

## **Experimental and Numerical Study on Behavior of Externally Bonded RC Beams Using FRP Composites**

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### **Abstract**

This paper explores the flexural behaviour of carbon fiber reinforced polymer (CFRP) strengthened reinforced concrete (RC) beams of M-20 grade of concrete. The experimental programme consists of strengthening and testing of simply supported rectangular beam of size 150mm X 150mm X 700 mm strengthened with CFRP sheets. For flexural strengthening of RC beams, total eight beams were cast and tested over an effective span of 600 mm up to failure under static loads. Seven beams were strengthened with bonded CFRP fabric in single layer which are parallel to beam axis with different pattern and tested until failure; the remaining one beam was used as control beam. Static responses of all the beams were evaluated in terms of strength, load vs displacement curve and the associated failure modes. The theoretical strength and the load - displacement response of the strengthened beams and control beams were predicted by using FEA software ANSYS 14. Comparison has been made between the numerical (ANSYS 14) and the experimental results. The results show that the strengthened beams exhibit increased flexural strength, load carrying capacity, and composite action until failure. Thus it is a feasible method for strengthening and retrofitting of RC beams.

### **1) INTRODUCTION**

A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as

low as twenty - five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration can be mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze - thaw cycles, contact with chemicals and saline water and exposure to ultra - violet radiations. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

The most popular techniques for strengthening of RC beams have involved the use of external epoxy - bonded steel plates. It has been found experimentally that flexural strength of a structural member can increase by using this technique. Although steel bonding technique is simple, cost - effective and efficient, it suffers from a serious problem of deterioration of bond at the steel and concrete interphase due to corrosion of steel. Other common strengthening technique involves construction of steel jackets which is quite effective from strength, stiffness and ductility considerations. However, it increases overall cross-sectional dimensions, leading to increase in self-weight of structures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light - weight FRP Composite plates. FRPs help to increase strength and ductility without excessive increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibres. So concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

Advanced fibre reinforced polymer (FRP) composite is very effectively being used worldwide for strengthening structures. It provides a cost effective and technically more superior alternative to the traditional techniques in many specific situations. It offers high strength with low self weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. Conventional strengthening methods such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very expensive. In addition to that these methods are time consuming; require extensive equipment and significant labour. FRP repair systems provide an economical and technically better alternative to traditional repair systems and materials. Literature survey indicates there is considerable scope for research work in this area of “strengthening of beams with FRP composites”.

## **2) EXPERIMENTAL INVESTIGATION**

### **2.1 Details of the Beam Specimen:-**

The test program consisted of casting and testing of eight beams, of which one was control beams, all having size of 150 mm X 150 mm X 700 mm length, reinforced with 2 - 10  $\phi$  at bottom, 2 - 10  $\phi$  at top using 6mm diameter stirrups @ 120 mm c/c . The beams were cast using M 20 grade concrete and Fe 500 grade steel. The casting of beams was made as per IS code specification using M 20 grade concrete with 20 mm maximum size of coarse aggregate, locally available sand and 53 grade ordinary portland cement [ III - 3]. These beams were cured for 28 days in pure water and were

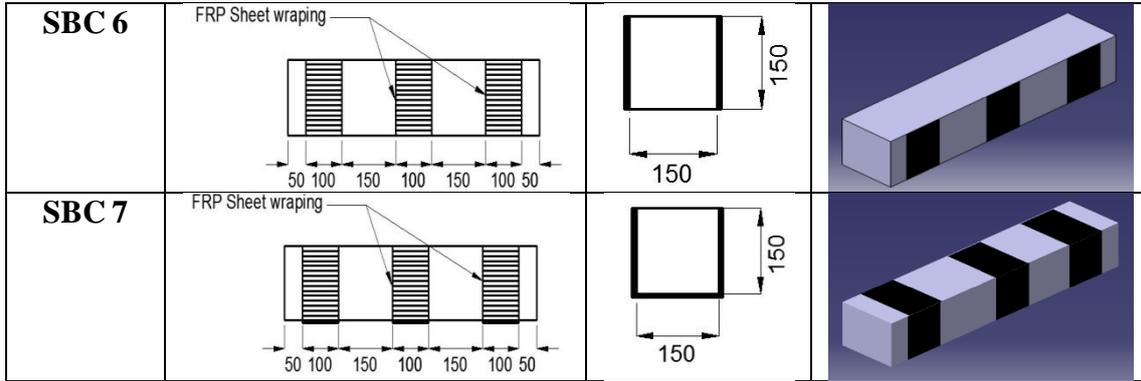
tested under two-point loading on a universal testing machine of capacity 1000 KN [III - 4].

