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Numerical investigation on the effect of shear connector type on the composite beam behavior under impact load

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Abstract: Composite beams are structural members that consist of a concrete slab lay on a girder and shear connectors link them together. Various types of shear connectors are used in this study the effect of changing the shear connector to angel and head stud connectors was numerically investigated using ABAQUS 2020. The model was calibrated against previous experimental data. It was concluded that the angel gives more load-bearing capacity by 4.6% than the head stud and 3% than the U-shaped shear connector and gives more stiffness than the beam linked by the head and U-shaped. The slip increases as the impact is employed and the slip value increases as the composite beam holds more load and stress

Keywords: Composite beam, head stud, angel connector, impact load

1. Introduction

Composite members comprise two or more different material combinations with differing mechanical characteristics. The physical connection between the distinct elements, known as a bond, is the most significant feature that controls the behavior of composite members. Various strategies must be applied to connect composite member components satisfactorily. Shear connectors are utilized in steel-concrete composite elements to transfer longitudinal shear pressures via the bond region. For this reason, many shears connector forms have been tried. The head stud connector is the most commonly utilized. Various elements influence the functioning of these connectors and determine the alternately interacting reaction of the connector and the surrounding concrete area.[1–4]. An impact load is a brief load that results from a hit or collision with a structure. The impact load can potentially harm the structure, including a reduction in its load-bearing capacity, stiffness, and elasticity. This impact may occur laterally or vertically. [5--11]

Lam and El-Lobidy [12] developed a finite element model (FEM) to study the impact of headed stud (HS) shear connectors on the performance of steel-concrete composite beams. They used non-linear material properties and validated their results with experimental results. theoretical investigation of the behavior of a composite beam joined by stud shear connectors and partially linked under flexural wave propagation was conducted by Hesham [11]. The author disclosed that because composite material combines the properties of many materials to create a component with a large carrying capacity, it can transmit and reflect waves as well as generate minor movements (slip, deflection, and rotation). Wang and Chung [13] used a large numerical program to investigate the entire spectrum of composite beam performance with flexible shear connectors. In their investigation, they used the nonlinearity interface with the nonlinearity material and geometric using two and three-dimensional FEM. Their findings were determined to be quite satisfactory when compared to the experimental findings. The performance of beam-type specimens with L-shaped shear connections under strut compressive stress is studied by Stoy and Shima [14] and the results are compared with FEM results. FEM was used to investigate a variety of parameters, including the strut angle, connector size, and concrete strength. Deng et al.[15] used push-out tests, primarily concentrating on shear resistance and ductile behavior characteristics, to assess the impact of varying the sizes of head studs and transverse rebars on the behavior of the single perfobond rib with head stud shear connector. The test results and values determined by a suggested shear-capacity equation were compared. The results of the studies demonstrate the higher ductility and shear resistance of the single perfobond rib with head stud shear connection. When the diameter of the head stud and transverse rebar increases, the specimens' shear capacity and related relative slip increase but their ductility declines. Khorramian et al [16]. conducted an experimental investigation to examine the behavior of composite beams concerning two inclined angle shear connections. Taking into account the size of shear connectors, two angle connectors with distinct degrees of inclination of 135 and 112.5 degrees. According to the author, the 135 connector has greater strength and rigidity than the 112.5-degree connectors, and load capacity improves with size. Chen et al.'s [17] investigation on the impact of corrosion on composite beam behavior examined the monotonic and fatigue behavior of a composite beam with rusted head studs. The procedure for treating connector corrosion involved immersing the beam in a 5% sodium chloride solution as the cathode, 200µA/cm2 of electric current flowing through it as the anode, and stainless-steel mesh as the cathode. They concluded that while the fatigue load produced stud shear fracture and a 29.69% reduction in the structural fatigue life, the presence of corrosion in the monotonic load caused local buckling. Shariati et al. [18] studied the behavior of C and L-shaped connections through experimental push-out testing. They discovered two failure modes: crushing-splitting of the concrete and shear connector fracture, and they concluded that the C connector has greater strength than the L connector and that decreasing the angle leg size increases the shear strength of the C connector while decreasing the strength and ductility of the L connector. Lowe et al. [19] looked into the longitudinal spelling behavior of the concrete slab under cyclic stress. Using a modified testing equipment, a modified push-out test was used to conduct the investigation. They declared that numerous cycles prevented premature failure of the concrete and enhanced its resistance to longitudinal splitting.

