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Performance of Steel Reinforced Concrete Beam-To-Column Joints Exposed To Fire

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Abstract - *The study focus on the behaviour of steel-reinforced concrete (SRC) column to SRC beam joints under combined loading and fire, including heating, cooling with constant loads and post fire loading. A finite element analysis (FEA) model was performed to simulate the response of SRC beam-to-column joints in whole loading sequences. Fire exposure study was conducted for four SRC joints in which beam internal I shaped structural steel was changing while keeping the same column internal H shaped structural steel to observe the deformation of the SRC joints during the heating phase is crucial for the development of an efficient and safe structure in fire. The sections were elite according to the cross-sectional dimensions of the beam and column. From the four models better model with least deformation was considered for the cooling and post fire phases. The heating time considerably affects the column axial deformation arising in the cooling phase. The influence of heating time was minor for the beam vertical deflection. The increase of the column and beam deflection arising in the cooling stage is much greater than that arising in the heating stage, which reveals the probable failure of the SRC joint in the cooling period.*

Key Words: SRC joints, Fire resistance, Thermal behaviour, Heating, Cooling, Post fire

1. INTRODUCTION

Steel reinforced concrete (SRC) consists of structural steel sections, reinforcing bars, stirrups and concrete. Such a structural kind combines the advantages of each steel and concrete, and therefore improves the structural performance at each room and elevated temperature. Because the concrete, which has lower heat conduction coefficient, considerably delays and decreases the rise of temperature in the steel sections. The outer concrete acts as a sacrificial coating for the steel section vulnerable to fire. So, it has a high fire resistance compared with conventional steel structures. The SRC structures has high stiffness, strength, excellent seismic-resistant and good fire performance.

2. FIRE EXPOSURE STUDIES ON DIFFERENT SRC JOINTS

Ansys Workbench 15.0 is used to study the behaviour of four SRC column to SRC beam cruciform joints with RC slab exposed to fire. Full-sized joints that is more representative of real constructions was modelled by fixing internal column structural steel section (H shaped) in all four cases and changing the beam internal structural steel (I shaped) according to the dimensions of the column and beam. Life-time performance of the SRC joints was studied analytically by adopting a loading sequence including initial loading, heating, cooling and post fire loading.

2.1 Geometric Details

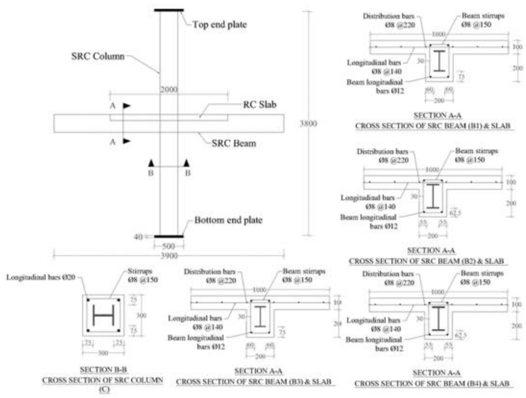


Fig -1: Geometric details

The height of the SRC column (H), was 3,800 mm, and the lengths of the SRC beam (L) and RC slab (L_{slab}) were 3,900 and 2,000 mm, respectively, as shown in Figure 1. Top and bottom end plates having a depth of 40 mm and a cross-sectional of 500 mm. The width (b_{slab}) and thickness (t_{slab}) of the RC slab were 1000 and 100 mm respectively.

Four SRC joints was adopted for the study CB1, CB2, CB3 and CB4 in which standard section ISHB150 was adopted as SRC column internal H shaped structural steel which is same in all four cases. In four SRC beams, I shaped internal structural steel were used. Standard sections ISLB150, ISLB175, ISMB150 and ISMB175 were used as B1, B2, B3 and B4 respectively.