**2.2 Preparation of Test Specimen:-**

The description of test specimens is summarized in Table 1. The surfaces of the beams were cleaned using polish paper or grind to ensure a good bond between the FRP strip and concrete surface. Each of these beams was externally bonded with CFRP strips and epoxy to the beam as per the procedure given by the manufacturer.

**Table 1. Strengthens Patterns**

Beams ID	L – Section	C/S Section	CAD Models
CB 1			
SBC 1			
SBC 2	FRP Sheet wrapping 		
SBC 3	FRP Sheet wrapping 		
SBC 4	FRP Sheet wrapping 		
SBC 5	FRP Sheet wrapping 		



### 2.3 Test Setup:-

All the specimens will be tested on the universal testing machine (UTM) in the “Strength of Material” laboratory of SKN Sinhgad College of Engineering Pandharpur. The testing procedure for the entire specimen will be same. After the curing period of 28 days, all the beam & its surface will clean for clear visibility of cracks. The most commonly used load arrangement for testing of beams will consist of two-point loading. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. If the flexural capacity of the member is to be assessed, the load will normally be concentrated at a suitable shorter distance from a support.

Two - point loading can be conveniently provided by the arrangement. The load is transmitted through a load cell to beam. This beam bears on rollers seated on steel plates bedded on the test member with mortar, high - strength plaster or some similar material. The test member is supported on roller bearings acting on similar spreader plates.

The specimen shall be place over the two steel rollers bearing leaving 50 mm from the ends of the beam. Two point loading test shall be proposed. Loading is done by hydraulic jack of capacity 1000 KN. Cracks formed on the faces of the beams were marked and identified. All beam specimens were loaded and simply supported as shown in figure 1.



**Figure 1. Experimental Set Up**

Load - deflection, stress and strains have been recorded for each specimen. Concrete having mean cube compressive strength of 21.54 MPa was used. For all the test beams, the parameters of interest were ultimate load, mid-span deflection, composite action, and failure modes.

**2.4 Test Result:-**

During the experimental testing of beams it is observed that all the beams which strengthened, there is considerable increase in load values for initial cracks. For control beam initial cracks appeared at 35 KN and for all strengthen beam it was about 62 to 70 KN.

