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Application of a newly puzzel shaped crestbond rib shear connector in composite beam using opposite T steel girder: A parametric study

Ứng dụng liên kết kháng cắt kiểu mới Crestbond hở trong dầm liên hợp sử dụng dầm thép hình chữ T ngược: Phân tích phần tử hữu hạn

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ABSTRACT:
In this study, results from experiments on the behavior of crestbond-type bonds were performed. Then, this type of connection is applied to composite beams, steel beams, reinforced concrete slab, to analyze the behavior of the composite structure. The 3D finite element model of the 4-point bending test is applied to carry out the research. The behavior of displacement, relative sliding between steel beam and reinforced concrete slab, concrete deformation, steel beam deformation, failure mode are analyzed and compared in detail. In addition, the influence of the degree of connection, concrete strength, and size of the slab cross section are also included in the analysis. The obtained results show that the simulation model has achieved high reliability with experimental results. The COMBIN39 element is precise enough to reflect the nature of the Perfobond connector.
Keywords: Crestbond rib shear connector; FEM analysis; concrete-steel composite beam; composite behavior; loading test; shear resistance formula.

TÓM TẮT:
Trong nghiên cứu này, kết quả từ thí nghiệm về ứng xử của loại liên kết dạng crestbond đã được thực hiện. Sau đó, loại liên kết dạng này được ứng dụng vào dầm liên hợp dầm thép sàn bê tông cốt thép, nhằm phân tích ứng xử của kết cấu liên hợp. Mô hình phần tử hữu hạn 3D về thí nghiệm uốn 4 điểm được áp dụng để thực hiện nghiên cứu. Ứng xử về chuyển vị, trượt tương đối giữa dầm thép hình và sàn bê tông cốt thép, biến dạng của bê tông, biến dạng của dầm thép, dạng phá hoại được phân tích và so sánh chi tiết. Bên cạnh đó, ảnh hưởng của mức độ liên kết, cường độ bê tông, kích thước của tiết diện bản sàn cũng được đưa vào phân tích. Kết quả thu được cho thấy, mô hình mô phỏng đã đạt được độ tin cậy cao với kết quả thí nghiệm. Phần tử COMBIN39 là đủ chính xác để phản ánh bản chất của trình kết nối Perfobond.
Từ Khóa: Liên kết kháng cắt Crestbond; phân tích phần tử hữu hạn; kết cấu liên hợp bê tông - thép; ứng xử kết cấu liên hợp; thí nghiệm gia tải; công thức tính phản lực cắt

1. INTRODUCTION

The Perfobond rib shear connector was first developed by (Leonhardt *et al*. 1987). After this, many researchers examined its composite behavior and shear strength for applications to composite or mixed structures to take advantage of its higher shear resistance strength, easy fabrication [1-3] Modified Perfobond rib connectors were also suggested by several researchers [4]. Then, the composite behaviors and shear strengths of a T-shaped Perfobond rib, Y-shaped Perfobond rib [5-6], Y-shaped Perfobond with open holes [7] were examined.

Among the newly modified Perfobond rib shear connectors, a Perfobond with open holes is called a crestbond rib because of its appearance. This crestbond rib (Perfobond with open holes) shear connector allows the easy installation of rebar because of its open rib holes. In addition, it has a higher shear resistance strength than a typical Perfobond rib. Bui (2010) carried out a detailed study of structural composite beams with typical Perfobond ribs and crestbond ribs using ultra-high-performance concrete (UHPC) with a compressive strength of 140–180 MPa.

However, the experiment procedures will take long time, and spend a lot of money, even be impractical. Therefore, the finite element method (FEM) has performed, nowadays, almost of major field of engineering problems applied the FEM method to study and support for testing in the laboratory. In case of composite structures, the application of FEM is so widely and popular.

Previous FEM studies have been carried out to investigate the behaviour of composite beams. Nevertheless, most of them are based on two-dimensional analytical models [9-10] these investigations have shown that some tendencies already established in the literature regarding beams with full shear connection are not applicable to cases with partial shear connection. However, two-dimensional analytical models was still limited, thus not able to describe the complex behavior of composite beam that are full distribution of stresses and strains over the entire section of the structural components (steel beam and concrete slab), evolution of cracks and local deformations in the concrete slab.

