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A NOVEL MODELLING TECHNIQUE FOR BLAST ANALYSIS OF STEEL-CONCRETE COMPOSITE PANELS

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Abstract

Blast resistant structures usually undergo large plastic deformation and absorb energy before collapse. There are many structural forms that have improved blast resistance are reported in literature. Among these, steel-concrete composite panel has been considered as extremely resilient to blast loading. Conventionally, steel-concrete composite panels are analysed using solid element model for plates, concrete as well as shear connectors. In this paper, a novel modelling technique is proposed for analysis of steel-concrete composite panels under blast loading. As per the proposed technique, shell, solid and link elements are used to model cover plates, concrete and shear connector respectively. Validation and performance studies are carried out with a problem available in literature. The proposed model is found to be better with less demand on modelling requirements. It is also computationally efficient, while retaining the accuracy of results. Parametric studies are carried out using the proposed model on steel-concrete composite panel with through-through connectors subjected to air blast loading. Steel plate thickness, concrete core thickness, connector spacing and diameter of connectors are varied to study their influence on the response behaviour of the panel. It is observed from the study that connector diameter and spacing and core thickness significantly affect the response than the plate thickness.

Keywords: Blast loading, Steel-concrete composite, FE modeling, Transient dynamic analysis, Shear connector

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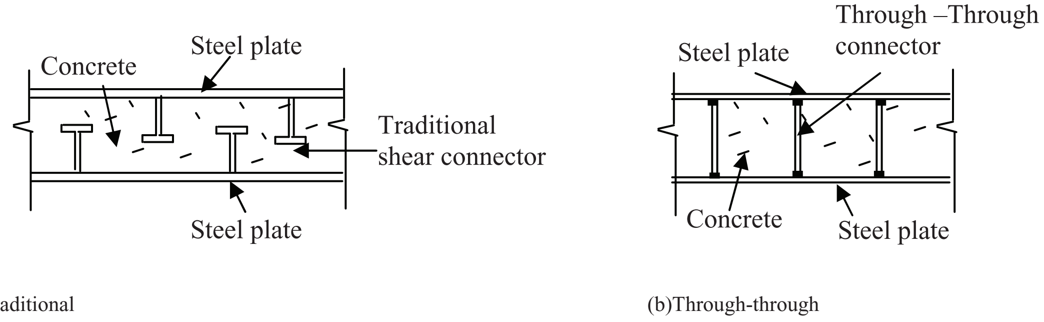
1. INTRODUCTION

Blast resistant structures are designed to dissipate the energy by large deformation. Construction materials must, therefore, have ductility as well as strength. Steel and concrete are common materials used in construction. Steel is ductile in nature. Concrete, which is brittle, is used in blast resistant construction either by modifying the matrix by inclusion of fibres or by ductile detailing. However, one of the disadvantages of concrete is the possibility of spalling/scabbing when it is subjected to blast loading. Loss of material caused by spalling/scabbing of concrete weakens the core and this could affect the integrity of the structure. An alternative but cost-effective way is to use composite structural forms which improve blast resistance. Some of these structural components are profile steel sheeting, steel-concrete composite panel, layered sacrificial claddings, corrugated metal sandwich cores, fibre-metal laminates etc (Lan et al. 2005). Among these, steel-concrete composite panel has been considered as an extremely resilient component in resisting blast loading.

Steel-concrete composite construction is a structural system consisting of a concrete core, sandwiched between two relatively thin steel plates, connected to the concrete by shear connectors as shown in Figure 1. Steel-concrete composite structure is one of the fast track construction methods. This form of construction combines the advantages of both steel and concrete to provide protection against impact and blast. The structural performance of steel-concrete composite systems has been reported as superior to over traditional engineering structures in application requiring high strength, high ductility, as well as high energy absorbing capability. The potential uses of steel-concrete composite construction are diverse, including submerged tube tunnels, gravity seawalls, floating breakwaters, anti-collision structures, nuclear structures, liquid containment, ship hulls and offshore structures, in which resistance of impact and blast loads are of prime importance (Liew and Sohel 2009).



(a) Traditional (b)Through-through

Figure 1: Shear connectors.

