	W150 × 24	250	7.00	1.11	x-x	4B1, 4B2, 4B3
5	W200 × 71	250	9.50	1.51	x-x	5B1

Table 3: Stand-Off Distance of Pressure Transducers

		Incident pressure transducers						Reflected pressure transducers				
Shot	Charge (kg)	FF1 (m)	FF2 (m)	FF3 (m)	FF4 (m)	FF5 (m)	FF6 (m)	P1 (m)	P2 (m)	P3 (m)	P4 (m)	P5 (m)
1	50	6.00	8.00	10.00	10.00	15.00	15.00	10.72	10.60	10.49	10.49	10.37
2	100	6.00	8.00	10.00	10.0	15.00	15.00	10.72	10.60	10.49	10.49	10.37
3	150	6.00	8.00	9.00	9.00	15.00	15.00	9.46	9.26	9.13	9.26	9.14
4	250	5.00	7.00	10.00	10.00	15.00	15.00	7.59	7.33	7.16	7.33	7.18
5	250	6.00	8.00	9.50	9.50	N/A	N/A	9.94	9.75	9.62	9.76	9.63

The result of reflected pressure from the experiment of the beam 1B1 under blast shot 1 and shot 5 are shown in Figure



(a) Shot 1 (b) Shot 2

Figure 11: The Typical Reflected Pressure for Blast Shot: (A) Shot 1 (B)Shot 2

3.4 Modelling

Using the Abaqus, there will be three model of experiments to be computed. The first one the experiment on static load subjected on the composite deck slabs, Second, the steel beam subjected to blast load and finally, the composite deck slabs subjected to blast load.

3.4.1 Material Properties

For steel-concrete composite slabs, the mainly components of this structure are steel deck and reinforced concrete. There also minor components like mesh reinforcements, and shear stud. In Abaqus, the computed components need to define their materials properties of the so that it can behave similar to real like components. For, steel deck we need to define its density, elastic and plastic properties. While for the reinforced concrete, density, elastic and instead using plastic function, Abaqus offers concrete damaged plasticity model which the briefing about this model can be found in paper from Polak, Aikaterini S. Genikomasu and Maria Anna (Polak, 2015).

For steel deck, the density, elastic, plastic properties can be found straight through literature from paper Marimuthu, Seetharaman, et al (Marimuthu V., Seetharaman S., et al., 2006) which are 7.85x10^{-9} MPa and for elastic properties the Young's Modulus and Poisson's Ratio are found to be 21000 MPa and 0.3 respectively. Same goes to the reinforced concrete material properties, they can be found from the same paper. The density is said to be standard density for concrete which 2.5x10^{-9} MPa and the Young's Modulus and Poisson' Ratio are 27085.18 MPa and 0.2 respectively. Paper from Polak and others (Polak, 2015), suggested that concrete damaged plasticity model is good for both dynamic and static analyses. Thus, in order to further understanding the please refer this paper and as mentioned before in chapter 2 the few parameters for this model can also been found in this paper.

Next, for the experiment of the steel beam subjected to blast load from paper by Nassr and others (Nassr A., 2012). Only one beam from total of 13 beams will be selected to model it in Abaqus. The computed model will be simplified just only one be selected and the only 3 transducers will be located in the simulation. The chosen beam is the beam 1B1 from the paper and the transducers will located in place of P1, P4 and P5 as shown in Figure 9. Thus, the only parts or component to be identified its materials properties are the steel beam where it is easily found in standard of steel properties for section W150 X 24.

3.4.2 Assembled

Assembly is the process to combine the parts of into one single structure and define the structure of what type of loading will applied to it. In this process also, we need to define the what type of interactions between all the parts that have been combine together to form single functioning structure. There are many types of interactions provided in the Abaqus where they are general contact, fluid exchange, self-contact and many more. Then, there also interactions properties of those contact we selected between the parts, whether there is just a normal contact or a wave like incident wave.

For the composite deck slabs computed model, all the parts of the structure were modelled with general contact with each other. But the interaction properties are different. For steel and concrete the friction coefficient are set to be 0.5 and friction coefficient between the steel rod where the load is applied and steel deck is 0.1. Figure 10 below show the computed model of composite deck slabs for static test.