In this study, three-dimensional FEM models of composite beam were developed continuously, in which all the main structural parameters and associated nonlinearities are included (concrete slab, steel beam and shear connectors).The goals of this study include:

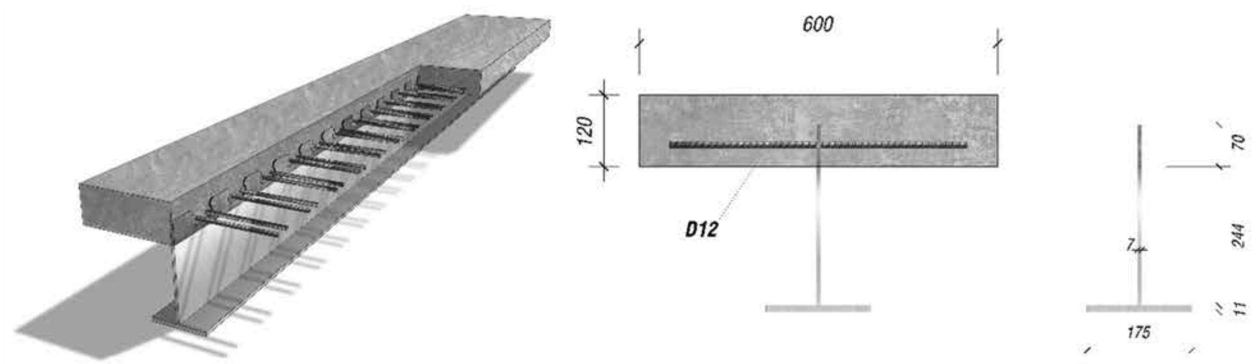
• All the main structural parameters and associated nonlinearities are included

• The application of FEM analysis to replace the experiment on the real composite beam based on the fully three-dimension FEM model.