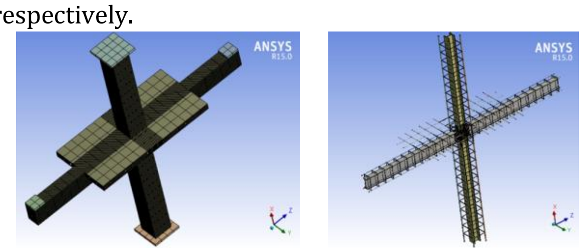


Fig -2: Mesh diagram

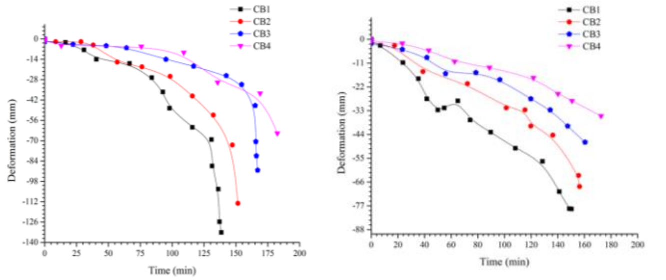
2.2 Boundary and Loading Conditions

The bottom end of the column was fixed, and the top end of the column was restrained against all directions except the vertical direction. The two ends of the beam were free from restraint. Heat radiation and heat convection at room temperature were adopted as thermal boundary conditions. The convective heat transfer coefficient and the surface radiation emissivity are taken according to European design guide (ECCS- 1988) to be 25 W/ (m2°C) and 0.5.

1. At the ambient loading phase, axial load (N_F) was applied to the column, and two vertical loads (P_F) were applied to each end of the beam on each side of the joint. The predetermined column load level (n) = 0.5 and beam load level (m) = 0.5. The levels n and m are defined as $n= N_F/N_{cu}$ and $m= P_F/P_{bu}$, respectively, where N_{cu} is the axial compressive capacity of the SRC column at an ambient temperature and P_{bu} is the ultimate capacity of the SRC beam under vertical loading. The values of N_{cu} and P_{bu} can be determined according to the Chinese standard JGJ 138-2001 (Construction Ministry of China 2002). N_{cu} and P_{bu} were taken as 4,240 and 86 kN, respectively.
2. In the heating phase, the applied loads on the column (N_F) and beam (P_F) were kept constant, and the space under the RC slab was heated. It would be optimal if real fire situation practiced by the fire exposed SRC building could be implemented in the numerical analysis. However, the applicable records were not available. So in this paper, the temperature was controlled by the ISO-834 (ISO 1975) heating curve, and the fire was continued until the fire resistance of 200 minutes. For heating phase the temperature was taken up to 600°C.
3. In the cooling phase, at the end of the heating phase, the environmental temperature started to fall. During this phase, the temperature inside the joint will be still very high, and the heat absorbed by the joint will be dematerialized to the air when the joint temperature is greater than the environmental temperature. It will take a long time for the SRC joint to cool down. In the cooling phase, the loads applied on the column and beam were kept constant until the joint cooled to an ambient temperature. At the end of the cooling phase the fire resistance was approximately 1900 minutes.
4. In the post fire phase, after the joint temperature fall down to the ambient temperature, the loads on the left and right beam segments were increased (10% increment) at the same time until the joint failed. During the loading phase, the column load N_F was kept constant. The fire resistance at the end of the post fire phase was 2100 minutes.

2.3 Behavior of SRC beams in heating phase

The beam internal structural steel section is changing in all



four cases. From the chart 1 we can see that the right limb deformation of the beam B4 was -64.84mm at a fire resistance of 180 min.

Chart -1: Right beam & left beam deformation vs time curve

In the case of left limb of the beam B4, the deformation is about -35.44mm at a fire resistance of 170 min. In the heating phase the beam deflection increases as the degradation of the material properties. The difference of the vertical deformation between the left limb of the beam and right limb of the beam is because of the load order given in the structure. If it was given in the opposite direction, the vertical deflection will be vice versa. . According to ISO-834-1 (ISO 1999), the failure criteria of SRC beams in the four models are within the limits.

2.4 Behaviour of SRC columns in heating phase

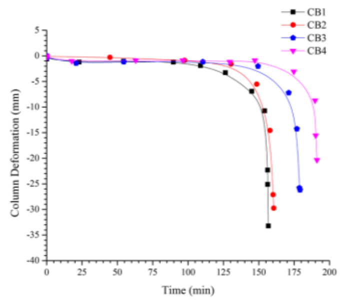


Chart -2: Column axial deformation Vs time curve

Column section is same in all four cases. ISHB150 was used for column internal structural steel. From the chart 2 we can see that the column deformation is very least approximately -20.35 mm for CB4. From that we understood that the CB4 can withstand the temperature loads at a fire resistance of 190 min. Also in the case of CB3 it can also withstand the fire up to 180 mins. Since the column deformation for the joint CB3 was approximately -26.19mm. Since the beam internal section is changing there is also a change in the column deformation. According to ISO-834-1 (ISO 1999), the failure criteria of SRC columns in the four models are within the limits. Comparing all the cases CB4 shows better result since it have least deformations.

