

Investigation of the Behavior of Reinforced Timber Beams

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Abstract- The low cost construction demand has led to utilize timber as a construction material. The need for better strength in construction material has resulted reinforcing timber with steel elements. Six timber beams, reinforced with four steel angles at their corners, have been tested to investigate the combined beams behavior. Experimental tests and finite element method have been undertaken in the investigation process. A good agreement has been noticed between the experimental and finite element method in predicting the load carrying capacity for the test beams. It has been found that the stronger bond used between top and bottom angles, the more load carrying capacity for beams can be obtained and higher beams ductility can be achieved.

Index Terms— combined beams , timber beams, tying plates, wood, load carrying capacity

1 INTRODUCTION

The growing need for cheaper constructions has led to utilize timber as a construction material. Timber is an inexpensive material as it is produced by using solar energy only. Forest is considered as a wood source that needs minimum amounts of power from maintaining it till timber productions, therefore timber is more cheaper than other construction materials. Environmental conditions, surrounded the wood growth, widely affect timber physical and mechanical properties. Timber is considered an orthotropic material and its physical and mechanical properties vary according to longitudinal, radial and tangential axes of a timber element [5]. Timber was utilized as main structural materials in past, it has many aesthetic properties which led to use it as major components in historical structures, it remains beneficial construction material in countries of diminishing resources.

Steel or reinforced concrete have more strength in comparison with timber, and to obtain better strength a bigger size of timber beams are required which are difficult to be obtained[1]. Alternatively, available timber beams can be strengthened with different material to produce composite beams that have strength similar to those of bigger size. Number of materials have been discussed for the enhancement of timber beam's load carrying capacity [3-4-6]. This paper was conducted to investigate the behavior of timber beams reinforced with steel angles at beams' corners. Seven beams, of 2 meters in length, have been tested in the scientific laboratories of the university of kufa, one of them was tested to obtain the timber load carrying capacity and the other have been strengthened by four L40*40*4 angles at beams' corners and then tested. Four point load technique has been adopted to investigate the flexural behavior of the beams. Mid-span displacements have been calculated to draw load - displacement diagrams.

and have cross section of (150*75)mm. the type of timber was chosen from the imported wood to Iraq which known as white wood. The wood beams were strengthened with steel angles at their corners, all angles were L40*40*4. The top and bottom angles were connected together by using tying plates from steel of (4) mm in thickness. Welds were used to connect the tying plates with the angles. The tying plates were different in width and spacing from beam to another to see the effect of angles bond on the beams' load carrying capacity. Table (1) explains each beam with its tying plates' arrangement.

TABLE 1
 BEAMS' NAMES AND TYING PLATES' ARRANGEMENT

Beam No.	Tying Plates Arrangement	Tying Plates Details for One Side
B1		9 tying plates of (24*200) mm
B2		7 tying plates of (24*200) mm
B3		1 tying plate of (24*200)mm + two tying plates of (200*700) mm
B4		3 tying plates of (24*200) mm
B5		9 tying plates of (24*200) mm
B6		1 tying plate of (24*200)mm + two tying plates of (200*300) mm

2 BEAMS SPECIMENS AND GEOMETRY

The test specimens have been built up at workshops of University of Kufa. All beams were two meters in length

The angles were set in case that the total depth of the beam is (230) mm including the timber beam depth of (150) mm and two angle depths of (40) mm each. Figure (1)

illustrates the cross section for the combined beams.

