# FEA of Ultra High Performance Fibre Reinforced Concrete -Encased Steel Composite Beams

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***Abstract*** **– The steel- Ultra high performance fiber reinforced concrete composite (UHPFRC) beams is simulated as non linear finite element model, to compare the behaviour of each elements individually and as composite beam. Three types models are analyzed, steel beam with and without vertical stiffeners, an UHPFRC beam and a composite UHPFRC beam. The study investigated the encasement effect of steel, the role of shear span to depth (a/d) ratio in composite beam and the effect of effective length of the steel beam on ductility, stiffness, ultimate load bearing capacity and failure pattern of composite sections.**

***Key Words*****:** ***Composite beams; Ultra high performance; Numerical models; Shear response; Encased beams; Non-linear analysis; Encased effect***

## 1.INTRODUCTION

To meet the requirements of globalization, India has doing a major leap on infrastructures development such as express highways, industrial and power structures, large dams etc. Conventionally, for the construction of civil engineering works, concrete play main role and a large quantum of concrete is being utilized. To achieve the intended durability and sustainability, the current infrastructure incorporates a mix of unique design styles, powerful technology, and high-end durable construction materials. The Construction Materials & Technology Promotion Council (BMTPC) was established by the Indian government in 1990 to encourage and promote the use of sustainable, energy-efficient, and environmental friendly building materials. This leads to the evelution of composite section. Pure steel and concrete construction now replacing with steel concrete composite sections and it accepted as a suitable alternative.

### *1.1 Composite Structures*

Using reinforced concrete member, increase the size of structure and cost of construction with load and span. It's possible with composite sections, same cross sections with different load and moment resistances can be created by changing the steel thickness, concrete strength and size of reinforcement. It helps the section to keep the outer dimensions as constant, and it makes more easiness in the construction and architectural detailing. The composite sections can withstand in high stresses and have excellent ductility.

### *1.2 Use of UHPFRC*

The UHPFRC matrix is composed of high amount of cement and silica fume, steel fibers, very low Water/cement ratio (0.18 to 0.25) and water reducers. It offers almost no shrinkage or creep and making it very suitable for concrete members under long-term loading. Compared to normal strength concrete, UHPFRC shows strain-hardening behaviour due to the bridging effect of short fibers. Presence of nano-additives improve the mechanical properties refines the pore structure, favours cement hydration, and improves durability. Moreover, in the cracked state, nano-constituents improve the self-healing capacity of concrete. Due to the dense microstructure and damage-tolerance characteristics, the UHPFRC provides significant enhancement in the sustainability of concrete members. The prestressed hybrid pedestrian bridge at Sherbrooke in Canada, is the first structural application of UHPFRC, which was constructed in 1997. 60meter is the total span length of the bridge.

## 2. PERFORMANCE ANALYSIS OF MODELS

There are four beam models with total five patterns considered under three concepts. They are shown in table 1 and the model geometries are shown in figure 1, 2, 3 and 4. The density of UHPFRC can vary depending on its specific composition and the proportion of fibers used, but typically ranges from 2200 kg/m3 to 2600 kg/m3. The density of steel fibers used in UHPFRC can also vary depending on their specific composition and shape. However, as a general approximation, the density of steel fibers used in UHPFRC ranges from 7800 kg/m3 to 8000 kg/m3. The addition of steel fibers to UHPFRC can significantly improve its mechanical properties, such as its tensile and flexural strength, as well as its resistance to cracking and impact. Table 2 shows the material properties adopted for analysis. The simulation process was carried out with ANSYS Workbench 2019 R3.

TABLE -1 BEAM MODELS

| **Sl. No.** | ***Name*** | ***Description*** |
|---|---|---|
| 1 | Model 1 | Steel Beam ISWB 250 |
| 2 | Model 2 | Steel Beam ISHB 200 |
| 3 | | Steel Beam ISHB 200 with vertical stiffeners |
| 4 | Model 3 | UHPFRC Beam (250mm x300mm) |
| 5 | Model 4 | UHPFRC- ISWB 250 Composite Beam (250mm x 300mm) |
| | | |

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TABLE -2 MATERIAL PROPERTIES

| Materi al | Poisson's Ratio | Young's Modulus (Mpa) | Yield Strength (Mpa) | Density (kg/m$^3$) |
|---|---|---|---|---|
| UHPFR C | 0.22 | 44000 | 150 | 2600 |
| Reinforce-ment Steel | 0.30 | 2 x $10^5$ | 550 | 7850 |
| Steel Beam | 0.30 | 2 x $10^5$ | 250 | 7850 |

Considered a span of 2500mm for models. Two end supports are provided as boundary condition. One end with a hinged support and the second with a roller support. ANSYS Workbench autogenerate most suitable mesh for the model. Range of a/d ratio considered from 1.456 to 3.056 with 0.4 intervals were analyzed. This aimed to find the effect of the a/d ratio on the load carrying capacity, ductility and failure pattern of the composite beams.