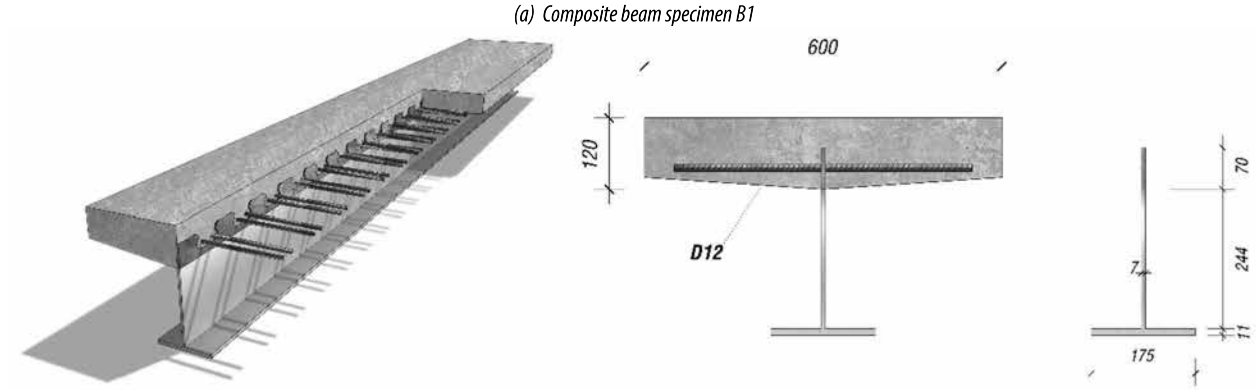
2. SUMMARY OF EXPERIMENTAL PROGRAM

2.1 Test specimens

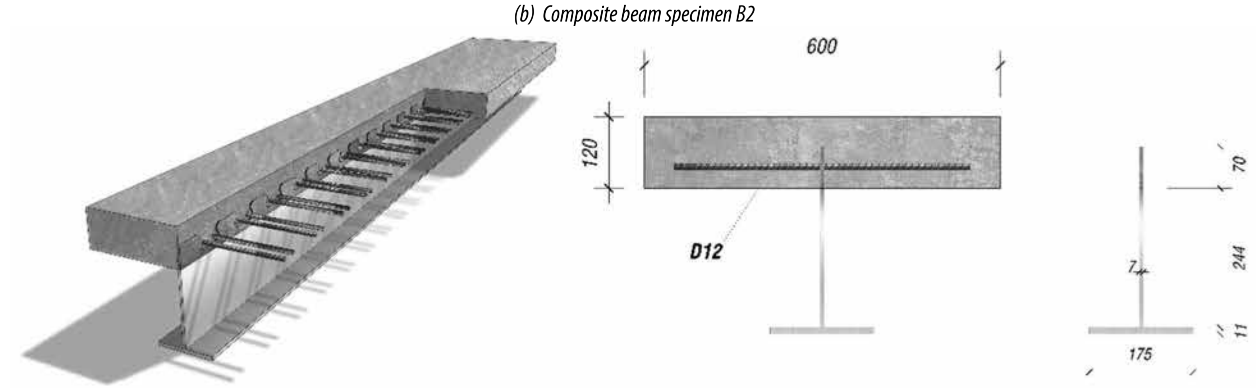
The shear strength of the newly puzzle shaped of crestbond rib shear connector was determined by the push-out test results and suggested design equation [10], and the degree of the shear connection of the composite beam specimen was determined to be a full shear connection. The sectional and material characteristics of each composite beam specimen are summarized in Figure 1.



(a) Composite beam specimen B1



(b) Composite beam specimen B2



(c) Composite beam specimen B3

Fig. 1 Dimensions of composite beam specimen.

Table 1 Material properties of composite beam specimen

Concrete				Steel beam and crestbond rib			
Number of test specimen	Compressivestrength (f_c)	Young Modulus (E_c)	Flexural strength (f_{ct})	Number of test specimen	Yield Strength (f_y)	Ultimate strength (f_u)	Young modulus
	MPa	MPa	MPa		MPa	MPa	MPa
B25-1	35.9	29×10^3	3.42	ST-1	253	395	200×10^3
B25-2	35.5	29×10^3	3.34	ST-2	255	390	201×10^3
B25-3	35.1	29×10^3	3.37	ST-3	248	386	201×10^3
B40-1	50.4	33×10^3	3.63				
B40-2	50.9	33×10^3	3.60				
B40-3	50.0	33×10^3	3.52				

Table 2 Test results

Beam	**P_u (kN)**	**Deflection at P_u (mm)**	**Relative slip (mm)**	**Plastic moment**		**Ductile factor**		
				Test (kN.m)	Design (kN.m)	Δ_{max}	Δ_y	μ
B1	486.2	50.07	1.5	376.8	306	1.5	0.37	4.05
B2	492.2	35.09	1.27	381.5	334	1.27	0.38	3.34
B3	491.9	37.34	0.85	381.3	330	0.85	0.25	3.4

2.2 Material properties

These specimens were cured under the same conditions as the composite beam specimens. The concrete cube specimens were used to measure the compressive strength and strain of the concrete, while the concrete cylinder specimens were used to measure the Poisson's ratio and elastic modulus of the concrete. These material properties were measured on the same day that the composite beam specimens were tested. The material properties of the concrete, steel beam, and crestbond rib are presented in Table 1. The yield strength and ultimate strength of the transverse and longitudinal rebars were 250 MPa and 390 MPa, respectively.

2.3 Test setup

These loading tests were terminated after decreasing the load back to 90% of P_{max}. Figure 2 shows the test setup and instrumentation.

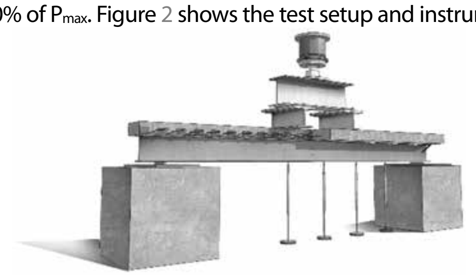


Fig. 2 Test schematic and arrangement of instruments

3. SUMMARY OF EXPERIMENT RESULTS

The ductile factor was definited by μ. Their failure modes included failures of the concrete slab and steel beam. No failure of the crestbond rib was found.

