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NUMERICAL AND EXPERIMENTAL STUDIES ON THE BEHAVIOUR OF STEEL-CONCRETE-STEEL BEAM: A REVIEW

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Abstract: - Steel-concrete-steel (SCS) beam comprises of a concrete core sandwiched in between two steel cover plates which are interconnected by shear connectors. The shear connectors prevent the uplift of the steel cover plates and hold the concrete core in position. Conventional RCC beams undergo huge damage due spalling of concrete when subjected to sudden shock loading and the conventional steel structures undergo drastic failure under fire loading due to high thermal conductivity. The SCS construction technique overcomes the disadvantages of conventional construction. In SCS system the high tensile strength of steel cover plates combines along with the high compressive strength of concrete enhancing the structural integrity, ductility, energy absorbing capacity and strength of the system. The use of composite construction has been increasing in recent years because of its high strength to weight ratio, efficient design, better structural performance and significant economies of cost and construction time. Some of the structural systems currently in practice are Steel Fibre Reinforced Concrete (SFRC), Profiled Steel Sheeting Reinforced Concrete (PSSRC), Laced Reinforced Concrete (LRC) and Steel–Concrete–Steel Sandwich (SCSS) composite. Among these alternative systems of construction, S-C-C construction is found to possess properties that are promising for higher flexural strength, impact and fire resistant structures. In this paper the numerical and analytical studies carried out to study the performance of SCS beams has been discussed.

Keywords: - steel-concrete steel sandwich beam, shear connectors, steel cover plate, energy absorbing capacity, impact load and composite construction.

INTRODUCTION

Steel-concrete-steel sandwich structures are widely in use now days. They are made by sandwiching flat steel cover plates with concrete and shear connectors. Concrete is the most widely used construction material for large structures, because it possesses considerable mass per unit cost compared to other construction materials, and has excellent fire resistance and is able to absorb large amount of energy. However, one of the disadvantages of concrete is the possibility of spalling/scabbing when it is subjected to accidental loads such as blast or impact. Loss of material caused by spalling of concrete weakens the core and this could affect the integrity of the structure. As a result, additional concern on personnel and equipment safety exists. An alternative but cost-effective way is to use structural forms, which can improve blast resistance. Some of these forms are material composites, layered sacrificial claddings, corrugated metal sandwich cores, fiber–metal laminates, profiled stainless steel and steel-concrete composites. On the other hand the structural steel member's posses high thermal conductivity and when subjected to fire loads they are vulnerable to fire induced collapse due to deterioration of strength and stiffness properties (Kodur and Naser, 2013). The composite action between the steel cover plate and concrete is obtained by providing proper shear connectors. They provide the necessary shear connection for composite action in flexure, and can be used to distribute the large horizontal inertial forces in the slab to the main lateral load resisting elements of the structure (Fig. 1). During an earth-quake, such shear connectors are subjected to reverse cyclic loading (Hawkins and Mitchell, 1984). This component enables the development of a composite action by assuring the shear transfer between the steel profile and the concrete deck (Vianna et al., 2009).

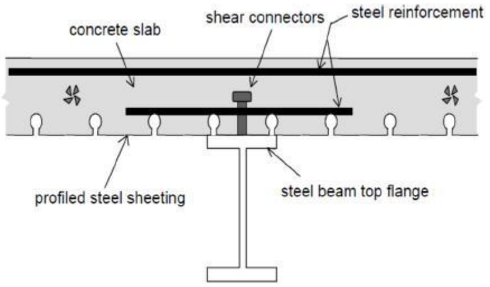

Fig.1 steel and concrete beam connected by shear connectors

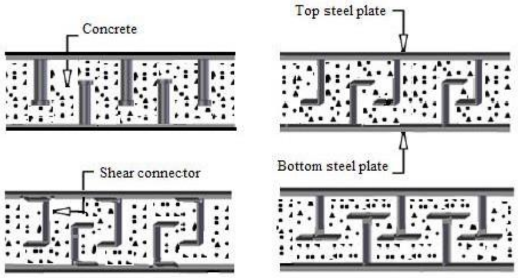

Fig.2 SCS beam with different connectors.