Figure 12: The Composite Deck Slabs for Static Test

For the steel beam computed model, the only interaction is incident wave type where this type will represent the blast wave acting on the beam. The interaction was applied to a reference point, RP1, located at one end of the beam to the surface of the beam. The interaction properties are where we define the mass of the blast in TNT. Figure 11 below show the simplified computed model of steel beam subjected to blast load.

The blast load was applied using incident wave pressure loads of the CONWEP type (IWCONWEP) in the filed output request. For that also the time point for the blast or incident wave need to fill out, to do that, we need to refer document (Unified Facilities Criteria, 2008) to make sure where the time points of the blast pressure exert on the structure.

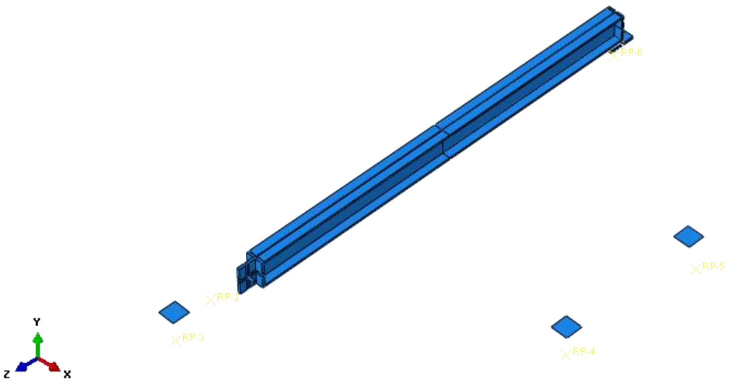


Figure 13: The Steel Beam Model Subjected to Blast Load

3.4.3 Boundary Condition

Composite deck slabs subjected to static load model have hinged and roller supports thus in Abaqus it is necessary to apply boundary condition where the ay the support there will be no displacement toward x, y, and z direction but the translation displacement will be there at x and z except y.

The blast test for beam steel, there will the same as above where it will be used hinged and roller at the support. Thus, same condition will apply toward both end of support. No displacement in every direction only the translational displacements at x and z direction.

For the boundary of the model composite deck slabs subjected to blast load, the concrete slab has to be restrained from twisting at both ends, prescribed boundary conditions have been assigned for both supports. The support was prescribed at the x, y and z-axes restrained the its translational displacement also have been restrained in all axes.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, there will be the result and discussion for the mesh parametric study for composite deck slabs, the validation of the static test of composite deck slabs and blast test for steel beam. The result from the composite deck slabs subjected under blast load will be analysed. Same goes to the result from the parameter study which specifically on the mesh reinforcement diameter will be analysed here.

4.2 Validation

The first step is to begin with mesh parametric study for computed composite deck slabs. This parametric study helps to decide the optimum mesh to use for the model of the structure which later will be used for static test and blast test. Here (Figure 13) is the result from several test run using difference mesh sizes which are 20, 30, 40 millimetres.

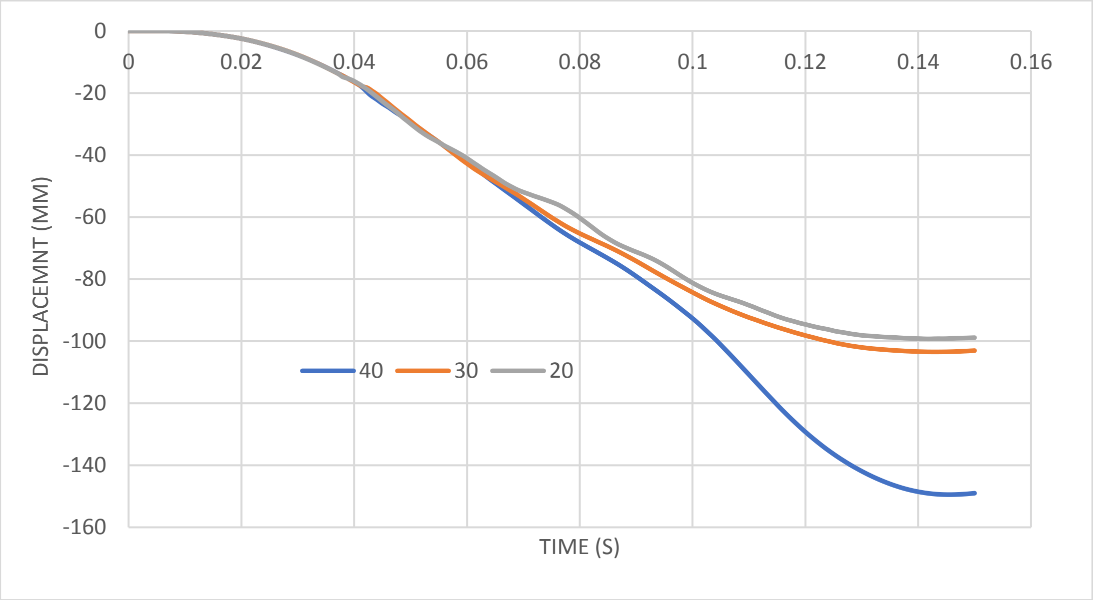
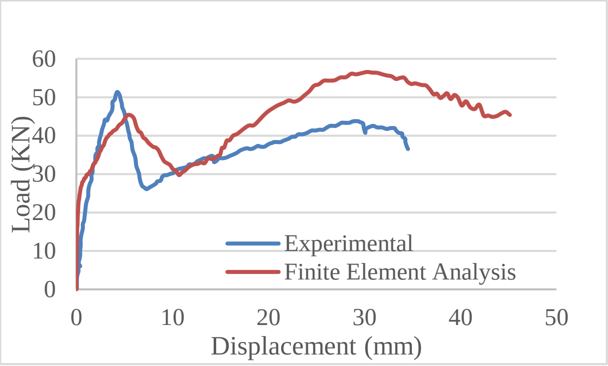


