NUMERICAL BEHAVIOR OF COMPOSITE BEAM UNDER MID SPAN LOADING

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ABSTRACT

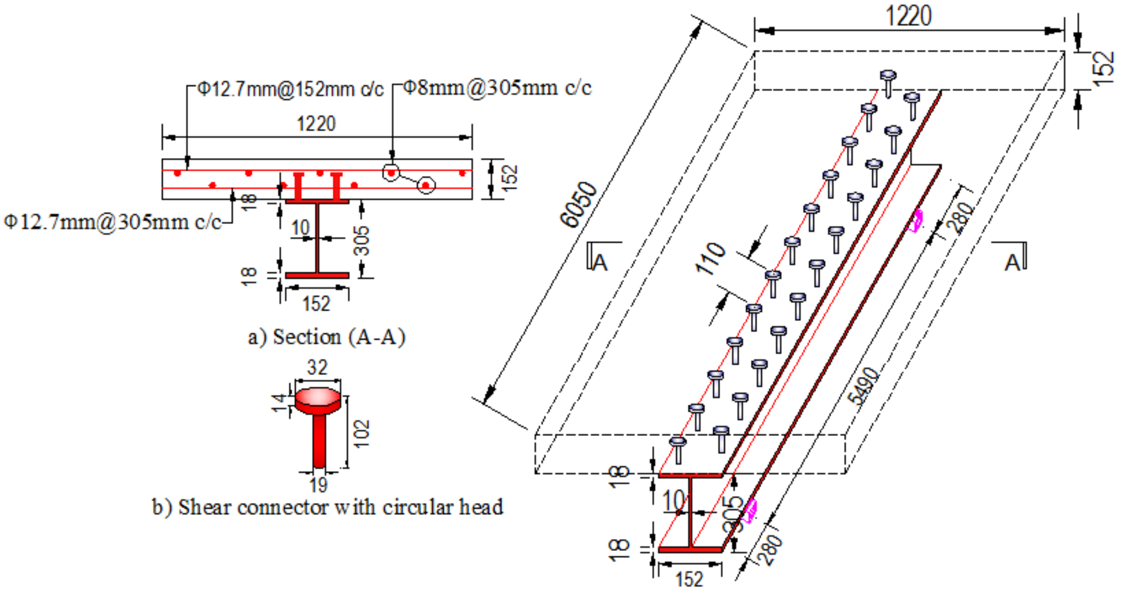
Composite structures are widely used in civil engineering construction throughout the world. A composite structure is defined by the interaction of two or more elements acting together as a single element. In a steel-concrete composite beam, the bonding between the steel and the concrete is established by the headed stud shear connector. It creates composite action by resisting the longitudinal sliding and uplifting between the steel beam and concrete slab. This composite structure provides higher strength and stiffness. In this perspective, a three-dimensional numerical model of a steel-concrete composite beam is prepared by ANSYS V15.0 software based on the Finite Elements Method. The model presented here has been investigated by Chapman and Balakrishnan experimentally. The numerical results had been compared with experimental findings. Based on the numerical model and its results obtained using finite element software ANSYS well agree with the experimental results.

Keywords: *Composite structure, Headed stud shear connector, ANSYS, Finite Elements Method.*

1. INTRODUCTION

Steel concrete composite structure has been recognized since 1940 as one of the most economical systems for Civil Engineering construction in developed and developing countries. This is due to smaller structural sections, savings in steel weight, and rapid construction programs. The presence of a shear connection between the concrete slab and the steel beam determines the behaviour of a steel-concrete composite beam. The shear connection prevents interface sliding and allows the concrete slab and steel beam to interact with each other. As a result, resultant compressive and tensile forces are generated in the slab and beam, respectively. There will be no composite action if the slab is not attached to the steel beam via shear connectors. In that case, the contribution of the concrete slab can usually be neglected. Then the ultimate load of composite beam are equals to the ultimate capacity of the steel beam individually.

