ABSTRACT

Steel-concrete composite (SCC) construction is one of the fast track construction methods. Concrete is known to have better compression resistance whereas steel is strong in tension. But, in this method synergetic bonding between reinforced concrete slab and steel beam achieved by means of mechanical connectors (i.e. Stud type), results in additional advantages. With this type of construction, not only optimum utilization of materials is achieved but it is proved to be economical also, from the consideration of life cycle cost of structures. The stud connectors are subjected to longitudinal shear forces developed at the interface between RCC slab and top flange of steel beam. Due to the complex force transfer mechanism, the analysis of SCC girders becomes relatively difficult as compared to either RCC or steel construction. In structural applications like construction of deck in bridges (both in railways and highways), floors in high rise buildings etc, analysis is simpler than the situations where SCC members are subjected to shock loadings. For the determination of shock resistance of SCC girders, one needs to determine dynamic characteristics as well as influence of impulse durations. Shock loading comprises of high magnitude pulse acting on a structural member for very short time. This paper presents review on analysis and design for shock loading on SCC girders. Various issues related to the analysis, effect of shear connections, application of shock loadings on SCC girders etc., are appropriately described.

Keywords: Steel-Concrete Composite Girder, Stud Connectors, Shock Loading, Interface Behaviour.

1.0 INTRODUCTION

Due to recent global terrorism activities and threat imposed danger to the public infrastructure, and thus the demands for blast and impact resistant design of structures have increased ever before (Mohammed and Parvin, 2011). There are very few studies have been reported on this
issue. Fujikake et al. (2009) have investigated the behaviour of RCC beams subjected to impact loading. They observed local damage near impact location only and reduced local failure due to increase in strength of compression reinforcement. He reported that besides cross-sectional details, mass, geometry, span are critical parameters to accurately predict the impact response. The composite construction is now a mature technology in developed countries, frequently chosen under competitive design techniques. Earlier composite beams were tested in 20's. Steel concrete composite (SCC) construction is one of the fast track construction methods. A number of infrastructural facilities like medium span bridges, residential and official complexes etc have been built in recent past using SCC construction. The SCC construction is a result of synergetic bonding between steel beam and reinforced concrete slab, where the bonding is achieved by means of the mechanical devices called as shear connectors. SCC girder sections are shown in Fig. 1.

![Fig. 1: Section of SCC girder (a) Longitudinal (b) Cross-sectional](image)

The studies were carried out on beams with part of web or top flanges embedded in concrete slab with and without shear connector. Recently four new flyovers using steel concrete composite method have been constructed in Calcutta by year 2006. Advantageous of SCC construction are time saving, economical and reduction in total weight.

Steel decking, box girders are the other types also used in the construction of composite girders. Connection plays a major role in the steel-concrete composite action. The connection at interface between two components depends upon strength and stiffness of shear connectors. Structures must design to resist from the different types of loads. SCC girders subjected to repeated and cyclic loadings are investigated by Seerja (2012), and Hanswille (2009). The failure in the composite girder due to crushing of concrete and the buckling of bottom flange steel and the failure is prevented by appropriate provisions (Liang et al. 2004). The vibration produced in the composite structure in the composite footbridge structure and the behaviour has been analysed (Gilvan et al. 2012) by using the finite element method. The vertical loads induce some deformation in the girders. The primary bending and shear formed due to the vertical loads (Bradford, 1991). The stiffness and capacity of composite structures depends on the material properties, connections etc.

The research on the shock response of SCC girders is still need momentum. There are is scanty information available on SCC girders subjected to shock due to impact or explosion loadings. There are no guidelines or code of practice on the design and analysis for shock resistance of SCC structures. There is also scarcity of knowledge on the impact responses of SCC structures or structures elements. The field applications where, these SCC members can be exposed to such extreme impact loading can be considered when the debris due landslides falls on the deck of SCC bridge decks or residential structures or by the sudden attack of aircraft in the infrastructures etc. Though less likely but the explosion may take place even in residential buildings due to blast or accidental explosion in inflammable gas containers etc. Therefore, to understand the behaviour of steel concrete composite girders under shock loads need serious consideration. A focused review is carried out related to issues of SCC construction and also their shock response.
2.0 MECHANISM OF FORCE TRANSFER IN SCC GIRDERS

When a transverse load is applied on the deck of SCC girders it is resisted by the strength of transformed composite section. And to maintain the strain compatibility between two elements, studs play an important role. In order to resist the interface slip, the dowel action and tension both develop in studs. The concrete near the stud root bears very high stresses and gets crush eventually. The design of interface shear connection decides overall load carrying capacity of composite girder. Under flexure loads concrete is trying to expand and steel is trying to contract at the interface. Maximum interface slip occurs near the ends of girder and zero at midspan. Due to resistance to the interface shear force, stud connectors near the ends undergo layer deformation than near the midspan, as shown in Fig. 1.

