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# Improved Strength and Stiffness Characteristics of Cross-laminated Poplar Timber Columns

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*ABSTRACT*

Timber apart from being a cheap construction material possesses numerous environmental advantages, which makes it one of the highly sought construction material, particularly for moderately loaded residential structures. Timber due to the easy cultivation of timber trees can be made available in abundance. Thus, can serve as an efficient and sustainable building material, provided its structural potential is tapped fully. In this study, various performance improvement techniques have been used for enhancing the axial strength characteristics of a timber specie (Poplar), that is available in abundance, in the northern part of India. Different binding/wrapping techniques have been adopted to utilize Poplar in a laminated form, known as cross-laminated timber (CLT). It has been found that a strength improvement of about 20% can be achieved in CLT short columns by simply bolting the laminates together, while as this improvement can be as high as 32%, provided cold form steel (CFS) sheets are used for strengthening these CLT timber columns. Similarly, in the case of long CLT columns, a strength improvement of 50% is attained when a double cross helix of fibre reinforced polymer (FRP) cloth is adopted for the strengthening purpose. Furthermore, this study is aimed at utilizing small unused, otherwise, waste timber logs/pieces in columns with strength improvement techniques for improved axial strength performance.

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## 1. INTRODUCTION

The last 60 years have witnessed substantial growth in the strengthening of primary structural timber components like beams and columns. Initially, the strengthening was carried out primarily by using metallic reinforcement, including steel bars, pre-stressed stranded cables and bonded steel and aluminum plates [1]. Later, the metallic reinforcement was replaced by fibre-reinforced polymers (FRP) due to its high strength and stiffness features that would suit a variety of structural strengthening requirements. Many researchers have reported about the improvement in structural parameters after reinforcing the timber beams and columns with fibres and fibre-reinforced polymers (FRP) [2–7]. All these studies have indicated an improvement in the strength as well as stiffness characteristics in glulam timber elements. Further, the results revealed that the improvement in the stiffness as well as the strength can range between 40-60%.

Cross-Laminated Timber (CLT) an engineered wood, was first developed in Germany and Austria in the 1970s and 1980s, [8]. However, it was only after the mid-1990s, extensive research was carried out on the same and it was established that CLT has a variety of utility in the building construction [9–13]. Further, CLT has found its adaptability in timber–concrete composites, [14–16] and connections in timber structures as well, [17–20]. Even in seismically prone areas, CLT is an excellent material for mid and high-rise building construction [21, 22]. Also, CLT has displayed a satisfactory seismic-resistant performance, when used as floor diaphragms and shear walls [23, 24]. Recently, CLT has been used for tall timber and hybrid buildings, and seismic retrofitting of capacity deficit member [25]. Most of the research on CLT (glulam) has been focused on beams, while very limited research output on columns is available. To enhance the strength parameters, glue-laminated (glulam) timber columns were strengthened with FRP sheets [26–29]. Similarly, the

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feasibility of glue-laminated timber columns strengthened with FRP sheets for improved buckling resistance of columns was carried out by Taheri et al. [30], wherein, many parameters such as slenderness ratio, boundary conditions, FRP reinforcement length, and relative cost were investigated. A study was also carried out to improve the compression resistance of timber columns (with longitudinal cracks) by retrofitting (with FRP sheets), [27]. It was found that FRP laminates could offer an incremental increase in both the strength and stiffness.

Since locally available timber species can be utilized sustainably, benefitting regions all over the world, research was focused on locally available timber used conventionally in beams/columns, reinforced with fibres and FRP materials. Plevris and Triantafillou [2], Triantafillou and Deskovic [3] explored the role of carbon/epoxy fibre reinforced plastics in reinforcing fire wood products. The effect of pre-stressed carbon/epoxy FRP (CFRP) reinforcement bonded to European Beech Lumber was studied by Triantafillou and Deskovic [3]. Some studies were also carried out on Yellow-Poplar glulam beams reinforced on the tension side with glass/vinylester FRP [31] and with pultruded glass/vinylester FRP on the tension side and both on tension and compression sides. Similarly, Tingley and Leichti [32] discussed glulam made from lower grade Ponderosa Pine, reinforced in the tension zone with pultruded kevlar and carbon FRP.