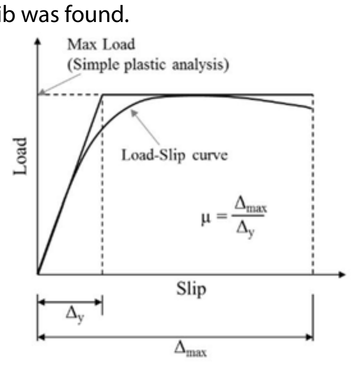


Fig. 3 Definition of ductile factor (Shariati *et al* 2016)

4. FINITE ELEMENT MODEL

4.1 Software, element types and mesh construction

Ansys 14 software is applied to analyze the structure, the model of specimens is shown in Figure 4

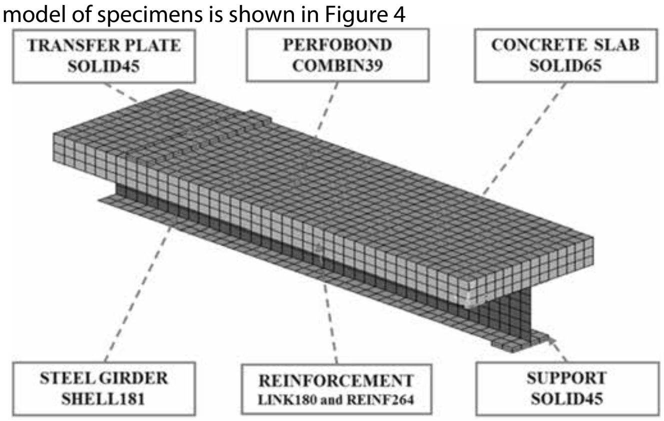


Fig. 4 Software, element types and mesh construction

4.2 Boundary condition

Because of the symmetry of the push-out test arrangement, the symmetric boundary condition (BC) was applied to the surfaces at the symmetric planes of the specimen as shown in Fiigure 5.

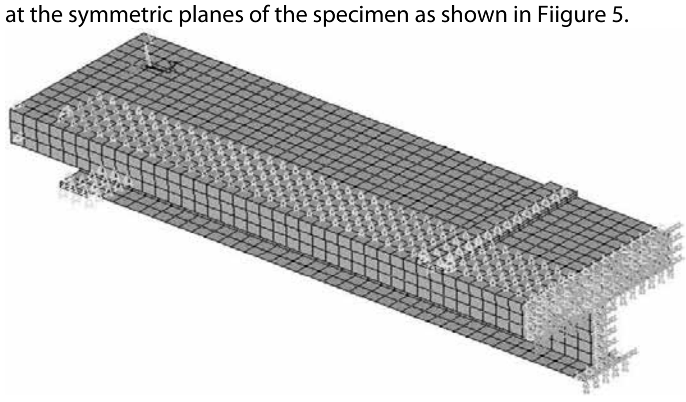


Fig. 5 Boundary condition

5. PARAMETRIC RESULTS

5.1 Comparison with experimental results

The results shown in Table 3

Table 3 Results for the experiment and numerical analysis

	Specimen	Experiment	Modelling	Error (%)
Load P_{max} (kN)	B1	486.2	490.2	0.82
	B2	492.2	493.8	0.33
	B3	491.9	494.2	0.47
Deflection (mm)	B1	50.07	50.3	0.46
	B2	35.09	35.3	0.60
	B3	37.34	38.8	3.91
Relative slip (mm)	B1	1.5	1.55	3.33
	B2	1.27	1.28	0.79
	B3	0.85	0.87	2.35

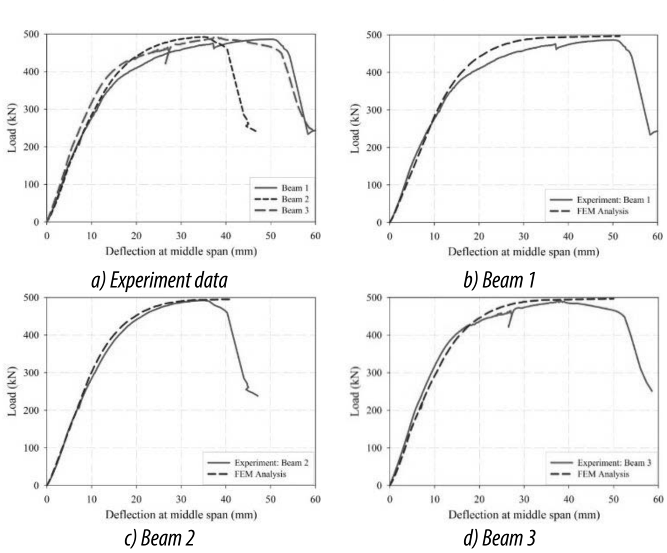
5.2 Load-deflection relationships at the middle of composite beam

The shape of displacement of composite beam was illustrated in Fig. 6. Figure 7 shows their load-displacement curves at mid-span of experiment data. The load-displacement curve of each composite beam was compared with their experiment result.