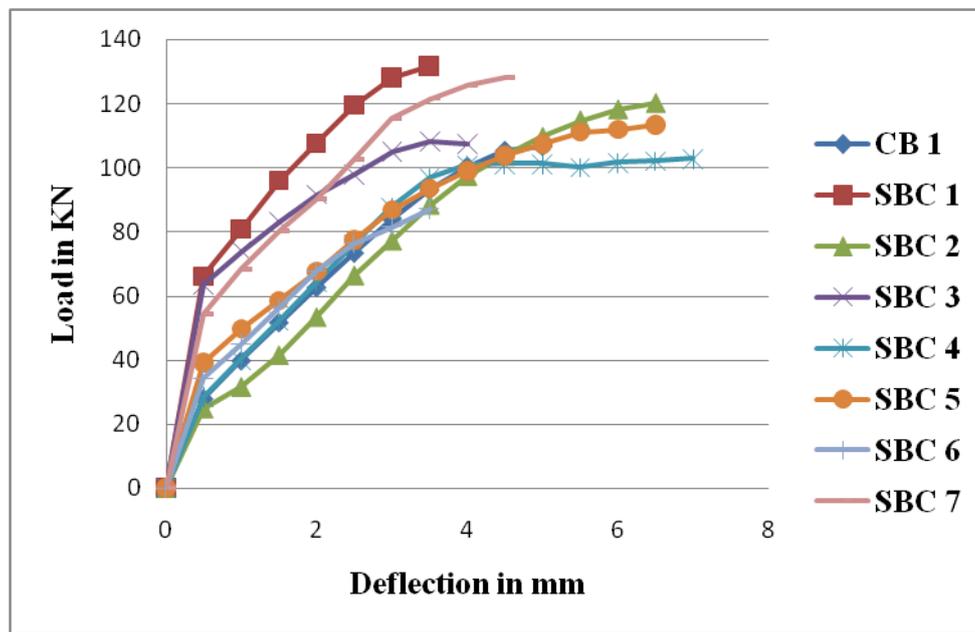
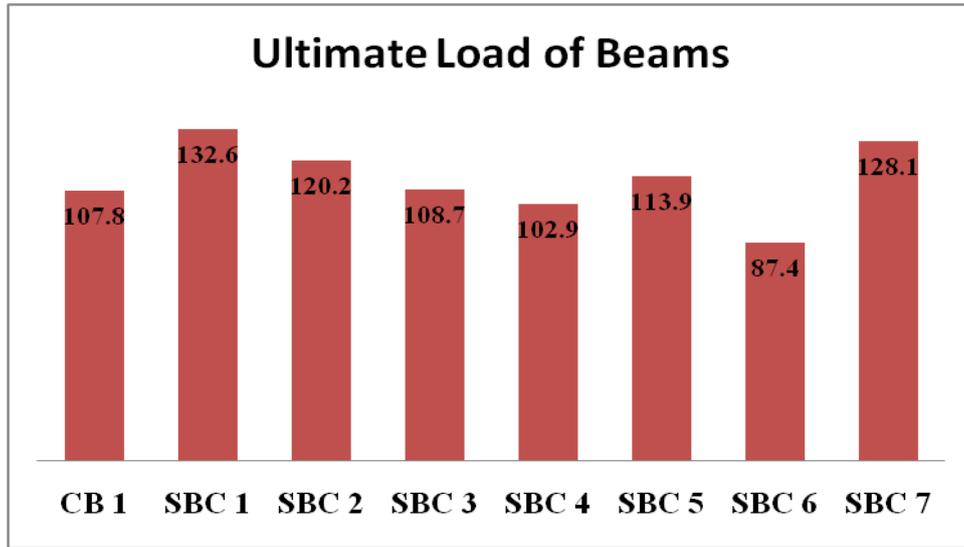


Figure 2. Load vs Deflection Curve for CB 1 and SBC 1,2,3,4,5,6,7

**2.5 Ultimate Load Carrying Capacity**

The load carrying capacity of the control beams and the strengthen beams were found out is shown in figure 3. The control beams were loaded up to their ultimate loads. It was noted that of all the beams, the strengthen beams SBC 1, SBC 2 and SBC 7 had the higher load carrying capacity compared to the controlled beam. An important character to be noticed about the usage of CFRP sheets is the high ductile behavior of the beams. The shear failure being sudden can lead to huge damage to the structure. But the ductile behaviour obtained by the use of CFRP can give us enough warning before the ultimate failure. The use of FRP can delay the initial cracks and further development of the cracks in the beam.