A number of researchers who worked on composite beams experimentally are Hafez et al. (2012), Loqman et al. (2018), Zhao and Yuan (2010), and Rehman (2017). On the other hand, Patil and Shaikh (2013), Pandilatha et al. (2017), Ibrahim and Ahmed (2013), Prakash et al. (2011), and Kotinda (2006) investigated the steel-concrete composite beam behaviour numerically. The numerical models developed in this study were compatible with the experimental investigation presented in Chapman and Balakrishnan (1964) for model beam "A3". The geometry of the beam "A3" model is shown in Figure 1. The total length of the beam is 6050 mm, the width of the beam is 1220 mm, and the thickness of the slab is 152 mm. The slab is double reinforced, with a steel joist depth of 305 mm and top and bottom flange widths of 152 mm. The thickness of flange and web is 18mm and 10mm respectively. A headed stud shear connector is used having a diameter of 19mm provided in two rows. The total numbers of shear connectors were 68 nos. The beam supports status is simple supported with mid span concentrated load. The experimental research is the main source for investigating the flexural behaviour of composite constructions or its components.

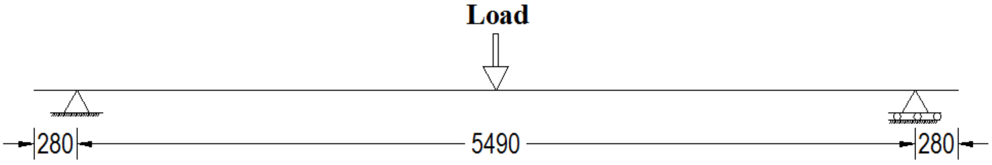


a) Section (A-A)

b) Shear connector with circular head

Isometric View

Note: all dimensions are in mm



c) Support condition

Figure 1: Geometry of the composite beams

However, it is widely accepted that laboratory tests are more time-consuming mater and are more costly. The finite element approach is a significant tool to observe the behaviour of wide range of engineering applications. Once the simulation model is developed, it will be easy to check the influence of any alteration of the geometry of the specimen, such as size, shape, thickness, and so on. Changing any structural part is also very easier than experimental study.

2. FINIT ELEMENT MODELING

The numerical simulation was done using pre-defined elements from the ANSYS library. The modeling strategy and the choice of the elements were adopted from numerical analysis developed by Kotinda (2006). The different type of elements considered for numerical analysis are described in the succeeding section.

2.1 Concrete Element (SOLID 65)

The concrete slab was modeled using SOLID 65 element. The element contains eight nodes, with three degrees of freedom for every node and translation in the x, y, and z directions. The Mander equations are used to calculate the stress-strain curve of concrete, which is considered to be a uniform isotropic material as shown in Figure 2. The Equations (1) and (2) define the Mander stress-strain curve for unconfined concrete:

For $\varepsilon_c \leq 2\varepsilon_c'$ (curve portion)

$$f_c = \frac{f_c' \, xr}{r - 1 + x^r} \tag{1}$$

where

$$x = \frac{\varepsilon_c}{\varepsilon_c'} \quad \text{and} \quad r = \frac{E_c}{E_c - \left(\dfrac{f_c'}{\varepsilon_c'}\right)}$$

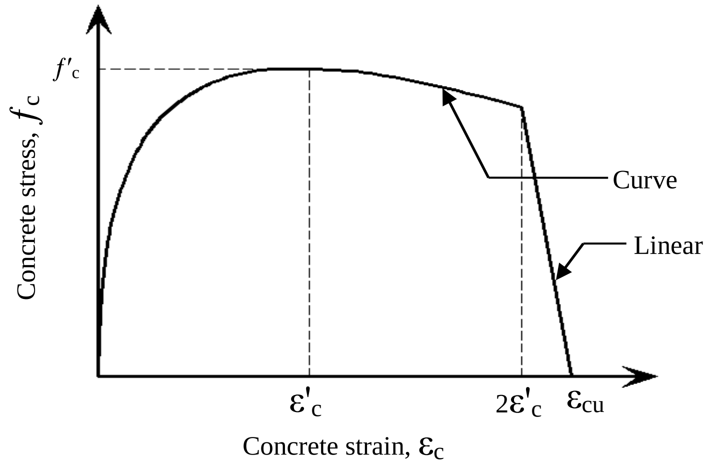


Figure 2: Mander unconfined stress-strain curve for concrete

For $2\varepsilon_c' < \varepsilon_c \leq \varepsilon_{cu}$ (linear portion)

$$f_c = \left(\frac{2 f_c' \, r}{r - 1 + 2^r}\right)\left(\frac{\varepsilon_{cu} - \varepsilon_c}{\varepsilon_{cu} - 2\varepsilon_c'}\right) \tag{2}$$

where r is as defined previously for the curved portion of the curve. f_c= Concrete stress (MPa), ε_c= Concrete strain, E_c= Modulus of elasticity of concrete (MPa), f'_c= Concrete compressive strength (MPa), ε'_c= Concrete strain at f'_c, and ε_{cu}= Ultimate concrete strain capacity.