Conventional approach of modeling the steel-concrete composite panel is to employ solid elements to discretise all the components, namely steel, concrete and shear connector. In this study, simple approach to model these panels is proposed and validated by solving a problem reported in literature. Then, parametric studies are conducted using a 2m x 2m steel-concrete composite panel with through-through connectors subjected to air blast loading. The studies concentrate to identify the influence of plate thickness, concrete core thickness, spacing and diameter of shear connector.

2. AIR-BLAST LOADING

Blast waves load different parts of a structure at different times with varying magnitude and for different durations. Shock wave due to blast moves at supersonic speed. The blast wave has sudden increase in pressure that immediately begins to decrease. As the blast wave travels rapidly away from the source, its peak pressure and velocity decrease (Kinney and Graham 1985). Consequently, as it strikes a structure, a reflected shock wave is formed. This has the effect of increasing the blast pressure. The value of the reflected pressure depends on the incident angle and the incident side-on overpressure. The shock wave is accompanied by blast wind causing dynamic pressures due to drag effects on any obstruction in its way. The reflected shock wave disintegrates until it is in equilibrium with the dynamic pressure due to the blast winds. The blast pressure, thus built up, decays exponentially with time. Idealised blast wave is shown in Figure 2.

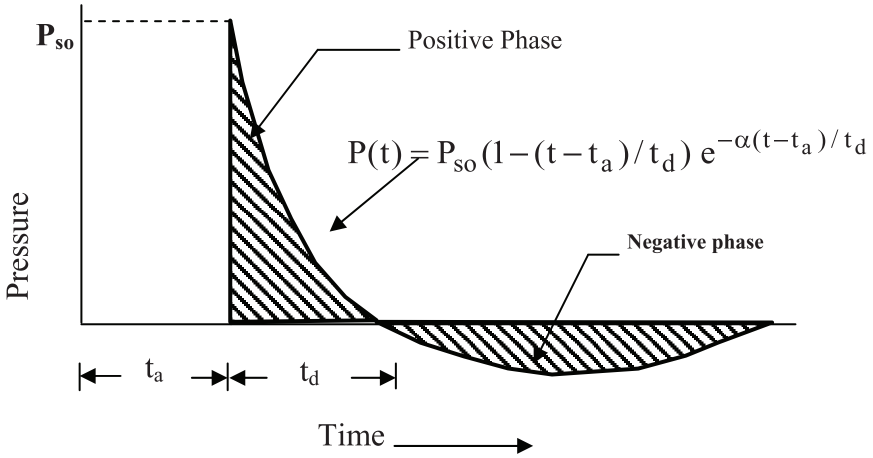


Figure 2: Features of an ideal blast wave.

3. FINITE ELEMENT MODELLING

Classical/analytical treatment of complex problems such as blast response analysis of structures is difficult. Hence, numerical modeling of these problems have to be sought to. Finite element method is widely used numerical technique. In general, solid elements are used to model the steel-concrete composite panels. This modeling approach results in huge degrees of freedom due to the complex nature of geometry. Moreover, interactions between the steel and concrete surfaces are to be modeled. This poses more demand on modeling requirements. A simple innovative approach is proposed in this study for modeling steel-concrete composite panels. Validation of the model is carried out with a problem available in the literature.

A steel-concrete composite panel of size 300 mm x 490 mm subjected to push out loading (Clubley et al. 2003) is taken up for validation of the proposed models. Thickness of steel plate and concrete core are 8 mm and 200 mm respectively. Diameter and spacing of connector are 25 mm and 200 mm respectively. Properties of the material used in the study are given in Table 1. In both the models, steel behaviour is modelled using bilinear stress-strain curve and a multilinear curve is used to characterise the behaviour of concrete.

Table 1: Properties of the material

Parameter	Material	
	Steel	Concrete
Yield stress (MPa)	350	-
Young’s modulus (GPa)	200	25.46
Cube strength (MPa)	-	40

3.1. Solid Model (SM)

Three dimensional finite element model of the steel-concrete composite panel is generated using ANSYS software and is shown in Figure 3. Solid element is used to model concrete core, steel plates and shear connectors. Due to complex geometry of thin plate with connectors, tetrahedral elements are used. Similarly, concrete block with space for shear connector is modeled with graded mesh of tetrahedral elements. Load transfer from concrete to steel plates is realised through the shear connector and friction between steel and concrete surfaces. This is modeled through surface to surface contact. Steel plate is fixed at the base and a load of 1000 N is applied on the opposite face, i.e., the concrete core is subjected to uniform pressure loading of 16.67 MPa. Nonlinear analysis is carried out and the deformed configuration is shown in Figure 4. Separation of plate can be noticed from Figure 4.