A lower grade timber (Poplar) is locally available in almost all parts of Kashmir valley (a part of northern India). The timber from Poplar belongs to the specie, Aspen, and has currently very less structural importance, which is mainly used in roof trusses of low-cost houses, formworks of slabs and beams, apple boxes, ply boards, etc. Despite, Poplar timber being available in abundance in the above stated region, it has failed to achieve the deserved popularity to be used in a structural system and is so due to its low strength, moderate stiffness, and moderate-high shrinkage issues. An effort has been made to improve the strength of this type of timber so that its utilization as a constructional material can boost low-cost sustainable construction in the region. This study focuses on the utilization of Poplar timber in cross-laminated form, with various strength improvement techniques. To ensure the preparation of high-quality CLT, the availability of suitable raw material (local/domestic wood species) is essential. Further, it is also important to consider the strength properties, bonding properties, and durability of that particular species. Typically, temperate softwood lumber is used to manufacture CLT [33]. This makes Poplar wood suitable for CLT production and an effort has been made to study the axial strength behavior of externally strengthened CLT columns of locally available Poplar timber, with various strength improvement techniques.

As already stated the timber from popular has very less structural importance and is principally used in making apple boxes, plywood boards and roof trusses of low-cost houses in this region. Since cross laminating timber has the advantage that it randomizes the weak areas of timber and knots of timber throughout the volume of the column, hence increases the strength of weak timbers. Also, small unused timber pieces, otherwise waste-timber, can be utilized in structural elements (CLT columns) with strength improvement techniques. The novelty of this study is that with an increase in strength and stiffness, the utility of local Poplar timber will get enhanced at a low cost. Further, with an increase in the popularity of the use of timber in structural elements, industrial units can be established for mass production, which in turn will increase the employment and boost the economy in this industry deficit state.

## 2. MATERIAL AND MATERIAL DATA

The desired physical and mechanical properties of Poplar timber have been computed as per the procedure laid down in IS 1708: 1986, [34] by testing timber prisms of size 20mm x 20mm x 100mm. The material properties are given in Table 1. A typical sample of a sawn Poplar timber is shown in Figure 1.

In addition to the main material (timber), the other materials used for strengthening purposes are bolts, cold form steel sheets, and Carbon Fibre Reinforced Plastic (CFRP) strips. A brief description of these materials is given as follows:

**TABLE 1.** Physical and mechanical properties of Poplar timber

| No. | Parameter | Average test value |
|---|---|---|
| 1 | Moisture content | 17.00 % |
| 2 | Compressive strength parallel to the grain | 27.0 N/mm$^2$ |
| 3 | Compressive strength perpendicular to the grain | 1.10 N/mm$^2$ |

**Figure 1.** A typical sample of sawn Poplar timber

**2. 1. Bolts** In CLT there is a tendency that the individual laminations of timber may rip apart. To hold the CLT laminations, three bolts of M6.8 (6mm dia) have been used. The properties of these bolts as provided by the supplier/manufacturer are shown in Table 2. Adequate spacing of 2d (200mm) between the bolts and an edge distance of 50mm has been provided. This would ensure the structural integrity of the CLT specimens and would prevent their delamination under the influence of the axial loading.

**2. 2. Cold-formed Steel** The columns were strengthened by cold-formed steel plates of 14G thickness (1.6mm) wrapped around all the long faces. Cold-formed steel conforming to Indian Standard IS-2062 [35] were used in this study. The properties of the cold-formed steel are given in Table 3.

**2. 3. Carbon Fibre Reinforced Polymer (CFRP)** The unidirectional CFRP strips of thickness 5mm were used to strengthen the timber CLT columns. These FRP strips were aimed to confine the timber laminations and improve the buckling/shear resistance of the CLT columns. As reported by the manufacturer, the modulus of elasticity, the tensile strength, and the strain at breakage for FRP are 175 $kN/mm^2$, 2000 $N/mm^2$ and 1.65%, respectively.

**2. 4. Epoxy** Epoxy was used as an adhesive between the timber laminations. The epoxy was a two-component adhesive one being resin and another hardener, where both the components were mixed in a ratio of 1:1. After thoroughly mixing the two, the mixed product was applied on the Poplar timber pieces within three minutes as prescribed in the manufacturer's manual provided by the manufacturer. As per this manufacturer's manual the epoxy was to be left to dry and harden for at least 24 hours before any testing could be done.

**TABLE 2.** Properties of Bolts

| | |
|---|---|
| Designation | M6.8 |
| Nominal Tensile Strength | 600 $N/mm^2$ |
| Minimum Brinell hardness HB | 181 |
| Nominal Yield Strength | 480 $N/mm^2$ |
| Elongation after fracture | 8% |

**TABLE 3.** Properties of cold steel

| Material designation | CS sheets |
|---|---|
| Thickness | 14G (1.6 mm) |
| Nominal Yield strength | 250$N/mm^2$ |
| Nominal Ultimate Strength | 410 $N/mm^2$ |
| Nominal %age elongation | 23% |

## 3. TEST SPECIMENS AND TESTING PROCEDURE

The sawn timber was kept for seasoning in air until the moisture content was reduced below 20%. The solid column was sawn into three laminations and the laminations were glued together with epoxy (araldite). The laminations were glued such that the grains in adjacent laminations are oriented perpendicular with respect to each other.