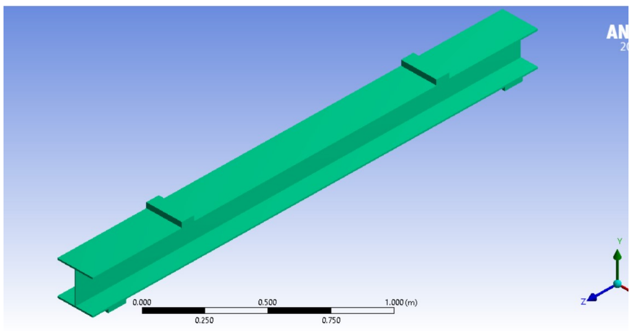


Fig -1 Steel Beam without vertical stiffeners

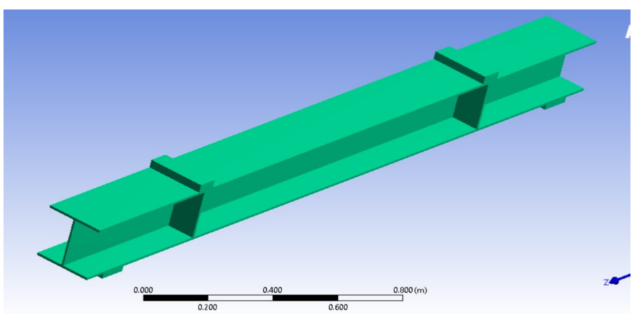


Fig -2 Steel Beam without vertical stiffeners

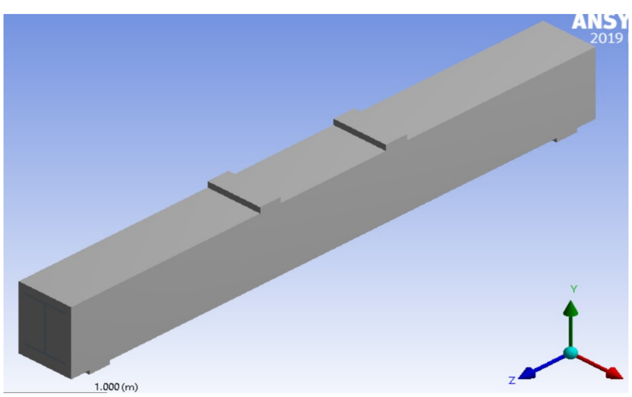


Fig -3 UHPFRC Beam

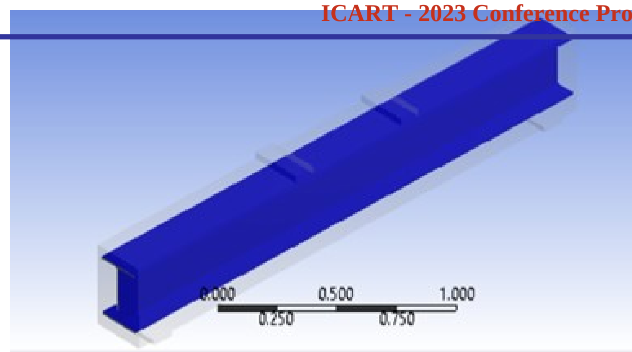


Fig -4 Composite Beam

## 3. RESULT AND DISCUSSION

In the simulation process, ISWB 250 performs better than ISHB 200, even they have almost equal per meter weight. With and without vertical stiffeners not exhibits comparable difference in performance. Hence ISWB 250 section without vertical stiffeners is used for composite beam, as an economical section. In comparison with the the behaviour of idividual elements, the combined beam's failure pattern is appreciably high. The stiffness of composite beam also increased by encasement.