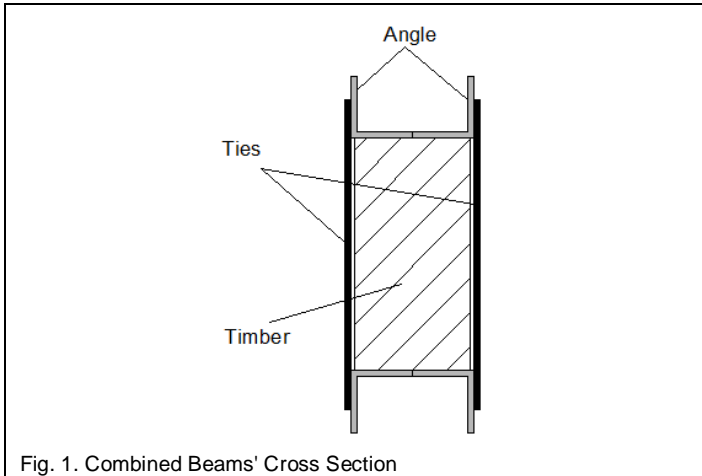


Fig. 1. Combined Beams' Cross Section

Each two parallel angles, at top and bottom of the beams, were connected with four plates of (25*50) mm in dimensions, these plates were welded to the angles in order to make the angles behave as a one part. Figure (2) illustrates the connecting plates arrangement.

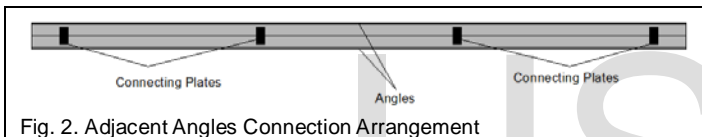


Fig. 2. Adjacent Angles Connection Arrangement

Additional two plates were welded to the top angles at the positions of applying the load which are at $L/3$ from each end. Also, two additional plates were welded to the bottom angles which were as bases for the test beams. The additional plate have been added to spread the stress on the angles from reactions and test loads and prevent the local buckling. Figure (3) illustrates the load plates and base plates arrangement.

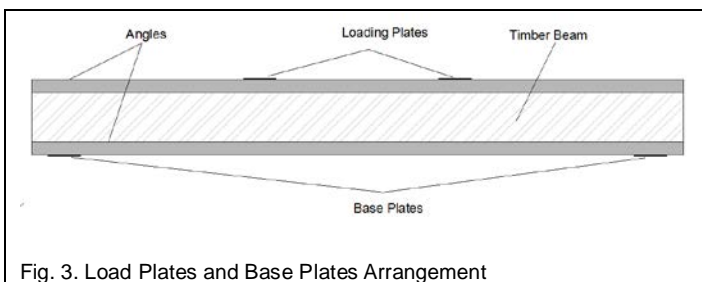


Fig. 3. Load Plates and Base Plates Arrangement

3 EXPERIMENTAL TESTS

The combined beams have been tested at the laboratories of university of Kufa after they were built up. The machine used in the test was a hydraulic pump, it can apply load up to 500 kN via steel frame used with it. Figure (4) illustrates the machine test.

From figure (4), it can be seen that the test beam was set on its bases where the base plates were located to prevent

local buckling in angles due to stress concentration at the reactions. The machine applies load vertically upwards and the machine structure prevents the vertical movements for the test specimens, therefore a stiff steel tool was put between the test beams and the machine structure. This stiff tool was connected to the test beams at their loading points which were $L/3$ from their both ends. When the test beams were set between the loading machine from bottom and the machine structure from top, the applying load from the machine would make the specimens under a four point load technique. The mid-span displacement was measured by using a gauge set under the test specimens, at their mid spans, during load applying. The gauge accuracy was (0.01) mm. All the gauge data were taken coinciding with load gauge, these data were used to draw the load- mid-span displacement for each test beam. Figure (5) illustrates the displacement gauge.



Fig. 4. Machine Test



Fig. 5. Displacement Gauge

4 FINITE ELEMENT MODEL

The combined beams have been modeled using ANSYS 12.0 software. There were two aims of using the finite element method in analyzing the beams. The first aim was to compare the results obtained from it with the results of the experimental tests to see whether the finite element can predict the actual behavior of the combined beams or not and secondly, to calculate the load carrying capacity for the angles and the tying plates without the timber beams to see the effect of the timber beams on the behavior of the steel angles.

Due to the symmetry of the combined beams, only half of the beams have been modeled. SOLID45 element has been used to simulate timber and SHELL63 to simulate the steel angles, ties and loading and bases plates [2-7]. Figure (6) illustrates a finite element model.