2.2 Structural Steel (SHELL 43)

The steel I-beam is modelled using a 4-node shell element (SHELL43), where each node containing six degrees of freedom. The element includes translations and rotations in the nodal x, y, and z directions. The steel yield strain, ε_{sy} is determined from $\varepsilon_{sy} = f_{sy} / E_s$, where, ε_s = Steel strain, f_s = Steel stress (MPa), E_s = Modulus of elasticity of steel (MPa), f_{sy} = Steel yield stress (MPa), f_{su}= Steel maximum stress (MPa), ε_{sh}= Strain at onset of strain hardening, ε_{su}= Strain corresponding to steel maximum stress, ε_r = Strain at steel rupture. The following equations define the simple parametric stress-strain curve for the structural steel.

For $\varepsilon_s \leq \varepsilon_{sy}$ (elastic region),

$$f_s = E_s \varepsilon_s$$

For $\varepsilon_{sy} < \varepsilon_s \leq \varepsilon_{sh}$ (perfectly plastic region),

$$f_s = f_{sy}$$

For $\varepsilon_{sh} < \varepsilon_{st} \leq \varepsilon_r$ (strain hardening and softening regions),

$$f_s = f_{sy}\left[1 + r\left(\frac{f_{su}}{f_{sy}} - 1\right)e^{(1-r)}\right] \tag{3}$$

where,

$$r = \frac{\varepsilon_s - \varepsilon_{sh}}{\varepsilon_{su} - \varepsilon_{sh}}$$

The equation (3) defines the simple parametric stress-strain curve for the structural steel as shown in Figure 3.

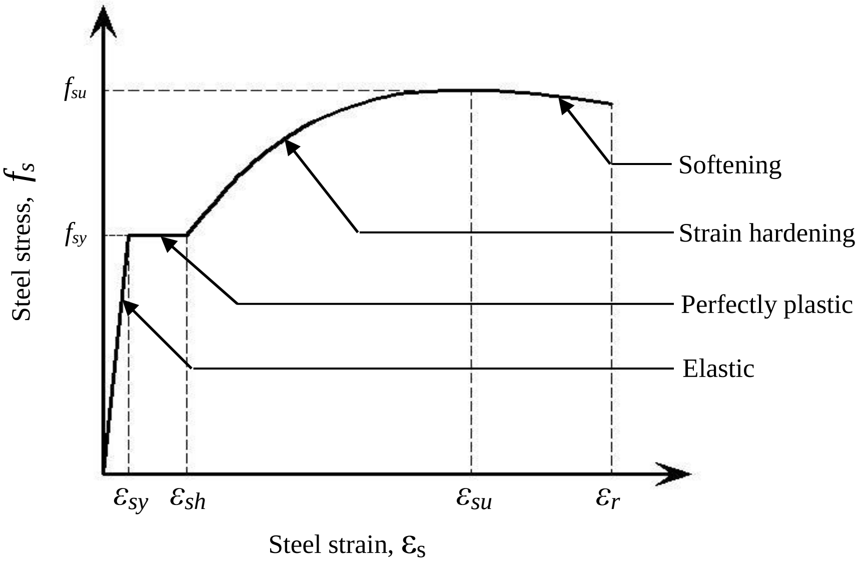


Figure 3: Structural steel parametric stress-strain curve

2.3 Shear Connector (BEAM 189)

The stud shear connector was modelled using the three-node beam element BEAM 189, which has six degrees of freedom at each node. The element contains rotations and translations in the x, y, and z directions. A bi-linear model with isotropic hardening used for shear connectors based on the von Mises criterion.