The deflection at the mid-span of beam B1at maximum load (P_{max}) is the highest, whereas that of beam B2 and B3 is same. The deflection of beam B1 was 42.7% and 34.1% increased than that of beam B2, and B3, respectively. This is reasonable because the flexural stiffness of beam B2 was the highest among these beams. This also shows that the concrete compressive strength significantly affect the behavior of concrete–steel composite beams using the newly puzzle shaped of crestbond shear connectors.

As can see that, the results from modeling and experiments are in agreement. The difference is approximate 0.83%, 0.33%, and 0.47% for B1, B2 and B3, respectively.

Fig. 6 Deflection of composite beam exported from Ansys

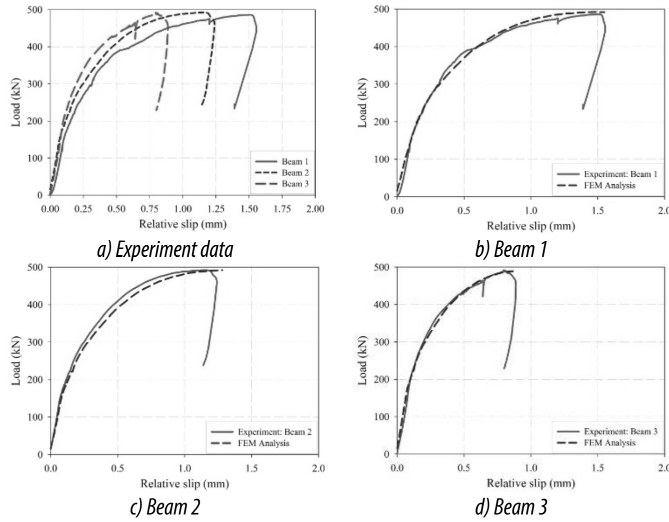


a) Experiment data *b) Beam 1* *c) Beam 2* *d) Beam 3*

Fig. 7 Comparison of load-midspan deflection between experiment and FEM analysis

5.3 Load-relative slip at composite interface

This is because the connection was fully shear. Therefore, the effect of the vertical shear in the support region was insignificant in comparison with that of the moment in the mid-span region. Comparisons of slip between test and modelling, it was exhibited that modelling result is good in agreement with experiment data. It is supposed that in modelling using COMBIN39 element which is enough exact to simulated actual behavior of Perfobond connector.

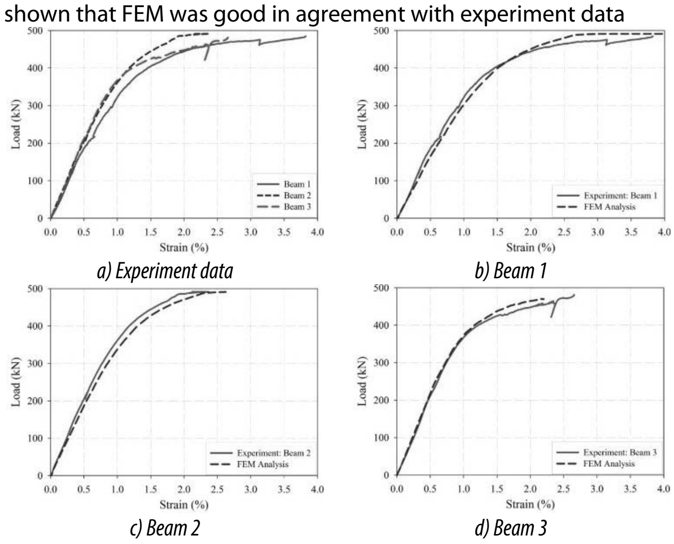


a) Experiment data *b) Beam 1* *c) Beam 2* *d) Beam 3*

Fig. 8 Comparison of load-relative slip between experiment and FEM analysis

5.4 Strain of concrete slab

Comparison of strain between test and modelling, the results shown that FEM was good in agreement with experiment data



a) Experiment data *b) Beam 1* *c) Beam 2* *d) Beam 3*

Fig. 9 Comparison of load-strain of concrete slab between experiment and FEM analysis

5.5 Strain of H beam

The distribution of stress in steel beam was illustrated in Fig. 10. Figure 11a shows their load-strain curves at strain gauge SG10 of experiment data. The load-strain curve of each composite beam was compared with their experiment result, as shown in Fig. 11b, c, d, respectively.

