STEEL CONCRETE COMPOSITE STRUCTURES: STATE OF ART

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Abstract: The aim of this review article is to examine solutions and challenges associated with composite construction. Structural steel and concrete, each of the two materials can be used to its best advantage and, therefore, composite structures have proved economical in terms of overall cost. Combination of steel and concrete systems has been conceived on the premises that each type of construction offers a natural advantage which when utilized together results in an efficient system. In the composite construction subjected to service load, in addition to instantaneous cracking, the time-dependent effects of creep and shrinkage in concrete can lead to the progressive cracking of concrete near the beam ends and result in considerable moment redistribution along with increase in deflections of composite beams. In the present article, a comprehensive review of analysis and behavior of composite construction with alternate shear connections are examined. Application of neural networks in composite construction has also been discussed in this article.

Keywords: Composite construction, creep, shrinkage, neural network, Shear Connections

I. INTRODUCTION

The composite structure is one of the economical forms of construction (Fig. 1). Use of Composite Construction has become increasingly popular due to the economy and speed in construction. The modern era of Composite Systems using steel and concrete for columns began with the work of the late Dr Fazlur Khan in 1966. Combination of steel and concrete systems has been conceived on the premises that each type of construction offers a natural advantage which when utilized together results in an efficient system. Recently, there has been an increasing use of such construction.

In the composite construction subjected to service load, in addition to instantaneous cracking, the time-dependent effects of creep and shrinkage in concrete can lead to the progressive cracking of concrete near the beam ends and result in considerable moment redistribution along with increase in deflections of composite beams (Chaudhary et al. 2007c). Similarly, concrete filled steel tubular (CFST) structures have been increasingly used recently owing to good structural performances by their high load-bearing capacity and energy dissipation ability (Vu et al. 2013).

A number of researchers have been carried out the study on the behavior of steel concrete composite structures. Researcher also presented methodology for shear connection slip demand in composite beams with solid slabs. Investigation on the structural performance of steel-concrete-steel sandwich beams interconnected by channel connectors with large interval has also been carried out. In this review paper, an attempt has been made towards to present state of art of composite construction.

Neural networks have been applied extensively for the analysis and behavior of composite structures. Studies carried out for the application of neural network in the composite construction has also been examined in this article. Headed Shear Connectors are mostly used for the steel concrete composite beams and bridges.

Fig. 1. Composite cross section (Chaudhary et al. 2009)

However, recently new types of shear connectors are being increasingly used and studies have been carried out such shear connectors. In this review articles, studies reported on alternate shear connectors are also presented.

II. ANALYSIS AND BEHAVIOR

A number of studies have been reported recently on the analysis and behavior of steel concrete composite structures. Chaudhary et al. (2007a, b) presented a hybrid analytical numerical procedure for the service load analysis of steel concrete composite structures. The procedure was analytical at the element level and numerical at the structural level. A cracked span length beam element consisting of an uncracked zone in the middle and cracked zones at the ends has been used in the procedure. The concrete portion across the cross-section is assumed to be completely cracked, when the stress in the top fiber of the concrete slab exceeds the tensile strength of the concrete. The procedure takes into account the effect of concrete cracking and time-dependent
effects of creep and shrinkage in composite beams of the composite frames subjected to service load. The procedure was extended to take into account the thermal gradient by Chaudhary et al. (2007c). Studies were carried out by Chaudhary et al. (2008) using the procedure to investigate the service load behavior of continuous composite beams with precast decks considering creep, shrinkage and cracking.

The procedure was also adopted for the control of creep and shrinkage effects in steel concrete composite beams and bridges (Chaudhary et al. 2009; Varshney et al. 2013). To types of construction were considered: shored and unshored. It was found that the changes due to creep and shrinkage, in steel concrete bridges and composite frames can be controlled effectively without changing any of the design parameters, by simply delaying the time of mobilization of composite action for both the shored and un-shored constructions. The changes were found to be reduced by more than 50% on the delay of mobilization. Zona and Ranzi (2011) compared different beam models finite elements for the nonlinear analysis of composite members with flexible connection. The models were obtained by coupling with a deformable shear connection two Euler–Bernoulli beams, an Euler–Bernoulli beam to a Timoshenko beam, two Timoshenko. The results were compared with the experimental results available in literature. A small difference was found among the results of the models when the bending was dominant whereas the difference was found to increase when the effect of shear increased.

Hozan et al. (2011) presented fire analysis of steel concrete composite beams with flexible connection. The effects of slip and moisture transfer on the behavior of steel–concrete composite beam, was observed. The analysis was performed in two separate steps (i) moisture and heat transfer analysis and (ii) mechanical analysis. The formulation was suggested to be applicable for the thermo-mechanical analysis of frame-like structures, as it is robust, reliable and accurate. Vasdravellis et al. (2011) carried out experimental studies for the ultimate capacity of steel–concrete composite beams under the combined effects of axial tension and negative bending moment. The results were compared with the rigid plastic analysis and were found to be acceptable. The tested beams were modeled by a nonlinear finite element model in the ABAQUS commercial software. The three-dimensional model was compared against experimental results. The model was found to be accurate for predicting the inelastic behaviour of the composite beams.