2. Specimen discretion

The finite element model was validated through an experimental study reported by Allawi and Ali [20]. The impact load was the main focus of the test, which was conducted on a pultruded Glass Fiber Reinforced Polymer (GFRP) -concrete composite beam. The specimen is a concrete slab with a compressive strength of 20 MPa that is 500 mm wide, 80 mm long, and 3000 mm thick reinforced with 75 mm-spacing 6 mm bars. As seen in Fig. 1, a pultruded GFRP I-section measuring 100 mm in width, 10 mm in thickness for the top and bottom flanges, and 150 mm in total depth is connected to the concrete slab by an inverted U-hook shear connector with a 12 mm diameter at 300 mm. This will be referred to as the reference beam. The shear connector type was investigated, two shear connectors along to the inverted U-shaped were used which are head stud of 16 mm diameter [21] connector and angel (60x60x6) [16].

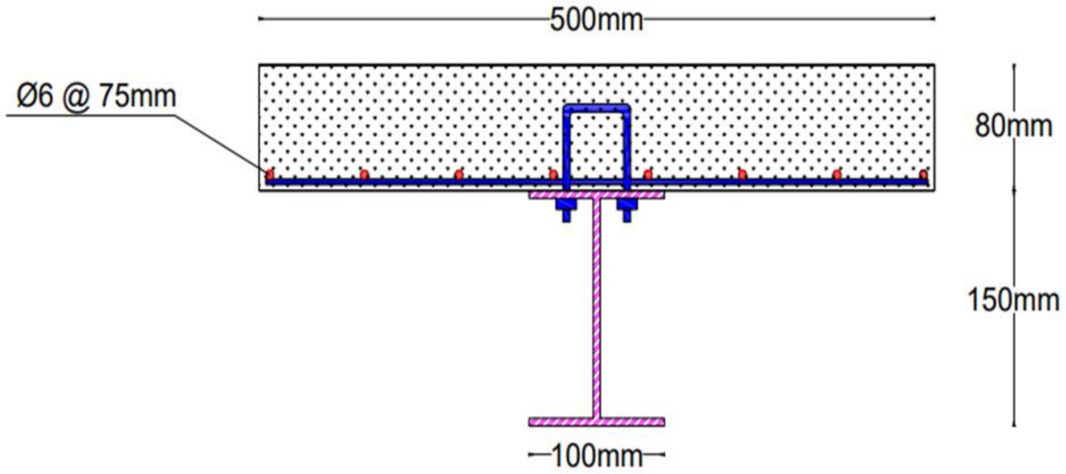


Figure 1. Composite beam cross-section

3. Numerical modeling

Engineers can utilize a wide range of methodologies, and one of the most versatile is Finite Element Analysis (FEA). The most effective engineering analytical techniques for handling complex geometries are numerical methods. The three-dimensional modeling of composite GFRP-concrete beams under impact load was assessed in the current work. Real-time experimental simulation on the beams under investigation was incorporated into the finite element analysis using the ABAQUS 2020 application. 3D stress elements were used to model the composite beams and deck slab, while 3D shell elements were used to model the GFRP. Regular 2D elements were used to model reinforcement steel and shear connectors. The concrete volume was represented using an eight-node solid brick element (C3D8R) with eight node integration points. An embedded truss reinforcement of a 2-node linear truss element (T3D2) was used to mimic longitudinal and transverse steel bars. Steel plates were also modeled using eight-node solid components under applied loads and resistive reactions. The impactor was represented by a 4-node 3-D bilinear rigid quadrilateral (R3D4). It should be noted that in this analysis, the perfect link between the surrounding concrete and the steel bars was assumed. The pultruded profiles with a Linear quadrilateral, type S4R element were modeled with the FRP composite material model (Hashin damage model). Using the damaged plasticity model (DPM), the concrete analysis was conducted. Combining scalar (isotropic) elasticity with non-associated multi-hardening plasticity, this model explains the permanent damage that happens during fracture. Concrete tensile cracking and compressive crushing are the main failure modes in this model [22].