NUMERICAL AND ANALYTICAL PERFORMANCE OF STEEL-CONCRETE-STEEL BEAMS

Clubley *et al*., (2003) Experimental and numerical studies have been conducted on steel-concrete composite panels using bi-steel connectors Fig.3. Bi-steel comprising of steel plates connected by an array of transverse friction welded shear connectors and filled of concrete. They have determined the shear strength of each friction weld shear connector by carrying out push out test. Finite element analysis using nonlinear discrete element models has been used to examine the local behaviour of concrete filled panels. Results from finite element analysis Fig.4 had been compared with experimental data for accuracy and behaviour trends. Test programme was conducted to examine the strength and stiffness of shear connector rods when the concrete was subjected to a shearing action relative to the steel plates. From the load–deformation relationships it was seen that steel–concrete composite panels have high ductility and deformation capacity. Numerical modelling using a combination of smeared and discrete element interfaces between the steel and concrete surfaces has been shown to accurately model physical behaviour. Use of numerical modelling has provided data which was not readily available from the laboratory and which confirmed that panel behaviour was a function of panel geometry.

Lam *et al*., (2005) Experiments have been conducted on structural components that include conventional reinforced concrete slabs, steel fibre reinforced concrete slabs and profiled steel sheeting reinforced concrete slabs. A total of seventy four specimens are tested using seventeen detonation phases; with charge weight ranging between 8 and 100 kg of bare high explosives and each at stand-off distance of 5 m. The main parameters observed in the tests are the generic construction form of the materials and slab thickness. Air-blast overpressure and accelerations of the specimens are captured. Failure modes of each type of specimens are recorded. It is found that for the same fibre concentration in SFRC panels it is noted that long fibre performed better than short fibres in resisting cracking and spalling. However, there is a limit to the fibre length to prevent ‘balling’ in the concrete mix. Test results show that the 1.0% fibre concentration is optimum in resisting damage. However, the cost may be high. Adding concrete to a hollow steel sandwich panel can significantly increase its blast resistance. Although the concrete increases the cost by about 10%, significant deflection resistance against blast loading is observed. In the event of a repeated blast, the concrete in-fill panel provides improved resistance compared with hollow sandwich panels. Debonding between the profiled steel sheeting and concrete was not observed in the PSSRC experimental tests. The slab thickness was varied from 150 to 300 mm. A number of PSSRC slabs with reduced rebar had minimum deflections. By ignoring the contribution of the profiled steel sheeting, these slabs would fail in a shear mode. In practical design of protective structures, profiled steel sheeting should be considered as additional reinforcement to reduce the rebar content.

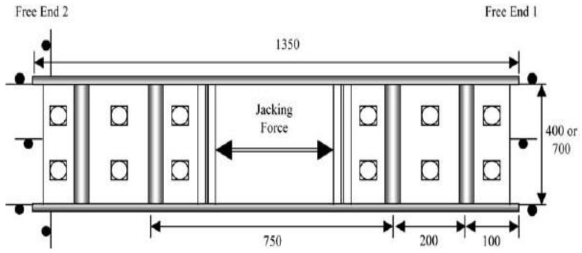

Fig.3 Experimental SCS beam with bi-steel connectors

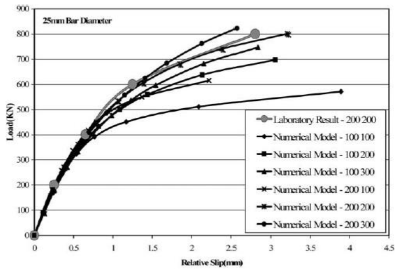

Fig.4 load-slip curve of experimental and numerical models

Liew and Sohel, (2009) A new concept for designing composite structures has been investigated comprising of lightweight concrete core sandwiched in between two steel plates which are interconnected by J-hook connectors. The restriction in core thickness in bi-steel connector has lead to development of a slim and lightweight SCS system J-hook connectors is proposed as a means to connect the two face plates as shown in Fig. 5 the minimum core thickness can be as thin as 50 mm. This connection technology together with the use of lightweight concrete core would reduce the overall weight of SCS system making it a competitive choice for marine and offshore structures.The hook connectors are capable of resisting tension and shear, and their uses are not restricted by the core thickness. Push-out tests confirms that the shear transfer capability of J-hook connector is superior to the conventional headed stud connector in achieving composite action between steel plate and concrete core. Using Euro codes as a basis of design, theoretical model is developed to predict the flexural and shear capacity considering partial composite and enable construction of sandwich structures with J-hook connectors. Compared with test results, the predicted capacity is generally conservative if brittle failure of connectors can be avoided. Test evidence also shows that inclusion of 1% volume fraction of fibres in the concrete core significantly increases the beam flexural capacity as well as its post-peak ductility.