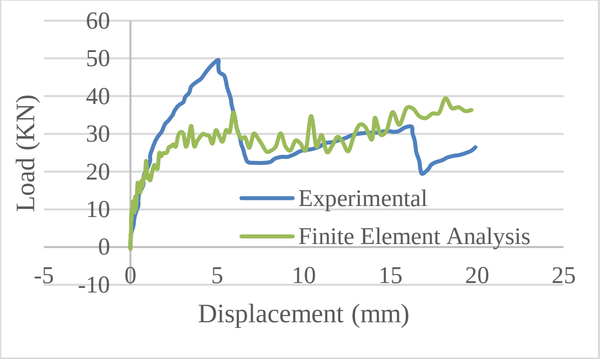
Figure 14: Different Mesh Result

Conducting mesh sensitivity study would be a good in most cases to make sure that mesh that used is better one. From the graph in Figure 13, the 40 mm mesh is having largest displacement result compare with these two sizes which are 20 and 30 mm. But for 20 and 30 mm sizes the result of the displacement having quite similar. This can indicate this two mesh already show a good result and the result is converged. For 40 mm mesh size even though it came out to be more large result, but considering the factor of computational time. It took longer than the rest. Thus, optimum mesh size for this study is 20 mm.

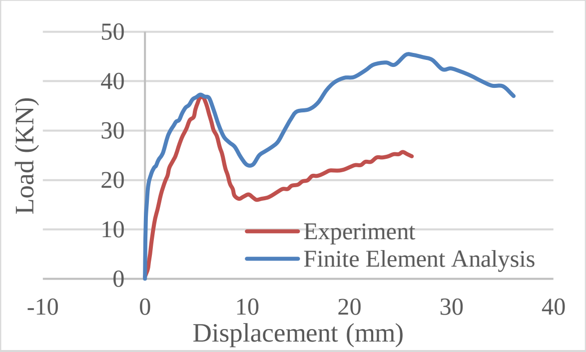
The second step is to validate the result from static test done by (Marimuthu V., Seetharaman S., et al., 2006) with the computed model. The explanation about the test have been already mentioned before in Chapter 2, Thus, in this chapter only the discussion from the comparison result from experimental and numerical will be discussed. Here (Figure 14) are the comparison between these two results.



a) 320 mm Shear Span



b) 350 mm Shear Span



c) 380 mm Shear Span

Figure 15: Static Test Comparison for Experimental and Numerical Analysis Result

Table 4: Comparison Of Maximum Load For Static Test

Shear Span, L_S (mm)	**Maximum Load from FEA (KN)**	**Maximum Load from Experimental (KN)**	**Percentage Different (%)**
320	56.57	51.37	0.052
350	44.85	49.57	-0.047*
380	45.36	36.69	0.086