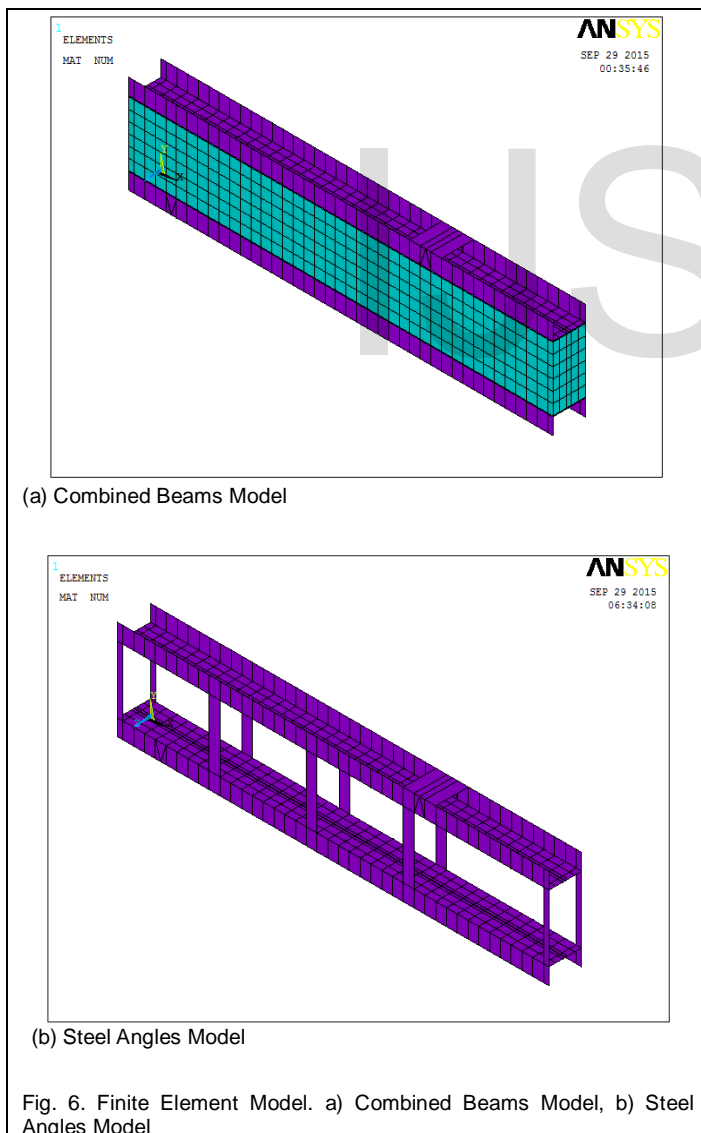


Fig. 6. Finite Element Model. a) Combined Beams Model, b) Steel Angles Model

5 RESULTS AND DISCUSSION

5.1 Experimental Results

After beams had been tested, load-displacement curves have been drawn for them. The results obtained from the experimental tests were the actual beams load carrying capacities and the mid-span displacement values. The actual beams load carrying capacities were specified when the mid-span displacement increased suddenly with the decrease in the applied load. Figure (7) illustrates the load - mid-span displacement for tested beams.

In addition to the tested beams, a beam from timber only was tested to determine the load carrying capacity for timber beam. The maximum applied load was (28.5) kN with mid-span displacement of (30) mm.

From the curves shown in figure (7), it can be seen that the mid-span displacement increases with the increase of the applied load and the relationship between them is nearly linear except for B3 and this may be attributed to the tying plates included in it which were two plates of (700) mm in length at both ends. These tying plates have increased the load carrying capacity for the combined beam and prevented the sudden failure. Also, B6 did not fail suddenly where B6 had two tie plates of (300) mm in length at both ends but had less load carrying capacity which was about (87) kN. Both B3 and B6 specimens have failed with high local buckling in both angles and tying plates as illustrates in figure (8). B1 and B2 specimens had nearly the same behavior where they both failed with load of (55) kN and maximum mid-span displacement of (18.5) mm for B1 and (19.7) mm for B2. Both B1 and B2 had tying plates of (25) mm in width with different spacing. Although B1 had less tying plates spacing at ends with (225) mm, it had the same load carrying capacity of B2 which had the same ties with larger spacing of (300) mm. This may be attributed to the large tying plates spacing of (325) mm for B1 at the middle third which had to decrease the load carrying capacity where the maximum moments are at the middle third which have been affected by the large tying plates spacing. B4 had the least load carrying capacity comparing to the other specimens, and this may be attributed to weak connection between the top and bottom angles where only three tying plates have been used at each side of the combined beam. B5 had more load carrying capacity comparing with B1, B2 and B4 and this may be attributed to the tying plates spacing of B5 specimens which was (225) mm for all of them. This value of tying plates spacing is nearly equal to the total beam depth.

