Nonlinear Analysis of Composite Beams under Negative Bending Moment

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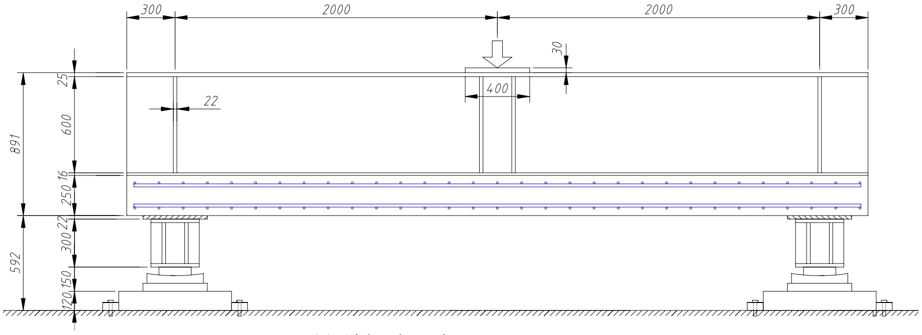
1. Introduction

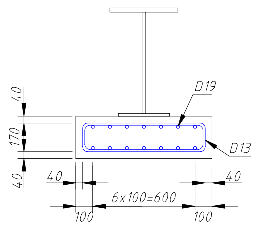
Composite steel-concrete structures are being widely used both in buildings and bridge structures due to their combination of component materials' advantages and obtaining efficient lightweight structural members. For simply supported composite beams, the ultimate capacity is usually governed by either positive moment or longitudinal shear capacity, which will be determined by the compressive strength of the concrete and tensile strength of the steel girder. However, there will be some differences for support regions of continuous composite beams, in which the concrete slab is usually in tension and the lower flange of the steel girder is in compression, resulting in some shortcomings in view of the durability and service life of the structures. Experimental studies have been done widely, but very few numerical studies were conducted on this important aspect until recent years. Similar studies have been performed by Fabbrocino et al.[1)], Nie et al.[2)] , Loh et al.[3)], Lääne et al.[4)], Nguyen et al.[5)]. This study aims to perform a comprehensive investigation to clarify the ultimate behavior of composite girders subjected to hogging bending moment by using the finite element method. Experimental results were also given to verify the presented numerical results.

2. Description of Test Specimen and Test Setup

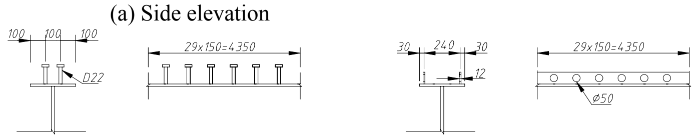
Two overturned simply supported composite steel-concrete beams CBS and CBP were tested under point load in mid-span. CBS was designed with studs as shear connectors while CBP was designed with PBLs as shear connection devices. Each of the specimens was 4600mm in length and was simply supported at a span of 4000mm. The concrete slab thickness was 250mm with a width of 800mm. Point load was applied at the mid-span. 22mm nominal diameter headed shear studs and 12mm thickness PBLs were used to connect the concrete slab and the steel girder. The typical geometry of the test specimen is shown in **Fig.1**.



(a) Side elevation



(b) Cross-section



(c) Shear connectors

Fig.1 Dimensions of test specimen and Test setup

3. Model Building

The modeling of the test specimen is carried out in three dimensions by using the finite-element method and the *DIANA* software. Solid elements, shell elements and spring elements are used to simulate the concrete deck, steel girder, PBLs and studs respectively. Also, in order to account for the slip between concrete slab and steel girder, interface elements are used in this model. The material tests for concrete and steel are performed, and the generated data are employed in the finite element analysis to simulate material properties of the concrete slab, steel girder and PBLs. Shear force-slip behavior of shear studs suggested by Ollgaard[6)] and Interface data suggested by Kouzuki[7)] are also adopted. Finite element model used in this study is shown in **Fig.2**. [1]

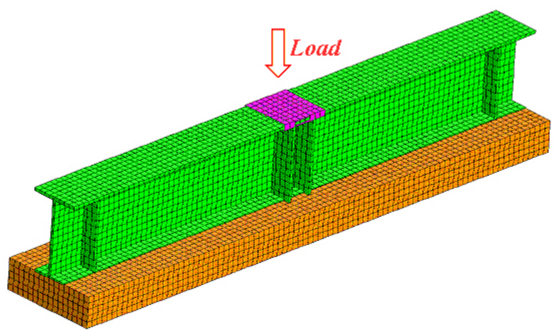


Fig.2 FE model of test specimen

4. Results and Discussion

4.1 Strength and deformation response

The load-displacement curve obtained from the numerical analysis is compared with the experimental data as shown in **Fig.3**. Both numerical and experimental displacements are taken from the vertical deflection at the bottom mid-point of each

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test specimen. It is found that in the linear region, the load-displacement curve from numerical studies agrees well with the measured results. However in the nonlinear region, the response of FE model changes with increasing displacements compared to the test girder. This is presumably because the residual stress is not considered in the finite element analysis, which may result in slightly larger stiffness of FE model than that of the test girder. Moreover, comparison of load-deformation response of each specimen indicates that the displacement of CBP become a little less at around 1000kN than those of CBS, which is presumably because the PBL dowels affect the rigidity of the entire girder when cracking has progressed to a certain extent.