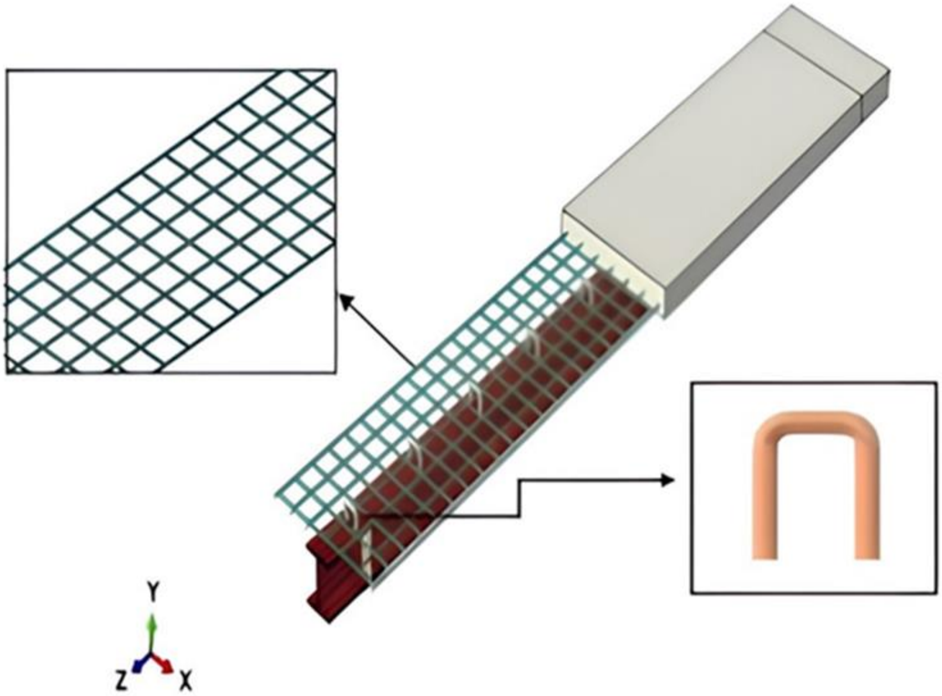


Figure 2. ABAQUS constructed specimen details

4. Loading process and data comparison

The simulated beams were tested in two procedures Pure monotonic load testing was applied to the first group till failure. Every beam in the second group was examined by single hit impact load using a 25 kg mass that fall freely from a height of 2 meters at a speed determined by calculating the equation of velocity equal to the root square [23]. Each beam was then subjected to incremental monotonic load until failure. The computational force was 42 kN, whereas the experimental impact force was 46.5 kN. The experimental and numerical behavior for either a monotonic load or an impact load, as well as the variations between the two behaviors, are made clear by Figs. 3 and 4. only with a monotonic load. The specimens evaluated under the effect of monotonic loads had a maximum percentage error of 5%, whereas the impacted beams had a percentage error of 6.5%. The maximum experimental load was 122.34, whereas the numerical maximum load was 116.51. The numerical maximum load was 90 kN, however the maximum experimental load was 95.85 kN.