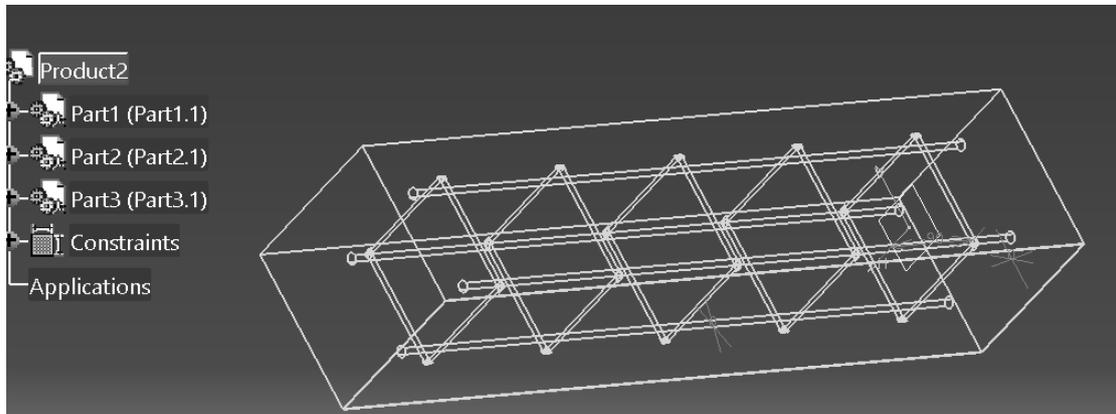


**Figure 3. Ultimate Loads of Beams CB 1 and SBC 1,2,3,4,5,6,7**

### 3) FINITE ELEMENT MODELING

Simulation has been carried out in ANSYS 14 which is a finite element package. In modeling 3D geometry of beams is drawn in CATIA 6 package.

Concrete is a nonlinear behaviour material during loading, it is analysis in ANSYS version 14.0 (workbench) to conduct analysis.



**Figure 4. CAD Modelling of Beam**

Similarly different configurations of beams which are modelled in CATIA 5.

CAD model is imported in ANSYS and it is meshed. Before mesh material properties are input to the software. Non-linear material properties are taken into consideration. These properties are obtained from experimentation. Following graph shows non linear behaviour of CB 1.

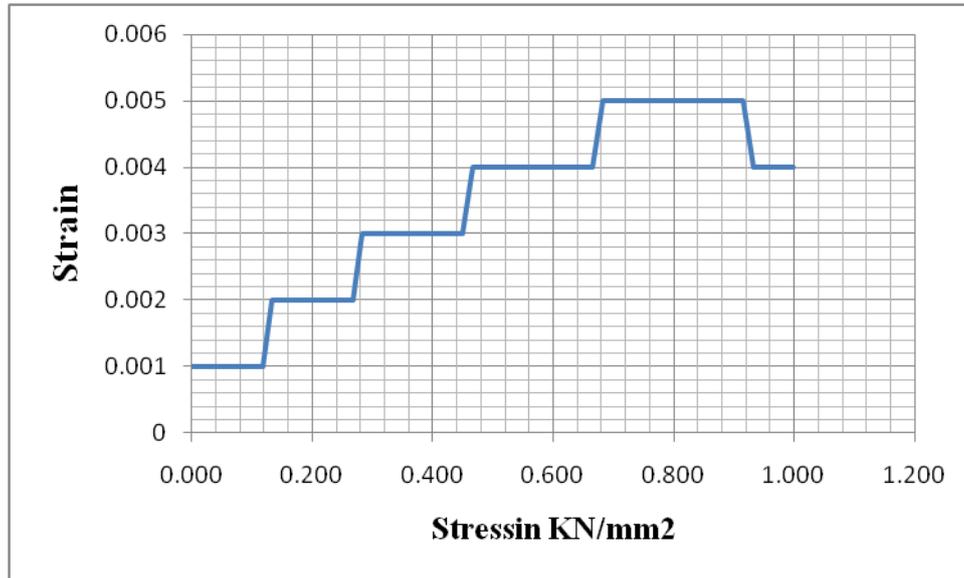


Figure 5. Stress vs Strain for CB 1

While meshing 10 node Tetrahedron and Brick 4 Noded 20 element are selected. Tetrahedron has been used for meshing steel bars and Brick 4 Noded 20 element was used for meshing remaining structure. Conta 178 element is used to model pair of steel bars with concrete and concrete with FRP.