For the strengthening of columns, five different techniques were used. For each type of strengthening technique, six specimens were fabricated (three short columns and three slender columns), making a total of 30 CLT columns; of which 15 were short columns and 15 were slender columns. In addition, 06 control columns without any strengthening and laminates (single piece) were tested to lay the basis for the performance comparison of the various strengthening techniques adopted. The columns were tested under concentric axial loading conditions in the structural Laboratory at the National Institute of Technology Srinagar.

The section and lengths of the columns used are as follows:

**a. Short Columns**
Length of column = 500 mm;
Cross-section of the column = 100 mm x 100 mm;
l/d ratio = 5;
Cross-section of one laminate = 33 mm x 100 mm, three layers of laminate making an approximate cross-section 100 mm x 100 mm.

**b. Long Columns**
Length of column = 1000 mm;
Cross-section of the column = 75 mm x 75 mm;
l/d ratio = 13.33;
Cross-section of one laminate = 25 mm x 75 mm, three layers of laminate making approximate cross-section of 75 mm x 75 mm.

As stated above a total of thirty CLT columns and six single piece control columns of two categories were fabricated under similar environmental conditions. The description of each column and their designation is given in Table 4. The symbol ‘S’ and ‘L’ associated with CLT indicates a short column and long column respectively. A sample of these columns is shown in Figure 2.

Each column was tested to failure under concentric axial loading. Short columns with both ends pin were tested in a computerized universal testing machine (UTM) of 1000kN capacity (Figure 3), the loads and corresponding displacements are recorded in the computer through data control and acquisition system. Due to larger lengths, long columns could not fit in the UTM, and as such were tested in a loading frame of 1000 kN capacity with similar conditions. The load was applied through a hydraulic jack and the displacements were recorded with

**TABLE 4.** Description and Designation of columns

| No. | Description | Designation | |
|---|---|---|---|
| | | Short column | Long column |
| 1. | Control column with no laminates | SCLT-0 | LCLT-0 |
| 2. | CLT column joined with epoxy | SCLT-E | LCLT-E |
| 3. | CLT column strengthened with bolts | SCLT-B | LCLT-B |
| 4. | CLT column strengthened with cold steel. | SCLT-S | LCLT-S |
| 5. | CLT column strengthened with single helix of FRP cloth | SCLT-SH | LCLT-SH |
| 6. | CLT column strengthened with double cross helix of FRP cloth | SCLT-DH | LCLT-DH |

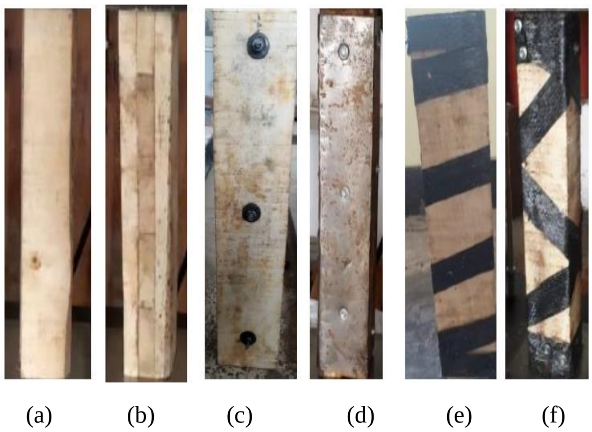


**Figure 2.** Sample Columns:(a) Solid column, (b) CLT Column, (c) Bolted CLT column, (d) Cold form sheet wrapped CLT column, (e) Single helix CFRP wrapped CLT column and (f) Double helix CFRP wrapped CLT column

the help of dial gauges fitted at the top and mid height of the column. The bottom and top surface of the columns were finished and leveled well to prevent any loading concentrations. Further, steel plates were used on top and bottom to distribute the load uniformly over the cross-section of the column.