TABLE -3 SIMULATION RESULTS OF STEEL, UHPFRC AND COMPOSITE BEAM

| Beam | Ultimate load (kN) | Maximum mid-span deflection (mm) | Failure mode |
|---|---|---|---|
| Steel ISWB 250 | 170 | 7.66 | Web buckling |
| Steel ISHB 200 | 107 | 7.64 | Web buckling |
| UHPFRC | 122 | 7.2 | Shear cracks |
| Composite beam | 1460 | 39.2 | Shear flexural cracks |

The results says that the failure pattern not affected by the a/d ratio and at the same time the deflection of beam affected, but not considerably . Flexural cracks in the bending zone is the reason of failure in all beams, before failure, shear cracks propagated in the critical shear span. All beams (samples considered)) has high ductility before failure. The stiffness and the ultimate load carrying capacity of combined section is inversely propotional to a/d ratio.

TABLE -4 RESULT OF a/d RATIO

| a/d ratio | Load (kN) |
|---|---|
| 1.456 | 1460 |
| 1.856 | 1260 |
| 2.256 | 980 |
| 2.656 | 870 |
| 3.056 | 840 |

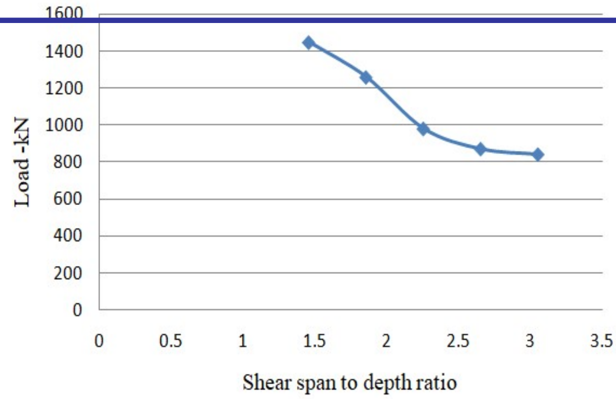


Chart -1 Shear span effect on ultimate load of composite beam

The encased steel beam length varied to 70, 80, 90 and 100% of total length. The results in Table 5 and chart 2 shows that the length of the steel beam effectively affects the behaviour of composite beams, in load-midspan deflection, stiffness, ductility and cracks propagations. When the encasement length was reduced to 10% (ie.,0.9L), the structural response of the composite beam is almost equal because the bonded area between the two elements was same, and the midspan deflection curves of the two composite beams were approximately identical. When the embedded steel section length decreases with respect to UHPFRC beam, area of bonding decreased. In addition, as the reduction in encasement length, the value of bending moment affecting the two ends of the steel section grows.

**Table -5:** Effect of encasement in composite beam

| Length (mm) | Ultimate load (kN) | Maximum deflection (mm) |
|---|---|---|
| 2500 (L) | 1460 | 39.2 |
| 2250 (0.90L) | 1460 | 38.9 |
| 2000 (0.80L) | 1230 | 27.3 |
| 1750 (0.70L) | 680 | 12.8 |

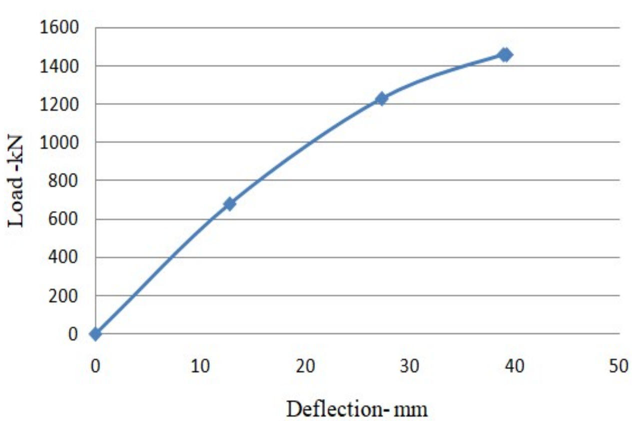


Chart -2 Effect of encasement on load – deflection

## 4. CONCLUSIONS

The conclusions of the study focussed in some specific points, first point is that the UHPFRC-encased steel beams exhibits noticable improvement in failure pattern than individual performance of each material. Shear-flexural cracks is the failure reason of the composite beam and which was due to without local buckling of encased steel section. Secondly, the performance of the composite element was 8.6 times and 12 times higher than (in ultimate load capacity) that of the steel and UHPFRC beams, respectively. Only the combined beam exhibits ductility index before failure in the analysed varied models such as steel beam, UHPFRC beam and composite beam. There is no significant effect with difference in a/d ratio, in deflection at yield. As the a/d ratio increased, the ultimate load capacity and stiffness of composite beams decreased. According to the findings, the encasement effect, the a/d ratio, and the encasement length influence the shear performance of composite beams. These are the main factors that must be considered while design a UHPFRC-encased steel composite beams.

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