**the result is opposite than others*

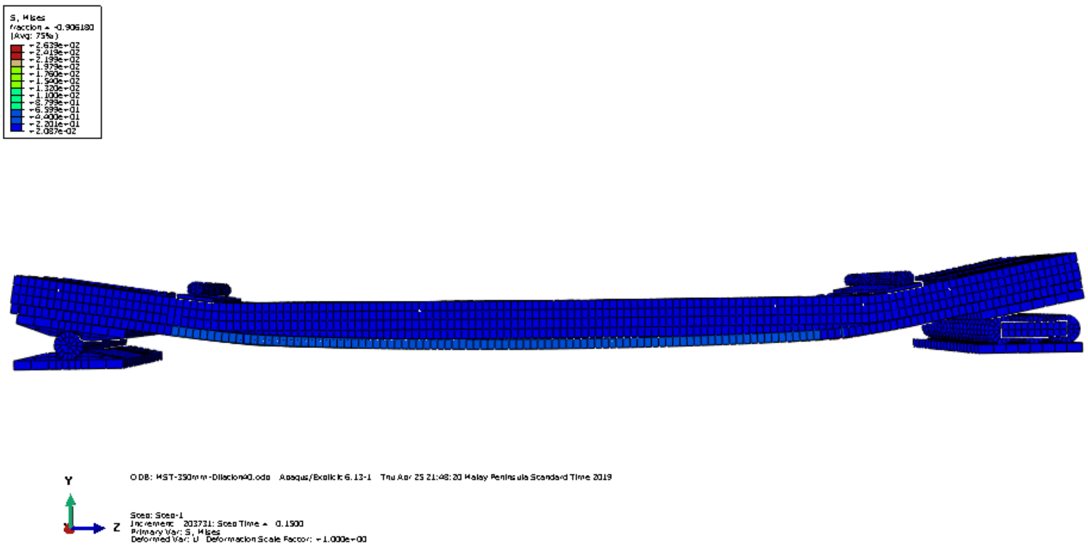
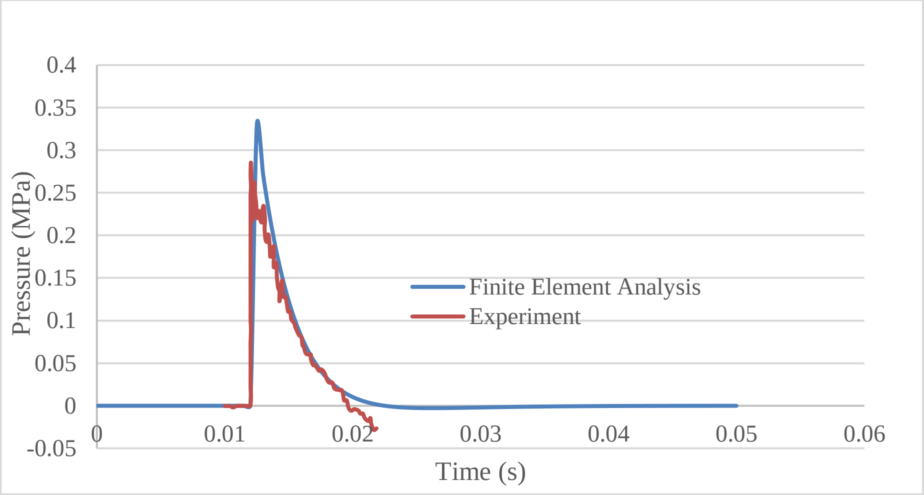


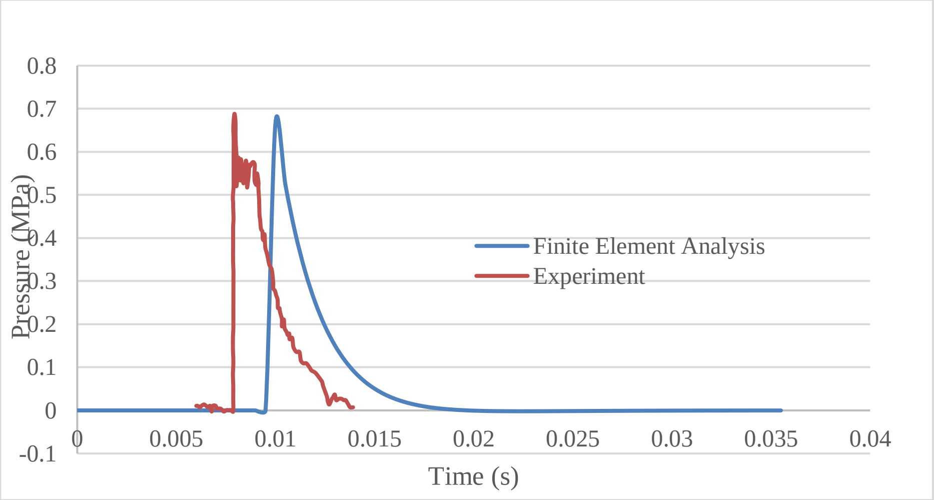
Figure 16: General View the Response of Structure After Subjected to Static Loads