Ibrahim et al. (2012) presented a nonlinear finite-element model for analysis of simply supported composite steel-concrete beams with external prestressing. The analysis accounted for nonlinear material and geometric properties. The results obtained by finite element solutions were found to be in good agreement with experimental results. Amadio et al. (2012) investigated the behaviour of steel–concrete composite beams at serviceability limit state. Two types of construction were compared: propped and unpropped. The maximum vertical displacements in the short- and long-term were evaluated for simply supported and continuous composite beams using accurate finite element models. Based on the results of parametric studies, a simple design criterion based on the limitation of stresses in the steel profile below the yield limit, and on the use of a simple relationship to account for the connection flexibility was proposed.

Ibrahim et al. (2013) developed a nonlinear three dimensional finite element model for the analysis of composite steel-concrete beams. The model was validated with the experimental results. Parametric studies were carried out to investigate the effect of number of shear connectors, grade of concrete, thickness to width ratio of concrete slab, the ultimate load for shear connector and yield strength of steel beam. It was found that, an increase in the thickness to width ratio lead to increase in the ultimate load by about 43%. Vu et al. (2013) carry out an experimental studies and finite element analyses to establish the effect of tendon damage on the structural behavior of concrete filled tubular tied arch girder (CFTA girder). The damage of tendon was considered in different stages by varying the number of damaged cables in the tendon. Static and dynamic structural parameters were observed at each stage. A good agreement in CFTA behavior was observed between the numerical and experimental results. The FE model presented in this study can therefore be a reliable tool for identification of tendon damage on the CFTA girder. It was also observed that all four tendons affect the static behavior of the girder, and the two inside tendons play a more important role in a comparison with the two outside ones.

Zhou et al. (2013) proposed the formulae of steel-concrete composite beam interfacial shear force, shear stress, relative slide strain and deformation, flexural deformation curvature for steel concrete composite beams subjected to sudden temperature change. The maximum interfacial shear stress, relative slide strain and deformation were found to be at the end of beam and decreasing to zero at the midspan. The Interfacial force and deformation were found to be linearly proportional to temperature difference. Souici et al. (2013) studied the behaviour of steel–concrete composite beams with shear connection realized by means of either the traditional welded-studs or an innovative bonded solution based by carrying out experiments. It was concluded that (i) full connection of the connected composite beam cannot be ensured after cracks, (ii) Performance of the partial banded composite beam is relatively small, (iii) Failure of the connected composite beam is due to the yield of the steel beam and (iv) behavior of the banded composite beams is elastic and linear until the failure. Minghe and Jing (2013) studied the behavior of composite structures under the condition of the different pre-stressing construction procedures. The different pre-stressing loading methods were found to influence behavior of structure. A suitable pre-stressing applying method was suggested by the Authors.

Gara et al. (2014) proposed a higher order numerical model for steel–concrete beams with partial shear interaction taking into account the shear-lag effects and shear deformability of concrete and steel. The model accuracy was established by carrying out the validation studies. Lowe et al. (2014) carried out studies on characterization of the splitting behavior of steel-concrete composite beams with shear stud connection. They carried
our experiments on 5 steel-concrete composite beams, with shear stud connections, for investigating the splitting behaviour at the stud-concrete interface. The concrete splitting and crack growth propagations were found to occur at very low applied loads in cyclic tests. It was concluded from the studies that the zone of transverse deformation around the stud is much localized.

Zona and Ranzi (2014) presented a methodology for shear connection slip demand in composite beams with solid slabs. An extensive parametric study was carried out to investigate the effect of different parameters on the slip demand. The most important parameters were found as construction sequence, the span length, and the steel section shape. It was observed that shear connection distribution can have significant effect on the behaviour of composite beams. It was also suggested to put more connectors near the support to limit the slip. Barbato et al. (2014) presented a probabilistic response analysis method based on the first-order second moment (FOSM) method in conjunction with response sensitivity computation through the direct differentiation method (DDM), to study the variability of the structural response of steel-concrete composite (SCC) beams. The method was found to accurately describe the effects of random spatial variability of material parameters.

Leng et al. (2015) investigated the structural performance of steel-concrete-steel sandwich beams interconnected by channel connectors with large interval. Nine simply supported sandwich beams with shear span/depth ratio between 1.0 and 5.5 were tested under static load. A model was proposed on the basis of the observed failure mode for the prediction of the ultimate shear resistance of steel concrete steel sandwich deep beams after critical diagonal cracking. The model was validated with the test results.

III. APPLICATION OF NEURAL NETWORKS

Neural networks have been applied extensively for the analysis and behavior of composite structures. Yam et al. (2003) presented an integrated method for damage detection of composite structures using artificial neural networks The neural networks were applied to establish the mapping relationship between structural damage feature proxy and damage status (location and severity). The methodology was found to be applicable to online structural damage detection and health monitoring for various industrial structures.