The timber utilized in the beams had cracks in some places of it. These cracks have affected the beams behavior according to the arrangement of them, where they have controlled the failure mechanisms of timber. No failure has occurred in timber before steel, but the stresses induced in timber have increased the small cracks up to the failure of timber.

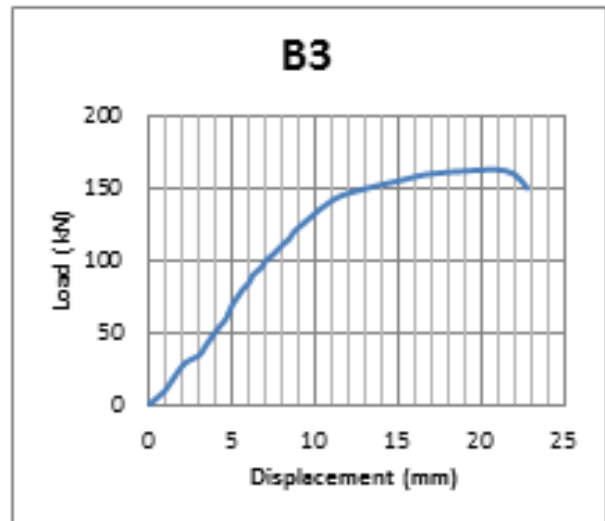
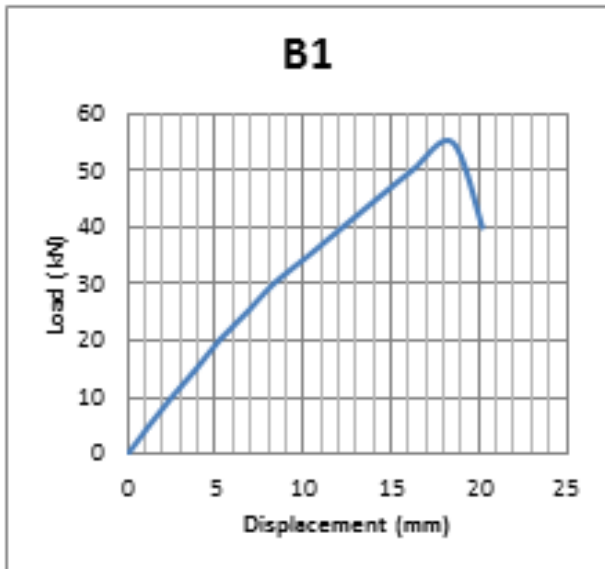
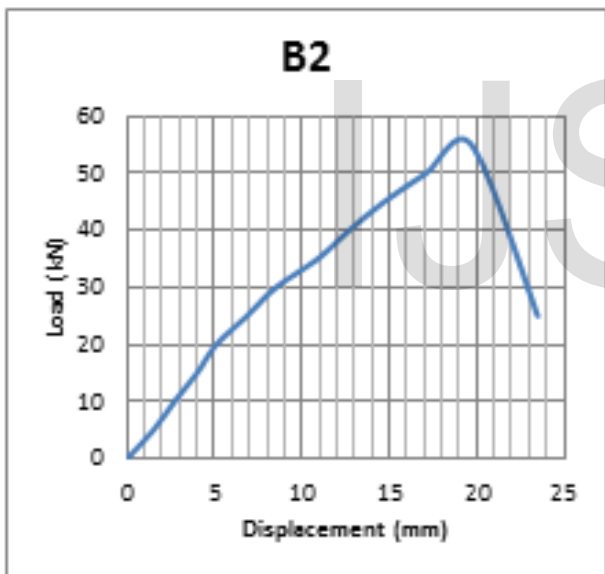