From the table above, the shorter the shear span, Ls, the more the load can be resisted. Furthermore, the percentage different of the result obtained between finite element analysis and experiment showing not big difference especially for shear span of 380mm. This can be concluded that the finite element model and the analysis can nearly replicate the result through experiment. Thus, the model computed can be used for other test such as composite deck slabs subjected blast load and another parameter study.

Third step is to validate the computed steel beam subjected to blast test. This can help to give assurance that the Abaqus have ability to replicate the blast test result from experimental that have been done by Nassr (Nassr A., 2012). Going these comparisons from disparate data test can also help to give assurance for upcoming test that related to blast load especially the composite deck slabs subjected to blast load that will computed later. Here (Figure 16) are the result of the comparison of blast test for experimental and numerical analysis.



a) Shot 1: Result experiment from gauge P1



b) Shot 2: Result experiment from gauge P5

Figure 17: Comparison Result for Steel Beam Subjected to Blast Load for Experimental and Numerical Analysis

The results in Figure 15 suggest the blast simulations using finite element analysis are able to produce reasonable results when compared to the experimental results. The peak pressure from Finite Element (FE) analysis in Shot 1 is slightly lower than the experimental result but in Shot 2, the FE simulation able to produce a peak pressure that agree very well with the experimental result. However, the blast pressure in Shot 2 arrives quite later compared to the test data, Conversely the arrival time of blast pressure is similar to the test data as shown in Shot 1. Nevertheless, the blast simulations using CONWEP can be considered as successful because the blast pressure profiles and main blast parameters agree reasonably well with the experimental data.

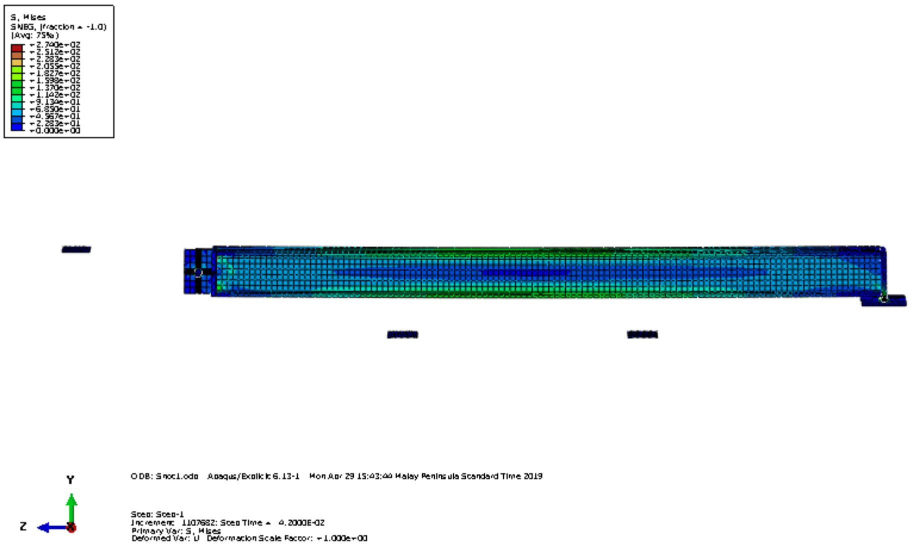
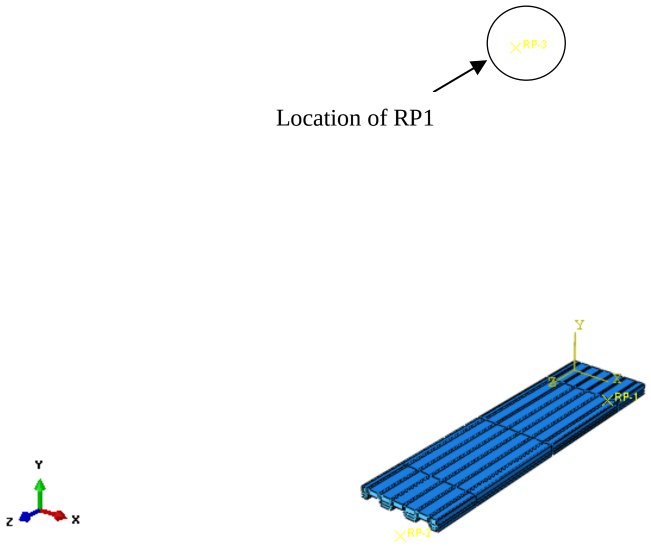