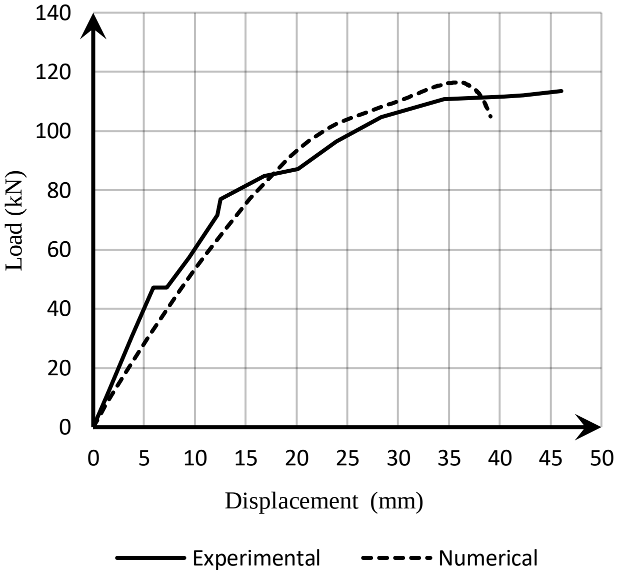


Figure 3. Data comparison for beams under monotonic load

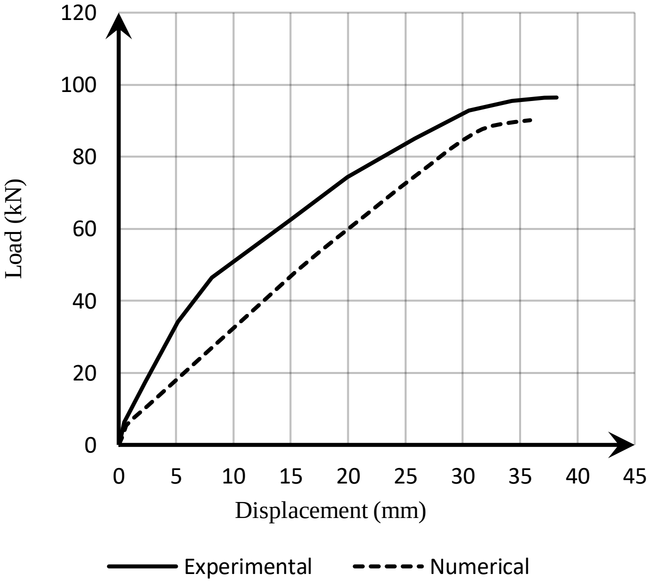
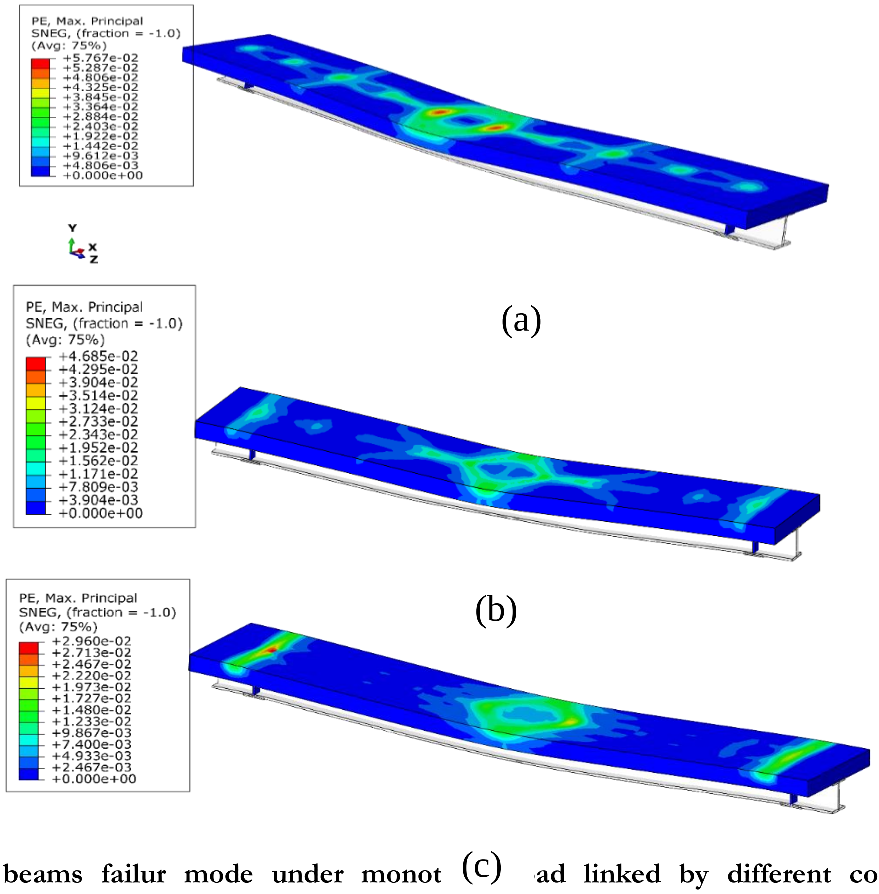