2.4 Reinforcing Bar

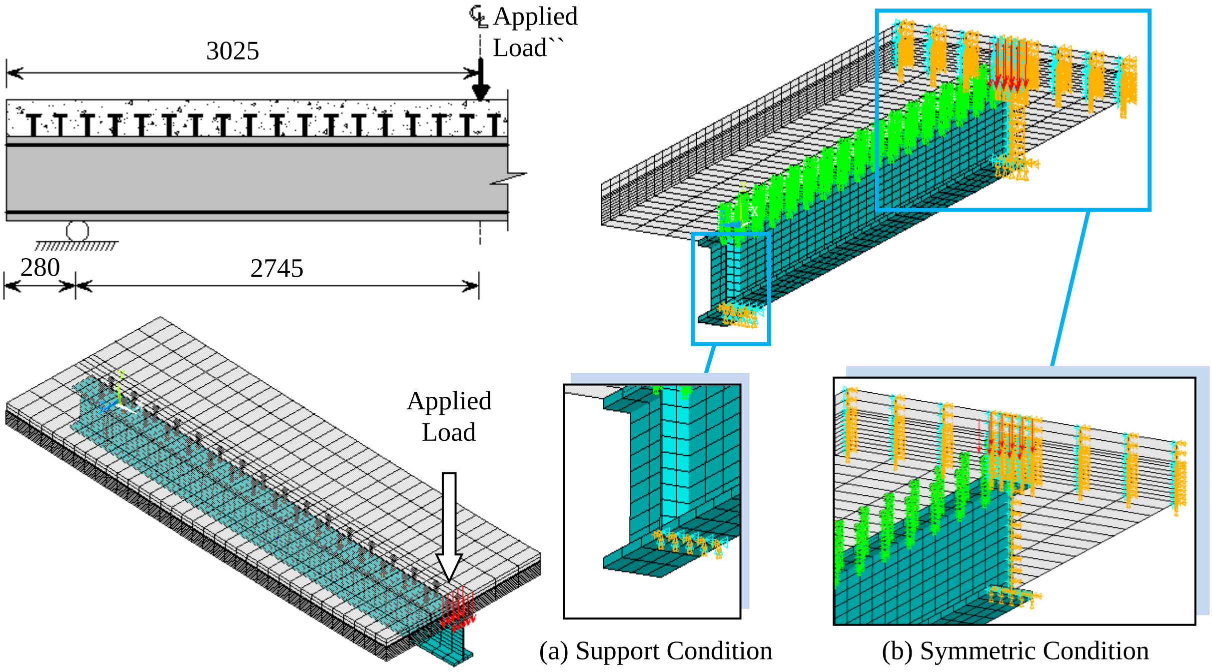
In this case the layer of reinforcement has been introduced as a real constant in SOLID 65 element. A perfect elasto-plastic model has been used for the reinforcing steel follows the von Mises criterion. The material properties and volume ratio are given as real constants. The volume ratio is calculated by dividing the rebar volume by the entire reinforcing layer volume.

2.5 Contact Characteristic (TARGE170 and CONTA173)

The TARGE170 and CONTA173 elements establish the contact among the slab and steel beam interface. When two surfaces come into contact, pressure is developed, and pressure becomes zero when they are separated. Besides simulating the pressure characteristics, this element may also model the friction and cohesion between both the concrete slab and steel beam interface.

2.6 Finite Element Meshing and Boundary Conditions

In numerical analysis, the mesh size must have fine and consistent in order to have great detail where information is necessary; nevertheless, very fine mesh may require a long time to analyze. In this investigation symmetric half portion of the beam has been considered for modelling because of reducing the elements and computational time. The load was applied in two steps. At the first step, it was considered the weight of the structure itself as the gravitational load. In the second step, applying the external load, concentrated in mid-span between two supports of composite beam as shown in Figure 4.



(a) Support Condition

(b) Symmetric Condition

Figure 4: Symmetric half of the composite beam with single point concentrated load

3. NUMERICAL RESULT

The vertical deflection under concentrated load at mid-span was the initial parameter used for the validation of numerical model; additionally relative end slip of composite beam has also been investigated.

3.1 Vertical displacement at mid-span concrete

To obtain the load-deflection curve, the applied load and the corresponding vertical displacement at the mid section are measured at each sub-step. The load-deflection curve is developed by plotting the applied load corresponding to the mid-span deflection. Figure 5. shows load verses deflection curve of composite beam, and the obtained curves compared well with the value reported by Chapman and Balakrishnan (1964). Figure 5. illustrates that the experimental and numerical results are equivalent up to the elastic range.