Figure 18: General View of Steel Beam Subjected to Blast Load

4.3 Blast Load Test

After such extensive validations done to lend credence to the model and provide reassurance that the computed model for steel – concrete composite slab in good condition to use and the responses of the blast impact can also be replicate using Abaqus. This led to next step, which the blast load be applied to the computed composite deck slabs model using the case study provided from the “Structure to Resist the Effects of Accidental Explosions” book (Unified Facilities Criteria, 2008).

The computed model of steel – concrete composite slab was taken direct from the model from static test but the roller and hinged support were removed. Thus, the boundary condition also was changed from pin-pin condition to fixed-fixed condition. Where the displacements and translational displacement in all directions were set to be zero. Since this model will be subjected to blast load instead of static load, the steel rod parts also will be removed. So, the interaction of steel deck and steel rod also be removed and change to interaction on incident wave between reference point RP1 to the surface of the structure. Figure below the view of computed model used for this test.



Location of RP1

Figure 19: Computed Model for Blast Test for Steel - Concrete Composite Slabs

From the Figure 17, the reference point, RP1, will be located in the above and middle of composite deck slabs. The distance for the RP1 and the surface of the composite deck slabs is will be set according to the stand-off distance of the explosive material needed to be. Table below will show different cases for the test where in every case will be different in stand-off distance and explosive mass used.

Table 5: Cases for The Blast Test and The Result of Maximum Displacement (m)

Case	**Standoff Distance (m)**	**Explosive Mass (Kg)**	**Reflected Impulse ($x10^3$ MPa.s)**	**Maximum Displacement (m)**
1	3.4	5.44	0.66	0.025116
2	5.4	5.44	0.38	0.004817
3	3.4	45.36	3.4	0.143052
4	5.4	45.46	1.8	0.064700

From the table above, the result from the blast test show that, first when there is short distance of stand-off distance but the explosive mass in bigger, they will produce high blast impulse. This mean the relationship for this stand-off distance and the explosive when comes to producing blast impulse is inversely proportional. But when high blast impulse hit the target structure, for this test which is steel-concrete composite slabs, larger displacement will be resulted. Thus, the relationship of impulse and the displacement of the structure is linear. Figure below the relationship of the blast impulse and the displacement of the composite deck slabs.