Figure 4. Data comparison for impacted specimens

5. Results and discussion

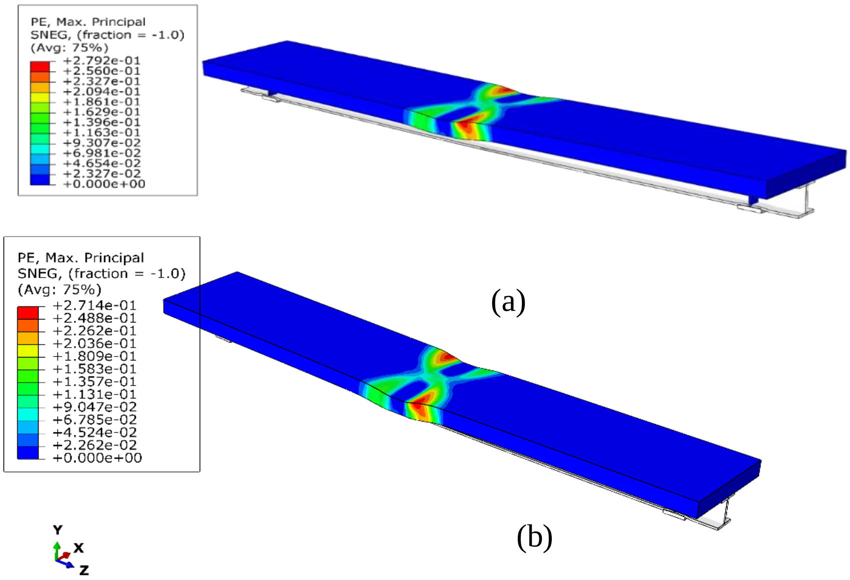
5.1. load deflection behavior and failure mode

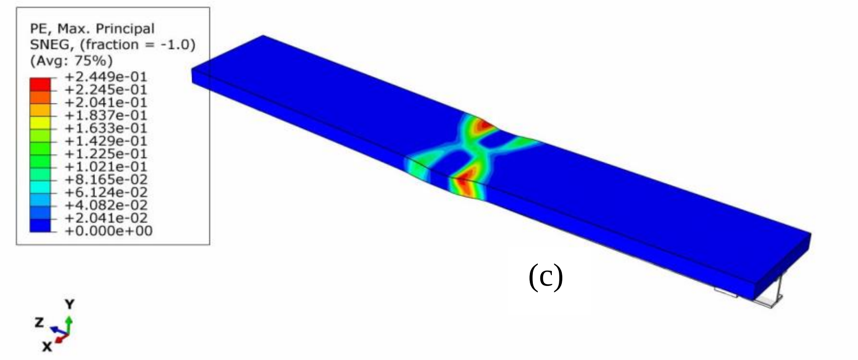
For the reference beam the slab fractures practically extend down the slab and in the vicinity of the connectors when a pure monotonic load is applied. The impact force from the falling mass weakened this area as it gathered around the damaged point. When the headed stud is utilized, the failure mode has altered according to the type of connector employed. Cracks can be visible in the space between the studs in addition to lifting at the edges. With the exception of there being no cracks that spread between connections, the angle connector provided a similar failure mode in the middle and ends of the beam as shown in Fig 5 and 6.