![Fig.1: Flexural behaviour of SCC girders](image)

In case of shock load on the SCC girders there can be local failure rather than global. Due to which girder may subject to local damage in the form of crushing of concrete or buckling of steel section. However during entire impact process the transition between local to global deformation is possible. The complex force transfer mechanism in case of shock loading need to be understood exactly.

2.1 Types of Shear Connectors and Shear Connections

Depending upon the ease and convenience various researchers have used steel connectors are shown in Fig. 2(a to h).

![Fig. 2: Types of shear connectors](image)

The mechanical shear connectors varied in shape, size and methods of attachment. The connectors are classified into flexible rigid and anchorage. The flexible connectors which are more popular compared to the anchorage or rigid. The head of stud connection resist shear through dowel
action and tension strength. Liu and Ni 2011 have developed 3D solid FE model to show the behaviour of stud connectors in composite girder.

2.2 Interface Behaviour in SCC Girders

The behaviour between concrete slab and steel girder interface is calculated by assuming load slip. The thickness of the connectors was affected by the interface behaviour and the calculation of interface stress in steel–concrete composite structures by elastic theory. To resist the shear in interface, the shear connectors were designed and the shear connectors welded along the span of steel flange in large numbers (Slutter and Fisher 1966). In the economical and efficient composite construction many researches were conducted and the design was changed in reduction of shear connectors. This was accomplished by using plastic analysis to determine the interface shear at ultimate strength of the composite girder. The analysis showed reduction in number of shear connectors needed for static ultimate loads on the bridge deck. To identify and control of collapse in the static load is simple but in the dynamic or repeated loading it is more complex. The deformation will increase under repeated and cyclic loadings, if the deformation is controlled under suitable situation and there is no deformation, this part is termed as shakedown. If the shakedown occurs, the permanent deformation takes place. And the incremental slip forms in the interface behaviour results in the collapse. Experimental tests were carried out to know about the behaviour of shakedown load (Thirugnanasundralingham, 1991).

2.3 Degree of Shear Connection

The degree of shear connection deals with the equilibrium of forces within a composite beam, whereas the degree of interaction deals with the compatibility of displacements (Ohlers et al. 1997). In the fully composite section, flexural strength depends upon the steel and concrete girders and the strength of the girders which does not governed by connectors. By calculating ultimate load transfer at the interface and develop the number of shear connectors which would achieve full composite strength. The plastic capacity of the fully composite cross-section occurs when the slab reaches its full compression capacity or when the steel girder is fully yielded. But in the partially composite girder flexural strength depends upon the shear connector’s strength. It is less effective compared to full connection while achieving the ultimate strength. The degree of shear connection related to the decrease in the flexural strength (Johnson and Molenastra, 1991). The degree of shear connection is governed by strength and spacing of shear connectors provided in shear span of composite beam.

3.0 EFFECT OF FULL AND PARTIAL SHEAR INTERACTION

By assuming the slip is prevented and the two elements are connected this case is called full interaction. The bond between no and full interaction, it is referred as partial interaction. The flexural capacities determined by strain profile, stress distribution, compressive and tensile forces are shown in the Fig 3. From a comparison of the stress profiles in Fig. 3, it can be deduced that the partial-interaction full-shear-connection flexural capacity is less than the full-interaction full-shear-connection flexural capacity.

It can also be seen by comparing the full-interaction strain profile with the partial-interaction strain profile, that partial-interaction reduces the maximum strain in the steel, and hence reduces the ability of the steel to strain harden (Oehlers et al. 1997). The beams to be design with partial shear connection at the interface, provision are not made for the evaluation of deflections of such beams. To develop methods of calculation, with little mathematics and at low cost (Nabeel. 1999).
The full interaction procedure is safe and simple. However, in the fatigue assessment of existing structures, more accurate assessment techniques are required in order to extend the life of the structure as much as possible. A simple assessment approach has been developed based on partial-interaction theory that can be used to predict the remaining strength or endurance of the shear connection (Seracino et al. 2000).

4.0 BEHAVIOUR OF SCC GIRDERs UNDER SHOCK LOADING

4.1 Shock Loading

Dynamic forces are those that are very much time dependent and these either act for small interval of time or quickly change in magnitude or direction. Earthquake forces, machinery vibrations, impact loading, Shock loading and blast loadings are examples of dynamic forces. It is very convenient to know the values of dynamic load factor (DLF) for the cases of designing structures for impulsive loads. Dynamic load factors are defined as the ratio between maximum dynamical stresses under impulsive loads and stresses under static loads.