Comparison of strain between test and modelling, the results shown that FEM was good in agreement with experiment data.

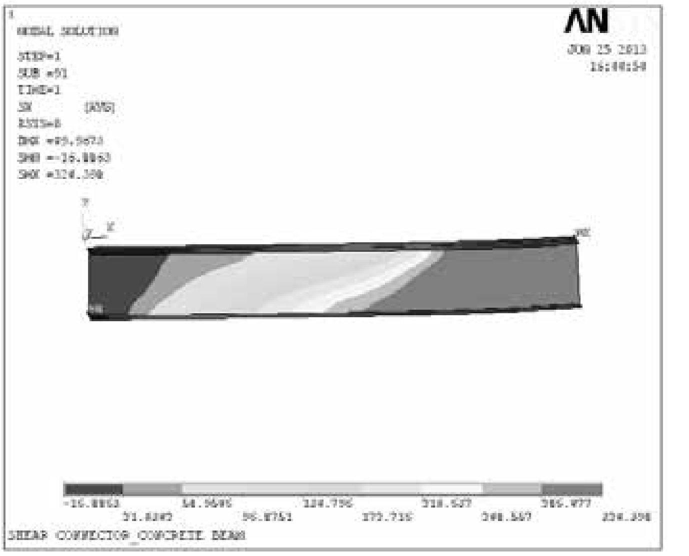
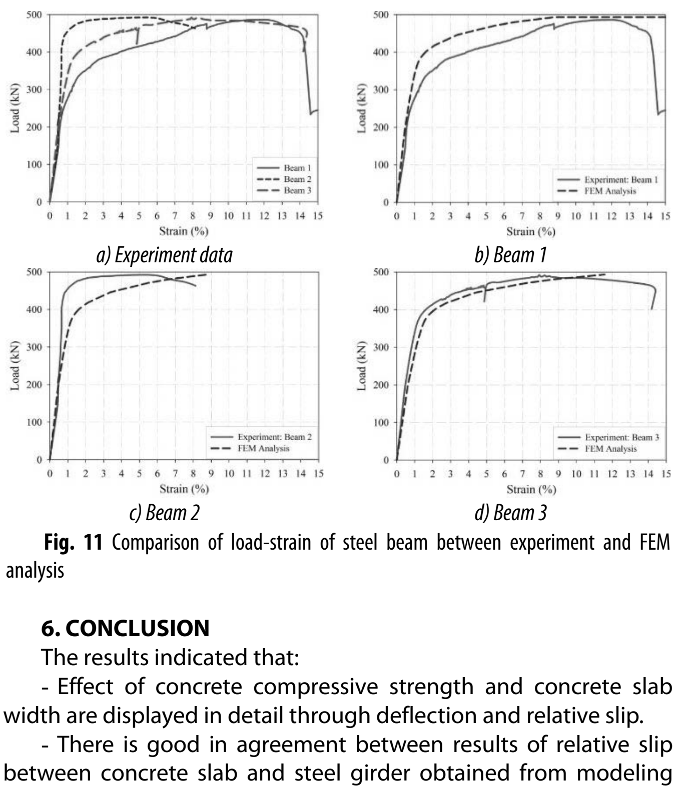


Fig. 10 Distribution of stress in steel beam exported from Ansys



a) Experiment data *b) Beam 1*

c) Beam 2 *d) Beam 3*

Fig. 11 Comparison of load-strain of steel beam between experiment and FEM analysis

6. CONCLUSION

The results indicated that:

- Effect of concrete compressive strength and concrete slab width are displayed in detail through deflection and relative slip.

- There is good in agreement between results of relative slip between concrete slab and steel girder obtained from modeling and experimental push out test results.

- It is supposed that using element COMBIN39 is correct enough to reflect the nature of the newly puzzle shaped crestbond rib shear connector in composite structures.

- The FEM analysis can be applied to replace the experiment on the real composite beam based on the fully three-dimension FEM model.

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