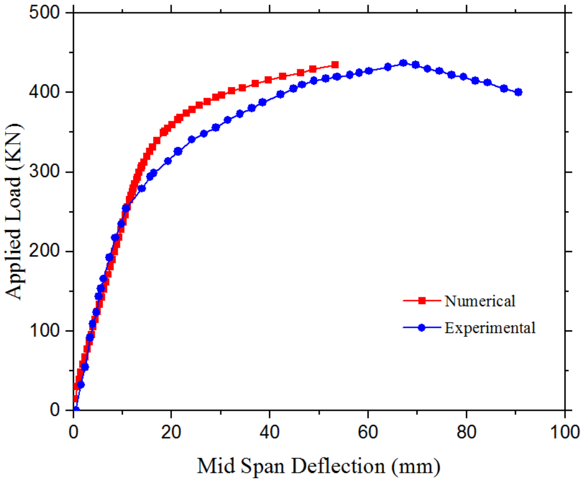


Figure 5: Load-deflection relation of the composite beam

Table 1 compares the values of experimental ultimate load with the same values obtained from numerical analysis. It demonstrates that the percent of variation between the numerical and experimental results is about 0.68% that indicates both results are well agreed. The maximum deflection at ultimate load obtained numerically at mid-span is found to be about 53mm which is lower than the experimental value of 67mm. The elastic strain energy at mid section was found 2050 kN-mm. The load deflection curve provides a result up to the yield point because the ANSYS APDL static solver has limitations while modelling negative transitions of curves. The input parameter in the model given up to yield point without considering the damage behaviour.

Table 1: Variation of ultimate load with maximum deflection

Composite Beam Model	**Experimental Ultimate Load Pu,exp (KN)**	**Numerical Ultimate Load Pu,num (KN)**	**Experimental Deflection at Ultimate Load Δu,exp (mm)**	**Numerical Deflection at Ultimate Load Δu,num (mm)**	**(Pu,exp ⁄ Pu,num)**	**Ultimate Load Variation (%)**
Beam (A3)	437	434	67	53	1.007	0.68 %

3.2 Longitudinal Slip at the End of the Beam

The relative slip between the concrete slab and the I-Steel joist was calculated numerically as the difference between the nodal displacements in the x-direction (Ux) at the concrete and steel joists, is illustrated in Figure 6.

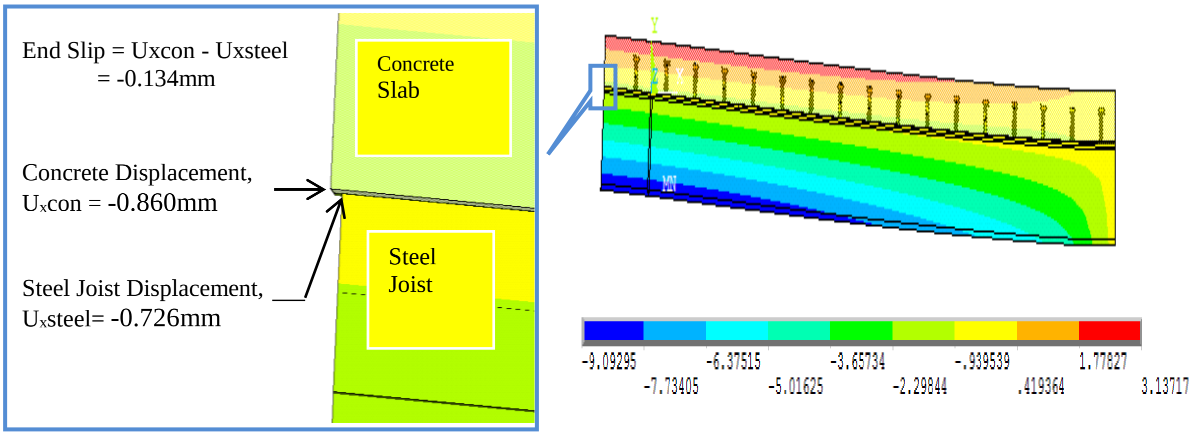


Figure 6: Relative end slip between concrete slab and steel joist of composite beam

The relative slip is plotted against the applied load, providing the load versus slip diagram as illustrated in Figure 7. According to the load-slip diagram, for both the experimental investigation and the numerical simulation, the average relative sliding remains null until a particular load of 331.4 KN. Beyond this load level, the bonding between concrete and steel in the interface begins to reduce and initiate relative shear movement or sliding.