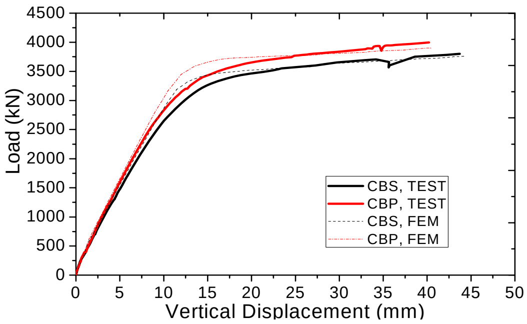


Fig.3 Load-deflection relationship

4.2 Movement of cross-sectional neutral axes

Fig.4 illustrates the movement of sectional neutral axis in both linear and nonlinear stage for each specimen. Measured section locates at 60 cm from the span center. It can be seen that when load is smaller than the initial cracking load, the composite neutral axis is similar to the calculated elastic neutral axis, and then moves towards the plastic neutral axis as the load increase. But in the experiment, the composite neutral axis seems to move earlier than in the numerical and theoretical analysis. This is because the experimental initial cracking load from the test is much smaller than that of the numerical and theoretical values, shown as **Table 1**.

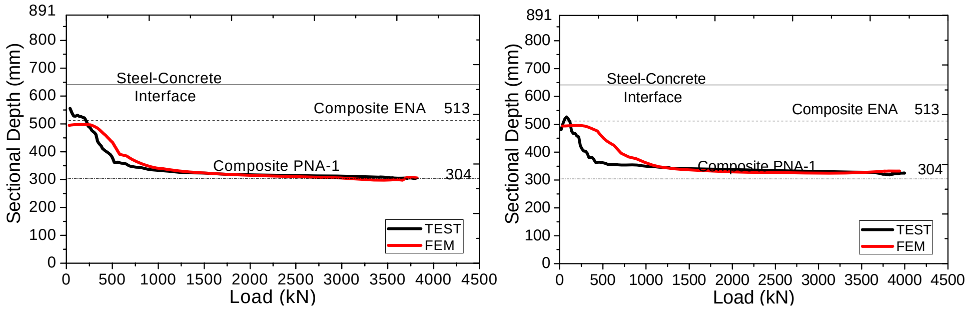


Fig.4 Sectional strains distribution and movement of neutral axis of CBS and CBP

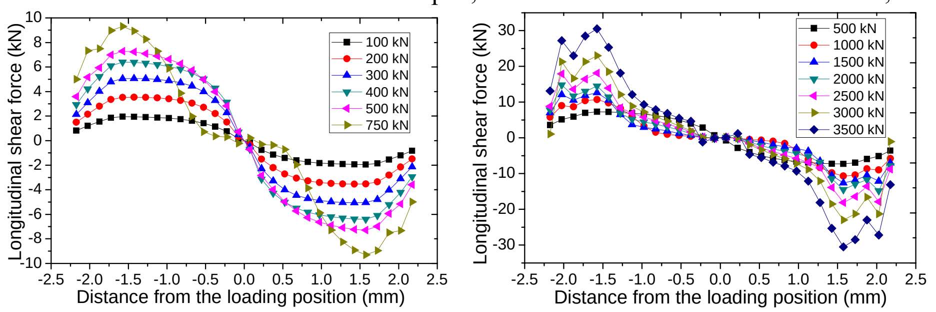
Table.1 Initial cracking Load

Specimen	Initial cracking Load (kN)		
	$P_{c,e}$	$P_{c,t}$	$P_{c,f}$
CBS	140	247	207-236
CBP	120	247	224-255

Note: $P_{c,e}$, $P_{c,t}$ and $P_{c,f}$ = Experimental, theoretical and numerical values of initial cracking load

4.3 Longitudinal shear force of stud

Fig.5 shows the longitudinal shear force of shear studs in both elastic stage and plastic stage of CBS. Numerical results show that: (1) in elastic stage, longitudinal shear force distribution of shear studs is similar to that of the shear force distribution of composite girders, and shear force of stud increases linearly with the load increase; however, (2) in plastic stage, longitudinal shear forces between studs in different locations will redistribute. In the mid-span, where the most serious crack occurs, the longitudinal shear force will decrease as the load increase, which might be caused by the cracking of the concrete slab.



(a) Elastic stage (b) Plastic stage

Fig.5 Longitudinal shear force distribution of stud in CBS

5. Conclusions

On the basis of the numerical and experimental results, conclusions can be drawn as follows: (1). The PBL connectors could slightly improve the rigidity of the composite girder under both the serviceability limit state and the ultimate limit state in comparison with stud connectors. (2). It is considered that composite neutral axis moves between the cross-sectional elastic neutral axis and the plastic neutral axis. (3). In ultimate state, the longitudinal shear forces of studs in negative bending moment region are very small and affected by the cracking of the concrete slab.

6. References

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