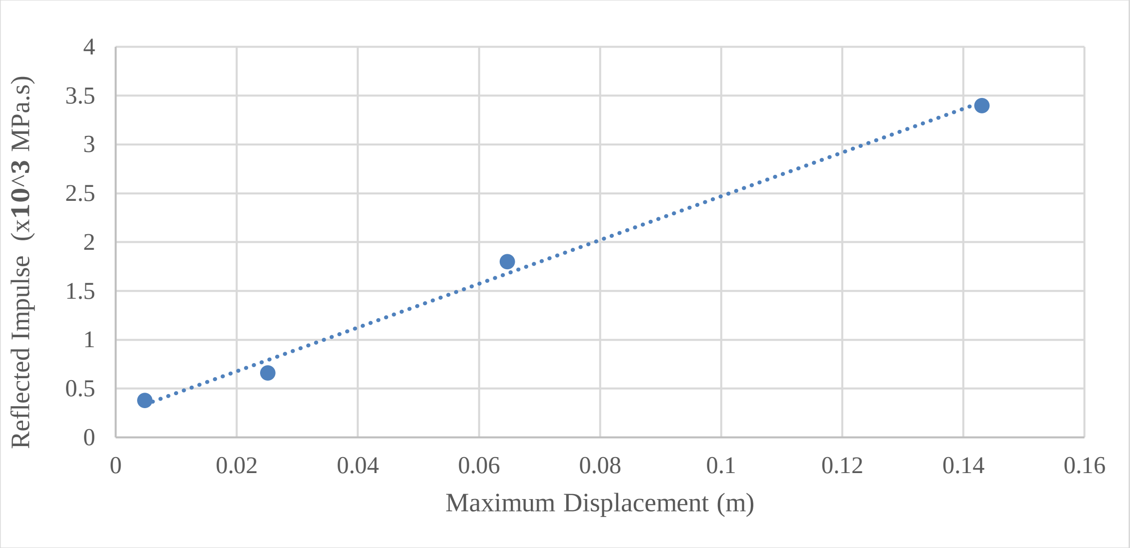
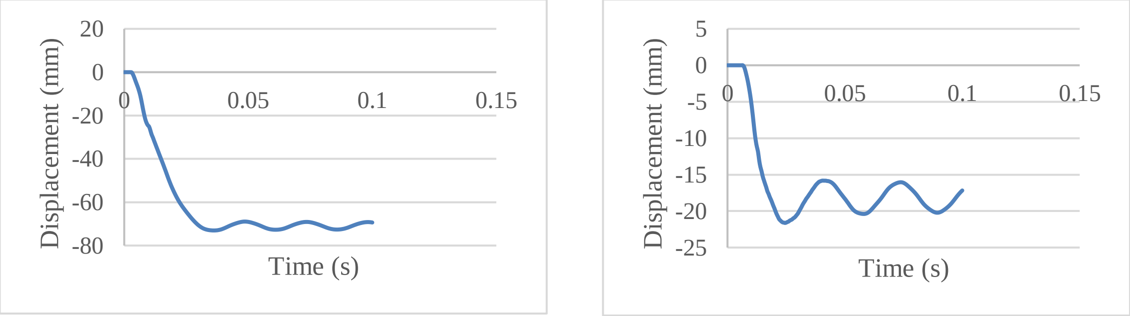


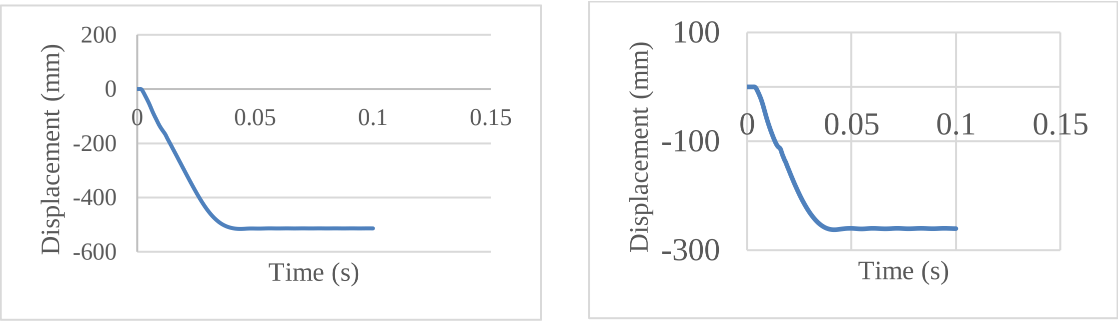
Figure 20: Relationship of The Blast Impulse and The Maximum Displacement of Composite Deck Slabs

Now about the behaviour of the deck slab when subjected to blast load, we can observe from the displacement of the composite deck slabs when subjected to different cases of blast loads in the figure below.



Case 1

Case 2



Case 3 Case 4

Figure 21: Displacement - Time Graph for Case 1-4

From the graph, we can observe that for Case 1 and Case 2 the steel-concrete composite slab displacement for both case having dynamic behaviour which it shows use that there is some resistance toward the blast impulse where structure able to damp the load with its own structural resistance integrity toward resistance. But difference with Case 3 and 4 where the impulse that exert on the structure to high thus there is permanent displacement happens to the structure. Thus, this may be concluded that the steel-concrete composite deck slab could achieve damaged failure when subjected to blast load with high impulse up to 3400 MPa.s.

4.4 Parametric Study

For the parametric study, the composite deck slab was tested with the different diameter size of mesh reinforcement. The Case 1 blast type will be chosen because this case will produce small amount of impulse necessary to understanding the behaviour of the composite deck slabs without having to damaged it. Here is the list of the diameter of reinforcement mesh will be tested.