Figuer 5. beams failur mode under monot ad linked by different connectors: (a) U-shaped connector; (b) head stud; (c) angel connector

The failure mode did not change when the impact was applied, and no change in the failure mode of the composite beam was observed.





Figuer 5. beams failur mode of impacted beams linked by different connectors: (a) U-shaped connector; (b) angel connector; (c) head stud

When the reference beam was impacted the load capacity dropped from 116.55 kN to 90.1 kN and the deflection dropped by 14% The load-displacement behavior of the composite beam is explained in Fig. 6 according to the shear connector that was used. When there is no impact, it is evident that the load carrying capacity of an angel connection is larger than that of a U-shaped connector and a stud by 3% and 4.6%, respectively, since more area of the angel connectors is in touch with the concrete slab and section. When the angle is utilized, the stud's deflection is reduced by 18% and by 25%, respectively. Using the stud reduced the load by 22% and using the angel, by 18%, when the impact load was applied. Because of the collision, the deflection was lessened by 7.6% and 15% on the stud and angel connector, respectively.

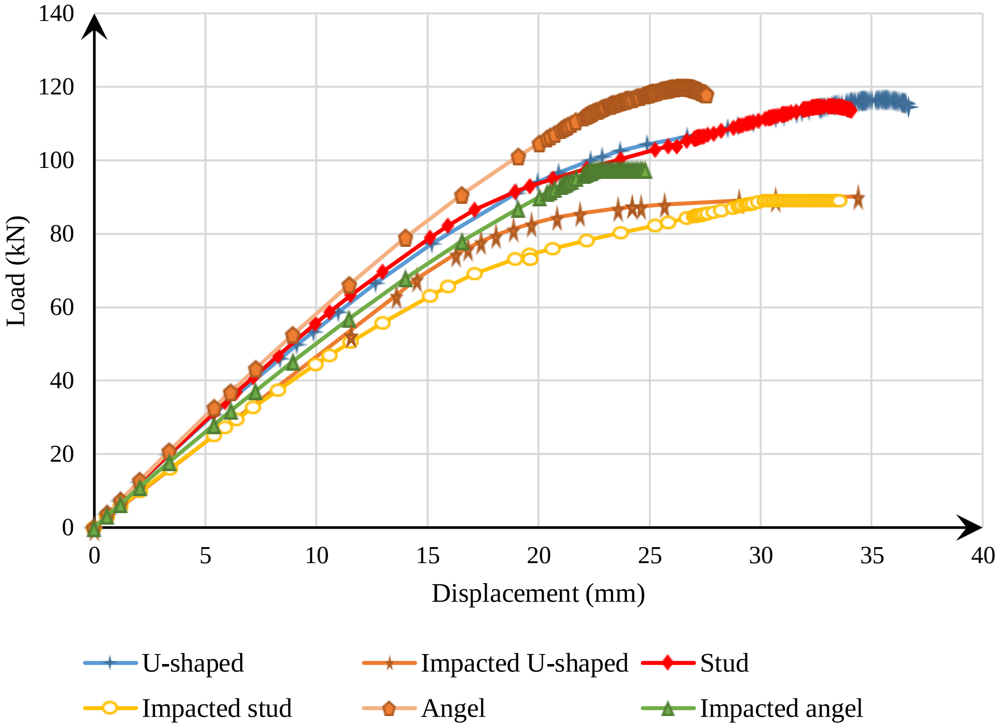


Figure 6. load displacement behavior for composite beam response to different shear connectors

5.2. Ductility and stiffness

Whether an impact was there or not, the composite beam with the U shear connector had the most ductility. Due to the stud's quicker failure rate and the angel's brittle behavior, there is less of a reduction in impact when both are utilized. Where the ductility reduced by 19% and 10% and 8% for the U shear connector and angel and stud respectively. When using an angel shear connection, the composite beam has the highest stiffness and the lowest stiffness value. When using a stud, the stiffness is lowered by 14%, and when using an angel, it is reduced by 17%. And it reduced by 27% for the reference beam. Tabel.1 clarifies these values and the reduction in it.