Nguyen *et al.*, (2003) A nonlinear finite element model (Fig.6) has been developed to investigate the capacity of large stud shear connectors embedded in a solid slab. The material nonlinearities of concrete, headed stud, steel beam and rebar were included in the finite element model. The damage and failure were included in the material model to accurately obtain the ultimate strength of the stud connector. The capacity and ductility of the connection, the load-slip behaviour and failure mode of the headed stud were predicted. The results obtained from the finite element analysis were verified against experimental results of other researches. An extensive parametric study was conducted to study the effect of the changes in stud diameter and concrete strength on the capacity and behaviour of the shear connection. The capacity and ductility of the shear connection obtained from the finite analysis were compared with those specified in EC4. It was observed that the LRFD specifications overestimated the capacity of the large stud shear connectors, whereas the design rules specified in Eurocode-4 were generally conservative for stud diameters of 22, 25 and 27 mm, and unconservative for diameter of 30 mm. The ductility of the large stud shear connectors is sufficient for practical application in composite bridges.

Fig.5 J-hook Connectors in SCS Sandwich System

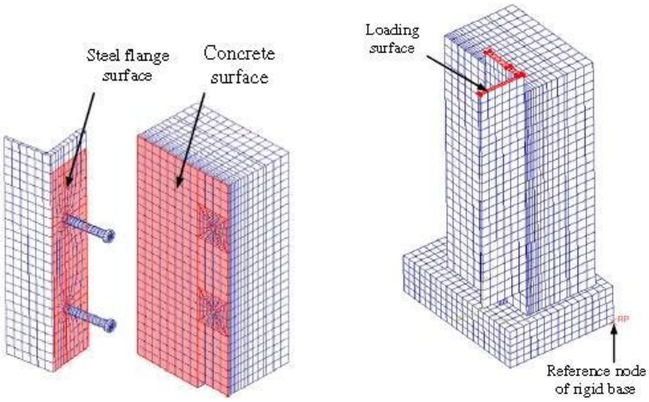

Fig.6 FEM model of large stud shear connectors in a solid slab

Youn-Ju Jeong *et al.*, (2009) Push-out and flexural tests were carried out with the same shear connection details with perfobond ribs and the longitudinal shear resistances are evaluated. The two longitudinal shear resistances are then compared with each other. In the results of this study, the longitudinal shear resistance of the slabs that resulted from surface loads, in the case of long shear span, agree with the pure longitudinal shear resistance resulted from push-out. However, since the shear span length is short, that resulted in an over-estimate because the frictional force between the steel plate and the concrete also increases according to the increase of normal forces at the interface. Also, it is considered that the longitudinal shear resistance under surface loads may result in an over-estimate because the surface loading condition is more unfavourable to the normal force at the interface than line loads. Therefore, it can be concluded that, in order to obtain the longitudinal shear resistance of steel–concrete composite bridge slab subjected to surface loads, it is desirable to use test data with a sufficient shear span length so that the effect of the normal force at the interface is insignificant. Viest carried out the initial studies on stud shear connectors, where full-scale push out specimens were tested with various sizes and spacing of the studs. The push-out and composite beam tests were used in studies on stud shear connectors to evaluate shear capacities. In order to investigate the behavior of headed shear stud connectors in solid slabs, an accurate nonlinear finite element model were developed by Ellobody (2002) and Lam and Ellobody (2005). The finite element model offered accurate predictions on the capacity of the shear connection, the load slip behaviour of the headed studs and the failure modes. Ellobody (2002) conducted another finite element model by considering the linear and nonlinear behavior of the materials in order to simulate the structural behavior of headed stud shear connectors. The use of the model in examining variations in concrete strength and shear stud diameter in parametric studies are also presented. The stud connector capacity may be assumed to be the failure load divided by the number of studs. According to previous researchers, there are several parameters that influence stud connectors. Among the most important are the shank diameter, the height of the stud and its tensile strength, as well as the compressive strength and modulus of elasticity of the concrete and direction of concrete casting.