Table 6: List of Diameter of Mesh Reinforcement

Types	**Diameter (mm)**	**Maximum Displacement (mm)**	**Percentage different with default A393 type (%)**
A 393	6	73.0413	-
A 252	7	61.7629	8.37
A 193	8	57.7895	11.66
A 142	10	57.7895	11.66

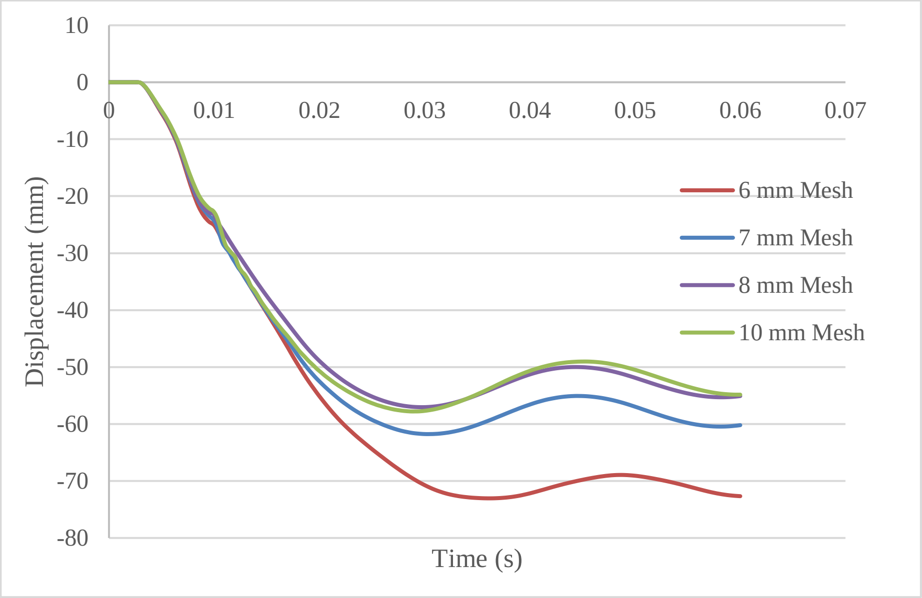


Figure 22: Result from Parameter Study of Mesh Reinforcement

The result from this study shows us that increase the diameter of the mesh reinforcement will provide more resistance of the steel – deck composite slab toward blast load. Also, there is significant increase in the resistance when 7 mm diameter reinforcement mesh is used. However, when increasing the diameter up to 8mm and 10 mm, the result show less increasing of resistance compare to 7 mm diameter. Plus, the result for 8 mm and 10 mm are more alike. This have shown that 8 mm diameter is the limit diameter to used if wants to increase the load resistance toward blast loads.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the research, these following conclusions can be drawn in conclude in this study. From the validations that have been done which are first validation of static test and second the validation of the blast test. For the first validation, we can ensure that the computed model of composite deck slabs is successfully being modelled where the result of the static load test using Abaqus is have similar comparison with the experimental data test.

Same goes to the second validation, the Abaqus have shown the ability to run the blast load test when it came up the result of the test quite similar to the experimental data. This have given assurance for the next test which is related to blast load which is the test of the steel-concrete composite slab subjected to blast load. The test is using the same computed model used in the first validation.

From the steel - deck composite slab subjected to blast load test, it is can be concluded that the higher the impulse exerted on the higher the displacement of the structure. High impulse is produced when there are short stand-off distance and large explosive mass used or vice versa. Plus, when the steel-concrete composite slab subjected to high impulse up to 3400 MPa.s, there may be a chance the structure would fail.

Lastly, when the parameter study has been done, it is concluded that the limit diameter for mesh reinforcement in the composite deck slabs is 8 mm. Because when increasing the diameter up 10 mm would have the similar result.

5.2 Recommendation

In this research, the performance of the steel – concrete composite slab has been analysed using the displacement result only. It can be more helpful in understanding the behaviour of this structure when subjected to blast load when other result could be obtained such cracking pattern of the slabs, the stress and the strain result. This result could be more valuable when it can be compared with other experimental data where the data could be verified. Thus, proper discussion about the structure can be discussed.

From the parametric study, the result shows that the limit diameter for mesh reinforcement for steel – concrete composite slabs is 8 mm, where increasing the diameter up to 8 mm would not give other significance resistance toward blast loading. Thus, in order to understand more the behaviour of the structure and the way to increase the resistant toward blast loading, further parametric study can be done such as increasing the thickness of the steel deck in structure, changing the type of support other than fixed - fixed supports or changing the profiled sheets.

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