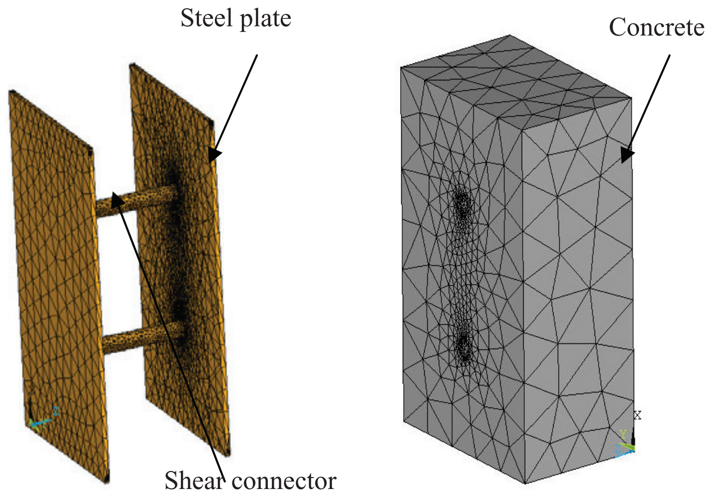


Figure 3: Solid model (SM).

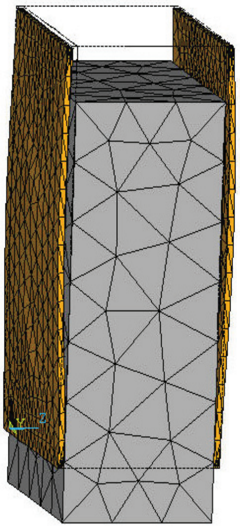


Figure 4: Deformed shape for SM.

3.2. Solid-Shell-Link Model (SSLM)

An alternate and simplified approach has been proposed to model the panels. Solid, shell and link elements are used to model concrete core, steel cover plates and shear connectors respectively as shown in Figure 5. Solid element is defined by eight nodes having three degrees of freedom at each node (translations in the nodal x, y, and z directions), while shell element has six degrees of freedom at each node (translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes). Link element is a uniaxial tension-compression element with three degrees of freedom at each node (translations in the nodal x, y, and z directions). Surface to surface contact is provided to model steel plate and concrete interaction. Nonlinear analysis carried out for an applied pressure of 16.67 MPa on concrete surface. Figure 6 shows the panel after deformation. In this model also, separation of plates is observed.

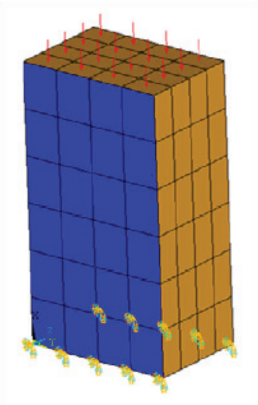


Figure 5: Solid-shell-link model (SSLM).

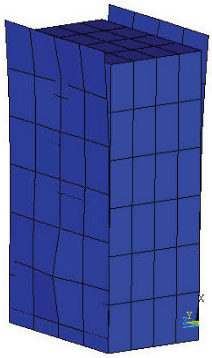


Figure 6: Deformed shape for SSLM.

3.3. Validation and performance of the models

The separation of steel plate from concrete core for the two FE models is obtained at the corners of the plate. The variation of plate separation with applied load is plotted in Figure 7 for the two FE models, which is in good comparison with the published experimental results. It is found that the model using solid elements has high computational demand, but the model using solid, shell and link elements require less time. From the comparative study of the FE models developed, it is found that solid-shell model has very low computational demand, but still retaining the accuracy.