Tabel 1 Ductility and stiffness values

Specimen	Maximum load (kN)	Ductility	Ductility reduction	Stiffness	Stiffness reduction
U-shaped	116.8	2.25	19%	5.44	27%
Impacted U-shaped	90.1	1.821		3.986	
Stud	114.814	1.932	10%	5.21	14%
Impacted Stud	89.815	1.733		4.49	
Angel	119.93	1.614	8%	5.87	17%
Impacted Angel	97.62	1.479		4.89	

5.3 Composite action

The slide that transpired in the interface was estimated using the axial strain. For each element independently, the strain was measured from two different locations. The overall findings showed that increasing the load and applying impact significantly increased the motion between the slab and the section connected to it. This can be explained by the impactor causing damage to the slab by weakening the bond between the composite beam members. Observing Fig. 7, it is evident that the angel connector yields the highest slip value since the U-shaped connector had a good yield strength and the composite beam connected by the stud fails under stress the quickest.

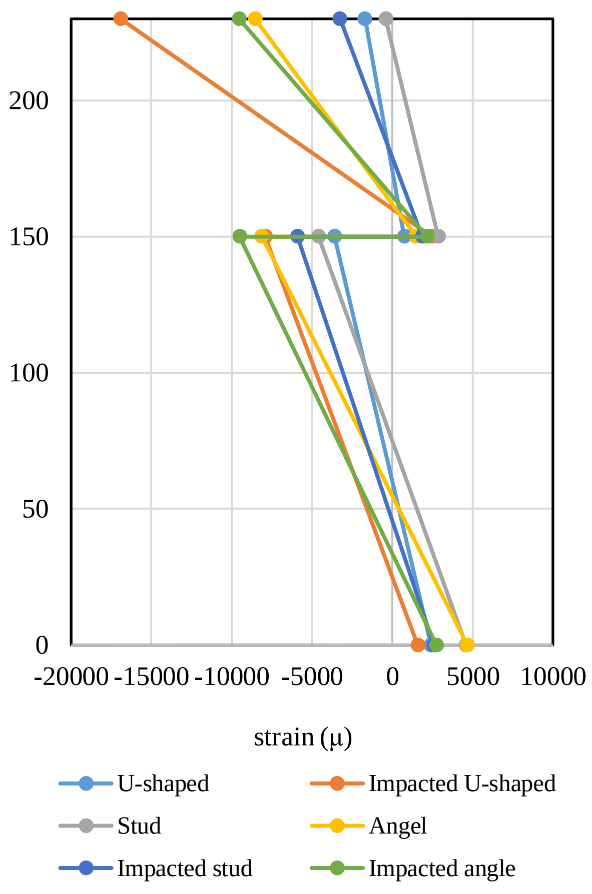


Figure 7. Effect of the shear connector type on the interface motion

6. Conclusion

This research presented a numerical investigation of the effect of connector type on the composite beam using the finite element software ABAQUS 2020. The major conclude remarks can be surmised as follow:

- The overall structural behavior of composite beam is highly influenced by the impact in terms of stiffness and ductility and slip.
- The composite beam bearing capacity is higher when the angel connector is used by 3% than the U-shaped connector and 4.6% than the stud.
- The composite beam linked by the U shear connector gave the best ductility and the angel connector gave the best stiffness
- The angel connector gave largest slip since more stress can be held by the beam before failure.

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