P. Sangeetha and R. Ashwin Muthuraman (2018) et.al investigated the behaviour of the sandwich beam under flexural loading. The shear connectors varied in the sandwich beam are L-Angle, Channel, Tee section Fig.7 and Headed bolt. The load-deflection, load-strain and load-slip behaviour was plotted and compared with different shear connectors of the sandwich beam. All the sandwich beams were also analysed using finite element software ANSYS. From the study it was concluded that sandwich beam with channel and Tee connectors performed better than the beam with angle and headed stud connectors. From the load slip behaviour, the stiffness of the different connectors was found. The load carrying capacity of the sandwich beam with Tee and Channel connectors were improved by 70 % compared to angle and headed stud connectors. The maximum deflection found from the analytical models was lesser than the experimental results. The analytical model is found to be stiffer due to rigid connections of the model.

Fig.7 Mould of SCS beam with T-Connectors

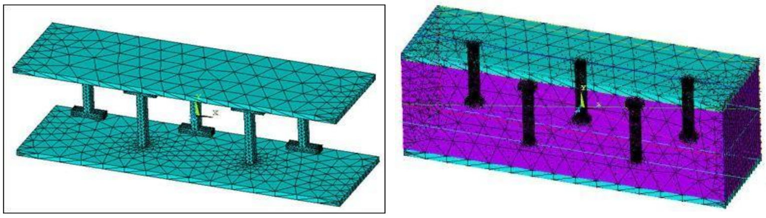

Fig.8 Numerical models of SCS beam with T-Connectors

Kodur and Naser (2014, 2016) developed a finite element model to study the fire response of composite steel beams by taking into consideration temperature induced sectional instabilities. This model, developed in ANSYS, was applied to investigate the effect of sectional slenderness on the onset of local instability and capacity degradation in steel beams exposed to fire. Results from finite element analyses were utilized to evaluate failure of beams under different limit states including flexure, shear, sectional instability and deflection criteria. These results show that under certain loading scenarios and sectional configurations, shear capacity in steel beams can degrade at a higher pace than that of moment capacity. In addition, results from numerical studies inferred that room temperature classification of steel beams, based on local instability, can change with fire exposure time; a compact section at ambient conditions can transform to a non-compact/slender section under high temperature effects. This could induce temperature-induced local buckling in steel sections and lead to failure prior to attainment of failure under flexural yield and/or shear limit state. Meng Chu et.al. (August 2013) This paper is concerned with the behavior of SCS sandwich beams with another kind of shear connectors channel steel connectors. 8 large-scale simply supported beams under static loading were tested, the beams were filled with ready-mix concrete of Grade C35, which would nominally give a cube strength f_{cu}=35N/mm2. Load conditions are two point loads, one point load, two point loads with tension. Although critical inclined cracks appeared in most of the beams, expect for the beam with shear span to depth ratio (λ) 5.5. The observed modes of failure were all ductile failure characterized by yielding of the tension steel plate. Failure mechanism of SCS beam is almost same as that of RC beams with symmetrically reinforced section, for transverse shear, the way in which SCS beams fail are rather different in their nature from the RC beams. The one of the difference is While the direct cause of diagonal section failure of a RC beams is the compression failure or tension failure of the compression zone concrete, the diagonal section failure of a SCS composite beam is caused mainly by yielding of tension steel plate in shear span followed with crushing of concrete in the web zone.

CONCLUSION

1. The proposed J-hook connectors can be fitted in shallow depth (where depth of the beam is restricted) between the steel plates for the construction of thin deck structure. J-hook shear connector is recommended that the spacing of shear connectors should be at least equal to the core thickness to prevent concrete shear failure for sandwich beams with core depth less than 100 mm.
2. Although critical inclined cracks appeared in most of the beams, expect for the beam with shear span to depth ratio (λ) 5.5. Test on sandwich beams subject to concentrated point load at the mid-length shows that it is necessary to provide adequate shear connectors in order to delay the formation of shear cracks in the concrete core and to ensure ductile failure mode.
3. Double skin composite beam exhibits three types of failure modes which are flexural failure, shear-compression and shear-tension failure. Rise-to-span ratio could change the failure mode from flexural to shear.
4. While the direct cause of diagonal section failure of a RC beams is the compression failure or tension failure of the compression zone concrete, the diagonal section failure of a SCS composite beam is caused mainly by yielding of tension steel plate in shear span followed with crushing of concrete in the web zone.
5. Axial tension promotes the yielding of steel plates, thereby reduces the bending stiffness, but significant axial tension does not seem to have an influence on the shear strength of SCS beams.

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