Chart 3 shows the column axial deformation (mm) verses time (minutes) relation curve of four SRC joints. It consists of four characteristic stages, i.e.,

1. Ambient loading stage: At this stage the initial load is applied on the joints before exposure to fire, and the deformation-time relation looks linear approximately. Ambient temperature is adopted as 22°C.
2. Expansive stage: At this stage, the loads on the joints were kept constant, and the four joints were exposed to ISO-834 (1999) standard fire. As the temperature increases, the material degradation of steel and concrete occurs. The thermal expansion also occurs at the same time. In this stage, the result of axial thermal expansion overpowers the effect of the column is observed. When the effect of material degradation and expansion are balanced, the expansion displacement reaches to the peak value.
3. Softening stage: In this stage, the load remain constant though the temperature increasing further. As the temperature increases, the contractive deformation made by the material degradation becomes dominant. The axial deformation of the column changes from expansive to compressive at this stage.
4. Accelerated failure stage: During this stage, the second-order effect took by the axial force is foremost, then the axial deformation of the column will increase quickly and the column fails when the maximum axial contraction or the rate of contraction reaches the failure condition specified in ISO-834 (1999).

2.5 Behaviour of CB4 in the entire loading sequence

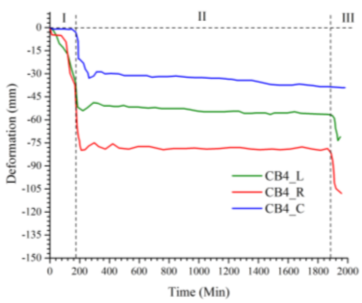


Chart -3: Deformation Vs time curve including initial loading, heating, cooling and post fire loading

For the SRC joint CB4, in the heating phase (I), the column experience an expansion stage because of the impact of thermal expansion at the start of the heating phase, and then as the temperature rises, the contraction due to material properties degrading becomes dominant. The beam deflection keeps increasing continuously due to the material degradation. At the start of the cooling phase (II), the beam vertical deflections rises considerably as the degradation of the material properties. The change of beam vertical deflections was minor till the end of the cooling stage. In post fire phase, the left and right beam loads were increased in 10% increments at the same time until the joint failed. The deformation in the cooling stage is much greater than that arising in the heating stage. Taking the right beam of the SRC joint CB4 as an example, shown in chart 3, the deformation growth in the heating phase is 64.84mm, but the deformation growth in the entire cooling phase is 79.44mm. The increment in the cooling stage is about 1.22 times that of the heating stage. The heating time considerably affects the column axial deformation arising in the cooling stage. The growth is 10.83mm. The influence of heating time is minor for the beam deformation. This may be due to the applied beam load is fairly less related with the column load.

The failure modes of SRC joints is affected mainly by the column load ratio. When the column load ratio is less than 0.8, the joint failure is usually measured by the failure of the SRC beam. During this case, two plastic hinges forms at both ends of the beam panel zone as the increasing beam loads due to the temperature effect, which causes the failure of the SRC joint. Because the plastic hinges occurs only in the beam, the failure mode is referred as the beam failure mode. Since here in this study, the column load ratio is lower than 0.8, therefore the joint failure is mostly controlled by the failure of the SRC beam.

3. CONCLUSIONS

This paper has studied the mechanical performance of various SRC beam to SRC column joints with RC slab subjected to a fire including heating and cooling.

1. The SRC beam-to-column joint under ISO-834 fire behaved in somewhat ductile manner.
2. By using the FEA modelling, a parametric study was conducted to find the better model with least deformation. Based on the study, SRC joint CB4 with standard section ISHB150 (SRC column) and ISMB175 (SRC beam) shows the better result. And it was considered for cooling and post fire phases. The joint CB4 failed because of the beam failure to support the applied beam loads.
3. The SRC beams shows considerably more deformation than the SRC columns.
4. The cooling phase must be considered for a real building open to fire in terms of the structural deformation. The structure might fail when the environmental temperature starts to fall.
5. In the post fire phase, the residual bearing capacity of the joint reduced with rise of heating time, but the effect of heating time on the failure mode was slight.
6. The post fire results evidently shows that the growth of the column and beam deflection arising in the cooling phase is much larger than that arising in the heating phase, which reveals the probable failure of the SRC joint in the cooling phase.

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