Fig. 7. Load – Mid-Span Displacement Curves for Beams



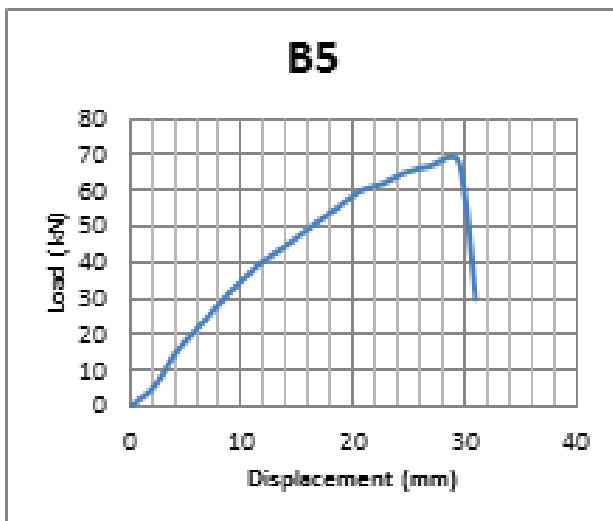
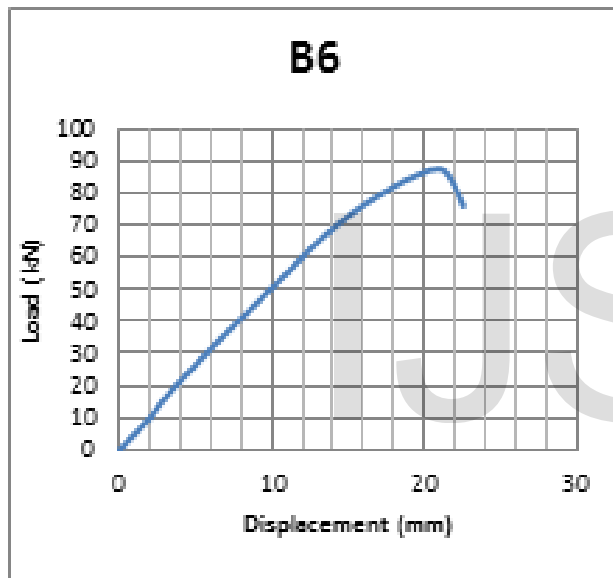
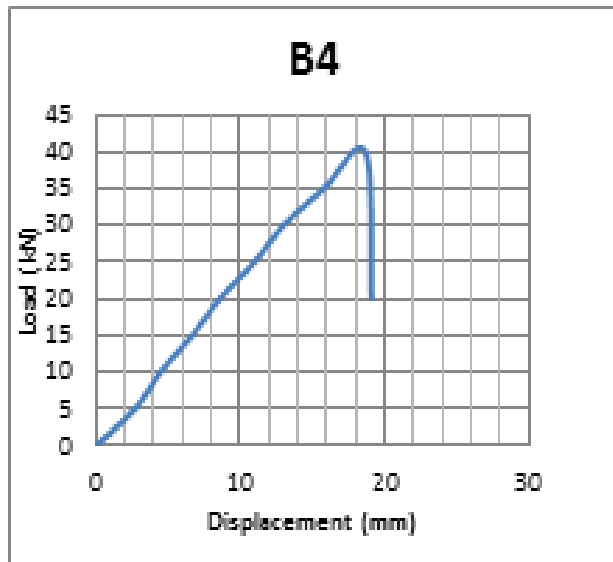


Fig. 8. Local Buckling in Angles and tying plates

5.2 Finite Element Analysis Results

The modeled specimens in ANSYS 12.0 software have been applied to loads gradually till the stress in steel reached the yield point. At this point, the applied load was considered the load carrying capacity for each modeled beam. In the experimental tests, all the specimens have failed after the steel angles had yielded. The modeled specimens have been analyzed again excluding the timber material from them. The obtained results were the load carrying capacity for the

specimens steel angles and their tying plates to see the effect of the timber on the behavior of the specimens. Table (2) explains the results obtained from the finite element analysis.