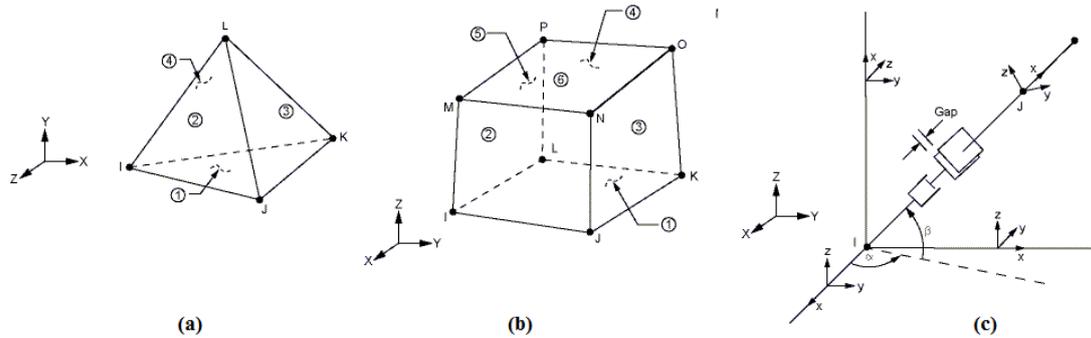


Figure 6. Tetrahedron Element (a), Brick 4 Noded 20 Element (b), Conta 178 Element(c).

In Conta 178 pairing, perfect bonded contact is provided in between FRP & concrete. 8542 number of element and 1881 number of nodes is generated after meshing. Non-linear static analysis has been carried out.

In boundary condition, all degree of freedom of both ends of beams are making zero. i.e. Beam is simply supported at both ends. Two point loads are gradually applied at

distant  $L/3$  from supports. Loads are applied in negative Y direction. It is also observed that there is excessive distortion of elements when beam is broken.

In post processing, ultimate strength of beams are obtained as shown in Table 2.