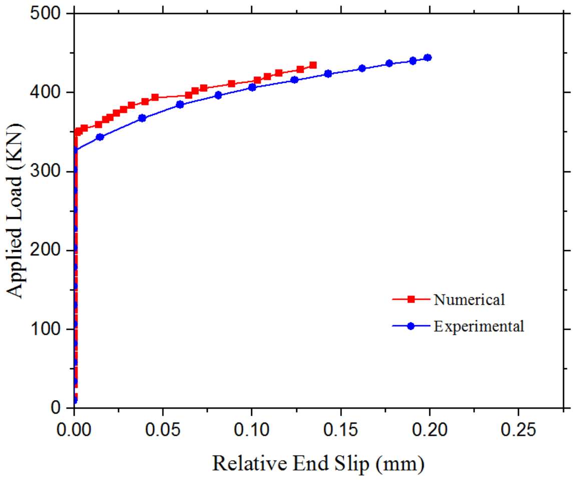


Figure 7: Load-slip relation of composite beam

The numerical model shows a slightly lower slip, while the sliding resulted in the experimental model being 24.09% higher as shown in Table 2.

Table 2: Variation of ultimate load with maximum slip

Composite Beam Model	**Experimental Ultimate Load Pu,exp (KN)**	**Numerical Ultimate Load Pu,num (KN)**	**Experimental End Slip at Ultimate Load Ux,exp (mm)**	**Numerical End Slip at Ultimate Load Ux,num (mm)**	**End Slip Variation (%)**
Beam (A3)	437	434	0.1772	0.1345	24.09 %

The validation of the results demonstrates that it is possible to numerically simulate an experimental model using the finite element software ANSYS and the results are acceptable. According to load-deflection in Figure 5 and load-slip in Figure 7, it may be concluded that the numerical model done using FE software ANSYS simulate experimental result well. Although little deviations are observed, that's are most likely caused by differences in numerical convergence and the adopted modelling strategy.

3.3 Mid Span Stress Distribution along the Depth of Composite Beam Section

The normal stress distributions along the beam cross-section at mid-span of the composite beams ″A3″ is shown in Figure 8. Stress distribution along ordinate, above neutral axis the compressive stress carried by concrete slab and the tensile stress below neutral axis carried by steel joist. The stress distribution of composite beam differs from normal concrete beam because of composite action. The stress distribution under a number of loads is shown in Figure 8.

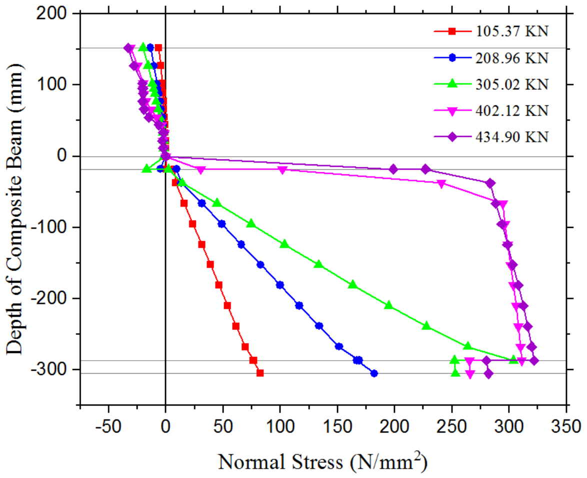


Figure 8: Mid span stress distribution along the depth of composite beam section

4. CONCLUSION

The following are the main conclusions obtained from the results of finite element analysis:

(i) According to numerical simulation of steel-concrete composite beam, the load-deflection are found well agreed with experimental results investigated by Chapman et al. (1964). These results demonstrated the accuracy and effectiveness of the developed numerical model.

(ii) In numerical analysis, no relative end slip was occurred up to a load level of 331.4 KN, and at ultimate load level, the relative end slip decreases by 24.09% as compared to the experimental results of Chapman et al. (1964)

(iii) The ANSYS APDL static solver has limitations while modelling negative transitions of curves. The input parameter in the model given up to yield point without considering the damage behaviour. Therefore, the load deflection curve provides a result up to the yield point.

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