The neural networks were applied for the bending moment prediction of continuous composite beams with rigid shear connections considering cracking and time effects by Chaudhary et al. (2007d) and Pendharkar et al. (2007). The neural networks have been applied for the prediction of deflection of continuous composite beams with rigid shear connection also by Pendharkar et al. (2010). Neural networks were developed by Pendharkar et al. (2011) for the prediction of moments in composite frames, with rigid shear connections, considering the cracking of concrete and effect of creep and shrinkage. Tadesse et al. (2012) presented neural networks for the prediction of deflection in composite bridges with flexible shear connections. Closed from expression were presented by the authors to predict the deflection based on the simple input parameters.

IV. ALTERNATE SHEAR CONNECTIONS

Headed Shear Connectors are mostly used for the steel concrete composite beams and bridges. However, recently new types of shear connectors are being increasingly used and studies have been carried out such shear connectors. Higgins and Mitchell (2001) carried out experimental studies of composite bridge decks with alternative shear connectors. The proposed shear connector consisted of concrete filled holes located in the webs of grid main bars and friction along the web embedded in the slab. The static and fatigue tests were carried out to investigate the behavior of composite structures with the alternative shear connectors. It was found that the shear connectors performed well even above the service load range. Jurkiewicz et al. (2011) carried out studies on non linear behavior of steel–concrete epoxy bonded composite beams. Two 3-point bending tests were performed on beams. It was observed from the tests that bonding can allow a large plastic strain without any shear failure.

Luo et al. (2012) carried out push-out tests for the strength evaluation of adhesive connection between steel and concrete. The epoxy adhesive between steel and concrete was found to be capable of providing a bonding strength of 6.36 MPa. The behavior of bonded composite beams was found to depend immensely on the material properties of adhesive. The debonding of bonded composite beams was found to mainly depend on the bonding strength and the bonding area. Shariat et al. (2012) carried out modified push-out tests to study the behavior of channel shear connectors embedded in high strength concrete slab. In each series, four push-out specimens were tested covering different sizes of channel shear connector and different strength level of HSC. The channel shear connectors were found to be sufficiently ductile. It was found that the strength degradation rate was lower in case of high strength concrete as compared to the normal concrete. The provisions of Canadian design code were found to overestimate the strength of channel shear connectors embedded in high strength concrete.

Rowe and Bradford (2013) investigated the use of high-strength bolts as shear connectors. The bolts can be installed in pre-drilled holes in the steel top flange and in precast concrete slab units. A model was proposed in which the interface shear was assumed to be resisted initially by the friction caused by preload in the bolts with full interaction and then by a condition in which the bolts slip in their pre-drilled holes and then finally bear against the holes in the slab and steel joist in a more conventional fashion. The concept was explained by a simplified model. Pavlovic et al. (2013) carried out studies on different types of shear connectors, particularly on the bolted shear connectors. They carried out push out tests to assess the strength of the bolted shear connectors. Experimental and finite element studies were carried out for shear resistance, stiffness, and ductility and failure modes. The shear resistance reduction factor has been was proposed for bolted shear connectors.

Papastergiou and Lebet (2014) presented a new type of steel–concrete composite beam for prefabrication, fast erection and enhanced durability. The connection has three mechanisms: adhesion, interlocking and friction. The
connection was tested for fatigue and design plastic moment was found to reach. The relative slip was also found to be sufficiently high. Guidelines were provided by the authors for the practical use of such type of shear connection. Baran et al. (2014) carried out studies for the flexural behavior of partially composite beams with channel connectors. The effect of partial composite action degree on strength and stiffness of beams was investigated. It was found that the behavior of connectors in beams is related to load-slip behavior from push-out tests. The composite action was found to result in significant improvement in the behavior of composite beams. It was also stated that the AISC specifications overestimated the stiffness of the beam.

V. SUMMARY AND CONCLUSIONS

This paper presents the challenges and solution associated with construction of composite structure. It can be said that models suggested by different research can be applied successfully to evaluate the effect of creep and shrinkage. In steel and concrete structures, steel and concrete can be controlled effectively without changing any of the design parameters, by simply delaying the time of mobilization of composite action for both the shored and unshored constructions. The maximum vertical displacements in the short- and long-term can also be evaluated for simply supported and continuous composite beams using accurate finite element models. The effects of slip and moisture transfer on the behavior of steel–concrete composite beam, was also reported. On the other hand, researcher reported that neural networks can be applied successfully on the composite construction models. Conventionally, headed Shear Connectors are mostly used for the steel concrete composite beams and bridges. However, recently new types of shear connectors are being increasingly used and studies have been carried out such shear connectors. Studies showed that epoxy adhesive can also be successfully used as alternate of shear connector in composite construction.

REFERENCES

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