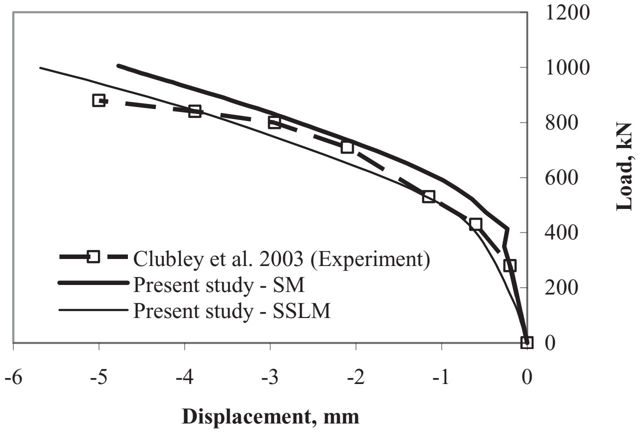


Figure 7: Comparison of separation of plates.

4. PARAMETRIC STUDIES

Steel-concrete composite panel of size 2 m x 2 m with simply supported boundary condition is used in the parametric study. Panel is modelled using the solid-shell-link approach. The panel is subjected to air blast loading due to an explosion of 100 kg TNT at a distance of 5 m. Pressure time history due to the applied blast loading is shown in Figure 8. Steel behaviour is modelled using bilinear stress-strain curve and a multilinear curve is used to characterise the behaviour of concrete. Cube strength of concrete is 40 MPa. Yield stress of steel is 350 MPa. Parameters considered and values used in this study are given in Table 2. Nonlinear transient analysis is carried out with time increment of 0.0003307 sec. Typical time histories of displacement at centre of the panel is shown in Figure 9.

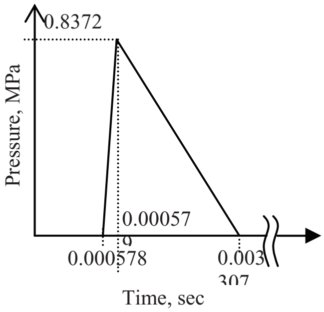


Figure 8: Pressure time history.

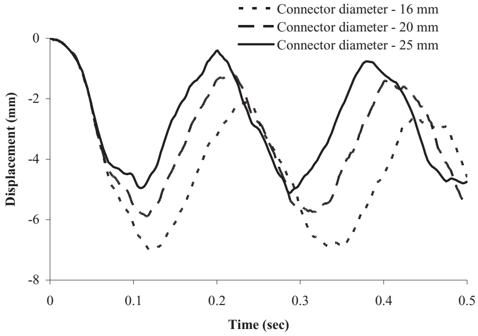


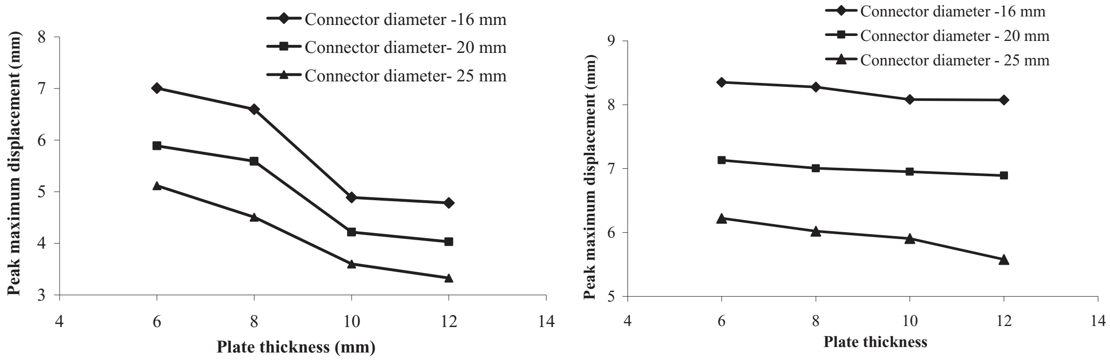
Figure 9: Time history of displacement for panel (tp=6 mm, sc=200 mm and tc=200 mm).