4.2 Single degree of freedom system

Considering a system at rest and subjected to a force $F$, which has an initial, suddenly applied value of $F_1$ and decreases linearly to zero at time $t_d$ (Fig. 4), the response may be computed by equation in two stages. For the first stage,

Stage1: $\tau \leq t_d$

Initial displacement, $y_0 = 0$

Initial velocity, $\dot{y}_0 = 0$

$$f(\tau) = 1 - \frac{\tau}{t_d}$$

$$y = y_0 \cos \omega \tau + \frac{\dot{y}_0}{\omega} \sin \omega \tau + y_0 \omega \int_0^\tau f(\tau) \sin \omega (t - \tau) d\tau$$

The above equation is a general expression for the response of an undamped, linearly elastic one degree system subjected to any load function and/or initial conditions.
The static displacement eq.(1), for one-degree freedom system having stiffness as k, can be given as:

\[ y_d = \frac{F_i}{k} \]  

(2)

Substituting initial conditions in general solution eq (3) and integrating it we get,

\[ y = \frac{F_i}{k} (1 - \cos \omega_d) + \frac{F_i}{kt_d} \left( \frac{\sin \omega_d}{\omega} - t \right) \]  

(3)

or, Dynamic load factor is given is in eq.(4),

\[ DLF = 1 - \cos \omega_d + \frac{\sin \omega_d}{\omega_d} - \frac{t}{t_d} \]  

(4)

The equation (3), defines the response before \( t_d \).

Stage2: \( t_d \geq t \)

\[ y_0 = \frac{F_i}{k} \left( \frac{\sin \omega_d}{\omega_d} - \cos \omega_d \right) \]  

(5)

\[ \dot{y}_0 = \frac{F_i}{k} \left( \omega \sin \omega_d + \frac{\cos \omega_d}{t_d} \right) - \frac{1}{t_d} \]  

(6)

\[ f(\tau) = 0 \]

Substituting these values in equation (1), replacing \( t \) by \( t-t_d \) and simplifying,

\[ y = \frac{F_i}{k \omega_d} \left[ \sin \omega_d - \sin \omega(t-t_d) \right] - \frac{F_i}{k} \cos \omega \]  

(7)

or,

\[ DLF = \frac{1}{\omega_d} \left[ \sin \omega_d - \sin \omega(t-t_d) \right] - \cos \omega \]  

(8)
Equation (7) gives the response after \( t_d \). The maximum value of dynamic load factor can be obtained nearly equal to 1.8 for \( t_d/T_n \) value as 2. For the higher ratio it approaches to DLF value 2. On the other hand the maximum value of rectangular pulse is 2 for \( t_d/T_n \) ratio as 2 and above. This simplified method is used for idealized systems.

5.0 ISSUES RELATED TO DYNAMIC ANALYSIS OF SCC GIRDER

Since the steel-concrete composite construction consists of the three main components namely, RCC slab, steel beam, and shear connectors. There are various issues involve in the analysis and design of SCC girders. The following principle issues are mainly exists with the steel-concrete construction and shock response of SCC members:

- Interface between steel and concrete needs due regard to the design of shear connectors.
- A stage of construction needs due consideration for analysis as whether pre-composite or composite.
- The location of plastic neutral axis plays a key role in deciding the design strategy. It is desirable that neutral axis may exist just below the concrete slab so that full concrete area can be effectively utilized.
- The determination of the effective width is another important issue, because whole analysis is dependent on the sectional properties of the composite girder.
- Mechanism of shear transfer between steel and concrete element, which is the main focus of the steel composite construction.
- Method of construction (propped or unpropped) is the matter of choice, which depends upon the owner's, will and site conditions.
- Shear connection (full or partial) is one of the most important design steps in steel-concrete construction.
- Design basis working stress method (Allowable stress design) or limit state method (loads and resistance factor design)
- Surface protection of steel is always being the point of prime consideration among the designers and engineers.
- Excessive vibrations in the steel composite bridges are reported due to its low damping characteristics as compared to more massive bridges.

5.1 Design guidelines and codes on SCC construction

It is also one of the main issues that there is no code of practice dealing with shock resistant design of SCC members. Although in India we have two codes related to design of composite structures viz. IS:11384-1985 and IRC:22-1986. The IRC:22-1986 is applicable to composite construction of road bridges. It is clearly mentioned in the scope of IS:11384-1985 that the provisions of this code is applicable to buildings only and, not for bridges. But there are number of deficiencies in both of the codes. In fact none of these codes satisfies the current design methods and practices which are used by various developed countries. Eurocode (EN 1994-1-1) is latest and most of the European countries are using them. However, shock response of SCC girders is not dealt adequately in any of the codes of practice.
6.0 SUMMARY

A comprehensive literature survey has been conducted and it is observed that there is need for further research in this specialized area. In spite of many advantages of SCC construction there is lack of guidelines and code of practice including shock loading and need research.

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