TABLE 2
 FINITE ELEMENT ANALYSIS RESULTS

Specimens No.	Steel + Timber		Steel Only	
	Load (kN)	Steel Stress (MPa)	Load (kN)	Steel Stress (MPa)
B1	56	282	41	280
B2	55	283	40	283
B3	164	693	128	690
	66	279	52	280
B4	40	286	10	280
B5	68	337	57	336
	56	278	48	283
B6	84	500	24	502
	48	285	13.6	285

5.3 Results Comparison

The load carrying capacity for each specimen has been taken from the experimental tests and compared from those taken from the finite element analysis results, all the results are summarized in table (3).

TABLE 3
 EXPERIMENTAL AND FINITE ELEMENT RESULTS

Specimen No.	Experimental Tests	Steel + Timber		Steel Only	
	Load (kN)	Load (kN)	Steel Stress (MPa)	Load (kN)	Steel Stress (MPa)
B1	55	56	282	41	280
B2	55	55	283	40	283
B3	162	164	693	128	690
		66	279	52	280
B4	40	40	286	10.2	285
B5	68	68	337	57	336
		56	278	48	283
B6	87	88	524	25	523
		48	285	13.6	285

It can be seen from table 3 that the finite element analysis has predicted the load carrying capacity for each specimen with good accuracy. B1, B2 and B4 have failed when the stress in steel angles reached about (286) MPa which is the yield stress for the steel angles. Whereas B3, B5 and B6 have failed when the stress in steel angles passed the yield point stress. These specimens (B3, B5 and B6) had stronger tying plates than other specimens which led to increase the load carrying capacity for each of them under high steel stress and high mid-span displacement when failure. This increase in beam ductility has a good aspect in enhancing resistance of structures under seismic and decreasing the

effects of timber defects such as knots and cracks.

By looking at the load carrying capacity of steel only specimens, it can be seen that all the specimens load carrying capacity has increased when the timber beams were used. The ratio of the load carrying capacity defers from specimen to another. For B1 and B2 the timber has increased the load capacity by 37% where (25) kN has been added to the load capacity which is about 88% of the timber carrying load capacity. B3 has increased with 28% of the load carrying capacity, (36) kN has been added to the steel load capacity and this value is greater than the timber load capacity which was (28.5 kN). This may be attributed that the specimen of only steel has failed by bottom angles failure due to the intensity of stress on them where the finite element analysis has indicated stress in top angles of (536) MPa and bottom angles had stress of (690) MPa while combined steel and timber beam has behaved as one beam and symmetrical stresses can be happened. The case of B3 of high load capacity increase can be noticed in B4 and B6 for the same reason of B3, where the load capacity increase in B4 and B6 were 400% and 76% respectively. B5 has increased with 19% of load capacity which was the least load capacity increase. Although B5 has least load capacity increase ratio, its load capacity is greater than B1, B2 and B4 and they all have the same tying plates type but at different spacing. It can be said that the tying plates spacing used with B5, which nearly equals the total height of the combined beam, has increased the load carrying capacity for the combined beam comparing to other combined beams with the tying plates dimensions and increased the beam ductility where B5 has failed when steel stress reached (337) MPa which is greater than the yield stress for the steel of the angles used in the combined beams.

6 CONCLUSIONS

In this research, four-point technique and finite element method were undertaken to investigate the behavior of reinforced timber beams. Four steel angles have been utilized to reinforce the timber beams at their corners. It was evident from the experimental tests that the mid-span displacement has increased linearly with the increase of loading except for B3. The tying plates, used to cover two thirds of B3, have increased the beam ductility and prevented the sudden failure. Strong bond can be recommended for enhancing resistance of structures under seismic and decreasing the effects of timber defects such as knots and cracks. It can be seen that the stronger bond used between top and bottom angles, the more load carrying capacity for beams can be obtained and higher beams ductility can be achieved. The noticeable load carrying capacity increase can be obtained when the tying plates spacing is equal or less than the total beam depth. The finite element method has indicated the beams behavior with good accuracy comparing with experimental test results and can be used to predict the stress of beams elements.

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