Table 2: Parameters used in the study

Parameters	Values (mm)
Plate thickness (tp)	6, 8, 10, 12
Diameter of connector (d)	16, 20, 25
Spacing of connector (sc)	200, 250, 300
Core thickness (tc)	200, 250, 300

5. DISCUSSION

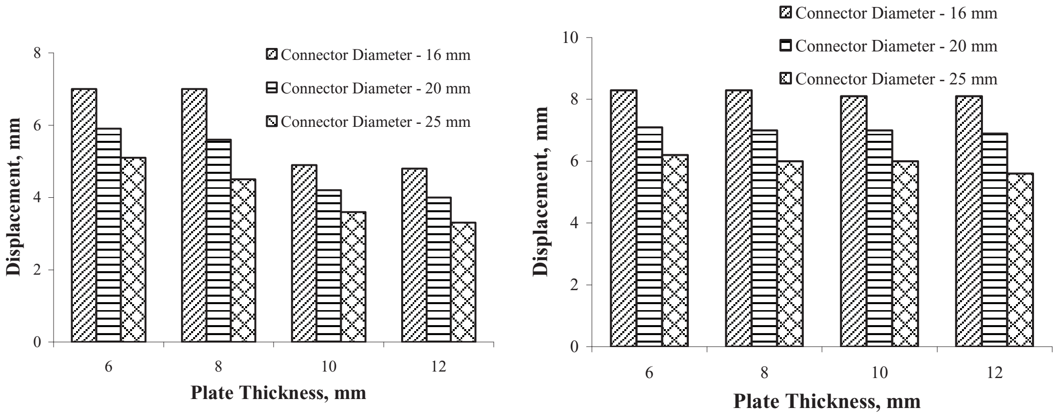
Variation of peak maximum displacement with plate thickness is plotted in Figure 10 for concrete core thickness of 200 mm. For connector spacing of 200mm, variation is found to be nonlinear and percentage increase for connector spacing of 200 mm is found to be between 46% to 53%, while for connector spacing of 250 mm, this value is between 3% to 11%. Similar trend is observed for connector spacing of 300 mm also. Therefore, it can be concluded that plate thickness has only nominal influence on the peak response, except for 200 mm connector spacing. It can be noted from Figure 11 that peak response reduces in a linear pattern with connector diameter and % difference varies between 34% to 58%, which shows that connector diameter has comparatively more influence than plate thickness.



(a) Connector spacing - 200 mm (b)Connector spacing -250 mm

Figure 10: Variation of peak maximum displacement with plate thickness.

Influence of connector spacing on peak maximum displacement can be observed from Figure 11. Peak response for 250 mm is found to increase by about 18 to 33% for plate thicknesses of 10 and 12 mm. Table 3 gives peak maximum displacement values for variation in core thickness. For 25 mm diameter of shear connector, peak maximum displacement reduces linearly by about 25-30% for increase in spacing of 100 mm. Trend of variation for 16mm and 20mm diameter are different, where reduction in deflection is less beyond 250 mm core thickness from that for 200mm.



(a) Connector spacing – 200 mm (b) Connector spacing – 250 mm

Figure 11: Peak maximum displacement for connector spacing of 200 mm and 250 mm.

Table 3: Peak maximum displacement for connector spacing of 250 mm

Cover plate thickness (mm)	Connector diameter (mm)	Peak displacement (mm) for core thickness		
		200 mm	250 mm	300 mm
6	16	8.3	6.3	5.2
	20	7.1	5.7	5.8
	25	6.2	5.8	4.7
8	16	8.3	5.9	5.5
	20	7	5.5	5.1
	25	6	5.1	4.1
10	16	8.1	5.8	5.7
	20	7	5.3	4.9
	25	6	4.9	4
12	16	8.1	5.7	4.8
	20	6.9	5.3	5
	25	5.6	5.0	4.8

6. CONCLUSIONS

From the numerical analysis carried out on an example problem, it can be concluded that the proposed model can be used to obtain blast response of composite panels. Parametric studies conducted leads to the conclusion that connector diameter has more influence than plate thickness on peak maximum displacement. For concrete core thickness of 200 mm, connector spacing is found to have negligible influence for spacing more than 250 mm. Concrete core thickness of 250 mm or more is found to have less influence on displacement compared to core thickness of 200 mm for connector diameters of 16 mm and 20 mm, while for 25 mm diameter connector core thickness variation affects the response to a larger extent.

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