Deflection of simply supported beam is as shown in figure 6.4

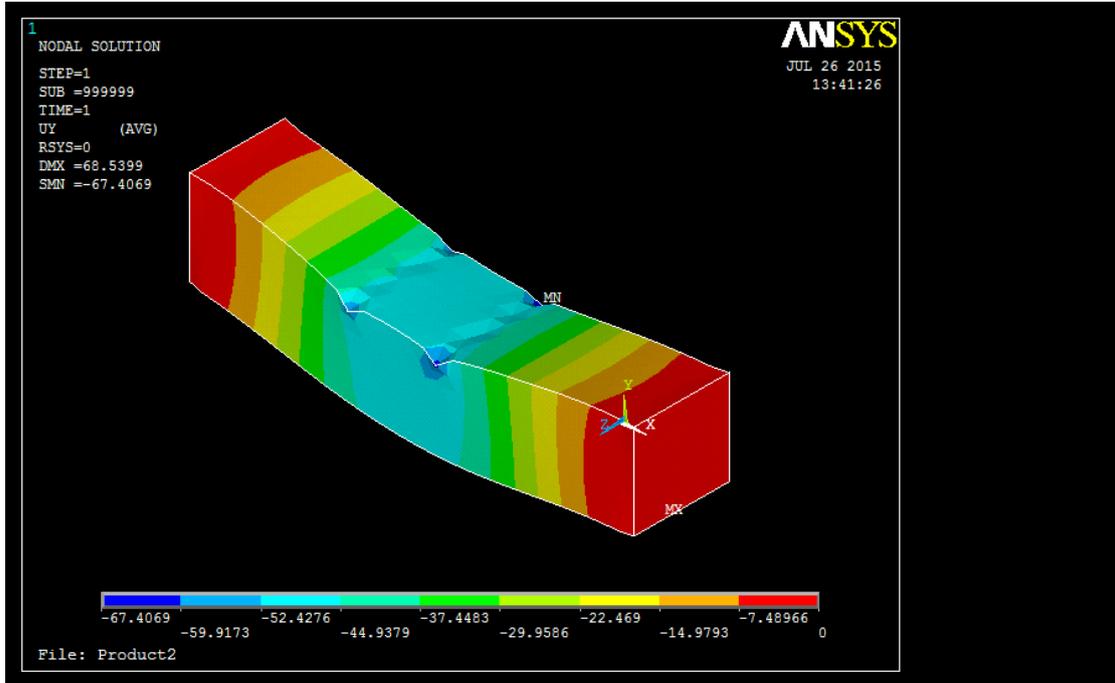


Figure 7. Deflection of Beam

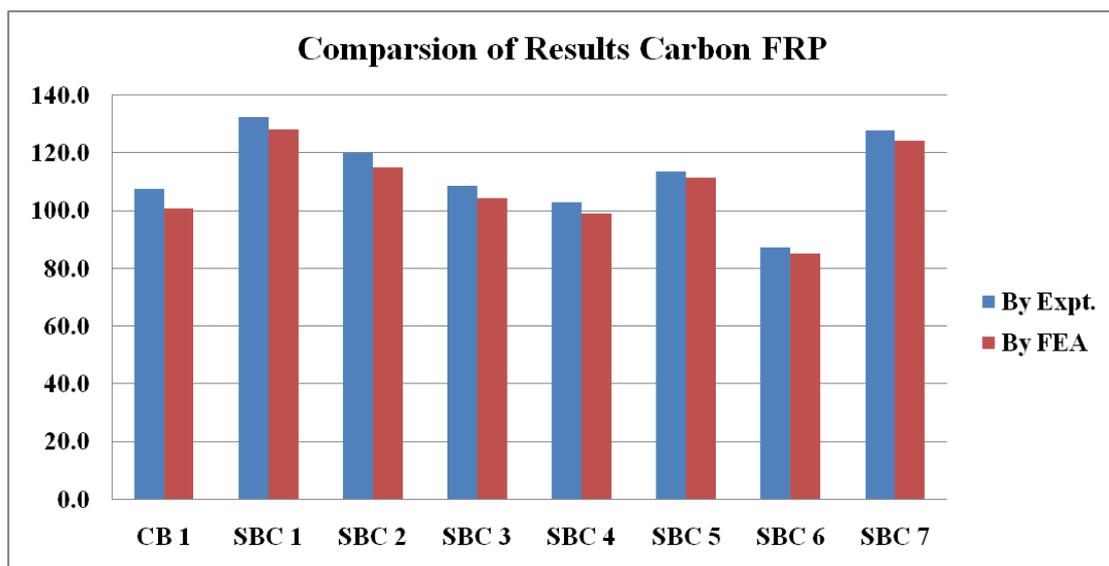
Table 2 Comparison of Results for Carbon FRP

Name of Beams	Ultimate Strength (KN)		% Deviation
	By Expt.	By FEA	
CB 1	107.7	103.3	<b>6.22</b>
SBC 1	132.6	128.1	3.39
SBC 2	120.2	115.2	4.16
SBC 3	108.7	104.3	4.05
SBC 4	102.9	99.2	3.60
SBC 5	113.9	111.6	2.02
SBC 6	87.4	85.3	2.40
SBC 7	128.1	124.3	2.97

### 3.1 Ultimate Load Carrying Capacity

Finite element analysis has also carried out to find the ultimate load carrying capacity and compared with the experimental results. It was found that analytical analysis predicts lower value than the experimental findings. It is observed that there is

maximum 6.22% deviation in ultimate strength obtained by experimentation and FEA. From the results, it is observed that the maximum deviation in case of carbon fibers is **6.22%**; whereas minimum deviation is **2.02%**. The deviation, may occur because as during software analysis it considers all the ideal conditions for analysis. As a matter of fact practically or during experimentation work it is highly impossible to create ideal conditions to perform the ideal lab work for preparation of concrete and during casting. The deviation may be consider the difference between ideal assumption and actual work.



**Figure 8. Comparison of Results for Carbon FRP (Expt. and FEA)**

#### 4) CONCLUSIONS:-

Based on the results obtained from experiments, and ANSYS analyses, the following conclusions are drawn:

- 1) **CFRP** fabric properly bonded to the tension face of RC beams can enhance the flexural strength up to **23%**.
- 2) At any given load level, the deflections are reduced significantly thereby increasing the stiffness for the strengthened beams. At ultimate load level of the control specimens, the strengthened beams exhibit a decrease of deflection.
- 3) Flexural strengthening of the beam increases the ultimate load carrying capacity, but the cracks developed were not visible up to a higher load. Due to invisibility of the initial cracks, it gives less warning compared to the control beam.
- 4) Finite element analysis has been carried out for result validation. It is observed that there is maximum **6.22%** deviation in ultimate strength obtained by experimentation and FEA.
- 5) It is observed that load at initial cracks was increased for all strengthening the beam.

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