## 4. RESULTS AND DISCUSSION

While performing the tests on columns, loads and vertical displacements were recorded during the entire testing period until their failure. These load and displacement values were averaged and plotted to obtain the stiffness, ultimate load, and maximum displacement. The failure pattern of short columns is shown in Figure 4. Control columns failed in the crushing of material, whereas

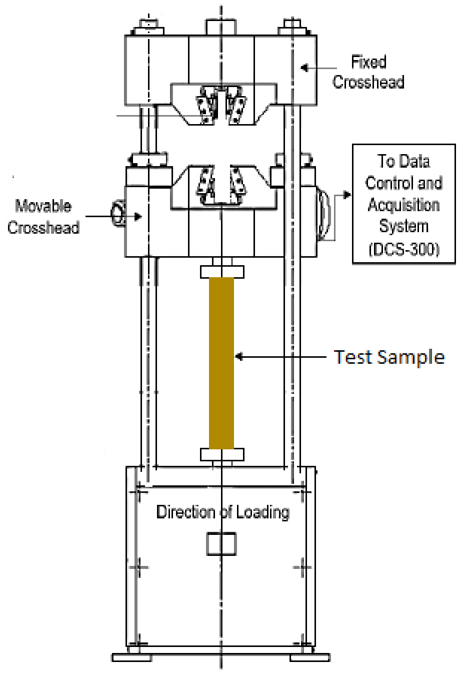


**Figure 3.** 1000 kN Universal Testing Macnine

SCLT-E failed due to the debonding of laminations Figures 4(a) and 4(b). Similarly, SCLT-B columns also failed due to the breaking of the Araldite bond followed by the buckling of the individual laminations Figure 4(c). However, SCLT-S columns failed by crushing of grains followed by the sudden opening of the cold form steel casing Figure 4(d). Similarly, in the case of SCLT-SH and SCLT-DH failure occurred due to the crushing of wood fibres and not by the debonding of the laminations as was found in the CLT column without strengthening (Figures 4(e) and 4(f)). Thus the FRP and cold steel sheet wrapping kept the laminations in position and enhances the axial carrying capacity of the CLT columns.

For short columns comparison of ultimate loads is shown in Figure 5. From this figure it is observed that the

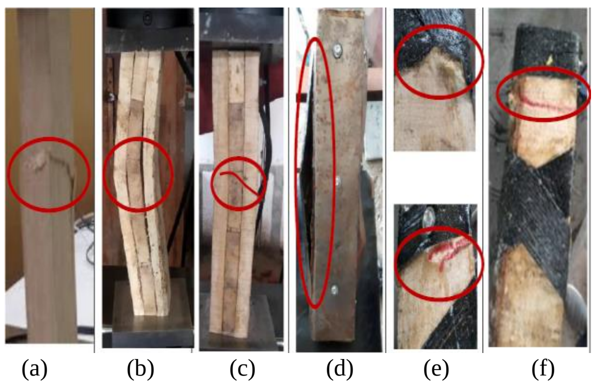


**Figure 4.** Failure pattern of short columns (a) SCLT-0, (b) SCLT-E, (c) SCLT-B, (d) SCLT-S, (e) SCLT-SH and (f) SCLT-DH

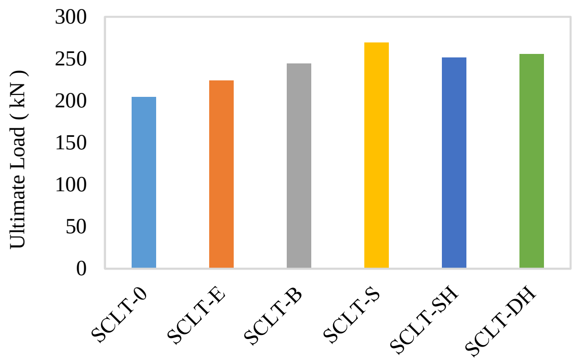


**Figure 5.** Comparison of Ultimate load carrying capacity for short columns

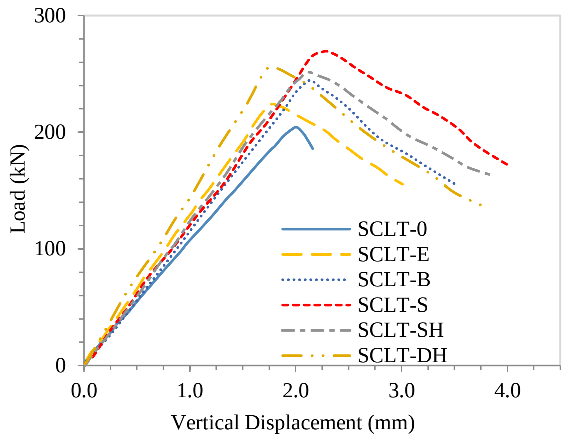


**Figure 6.** Comparison of load-displacement curves of various short columns

load-carrying capacity has increased in all the improvement techniques, however, SCLT-S has shown the maximum load-carrying capacity. The improvement in load-carrying capacity with different techniques is shown in Table 5. From this table, it is observed that using cross laminates with epoxy (SCLT-E) has increased the load-carrying capacity by 10%, and by adding few bolts (SCLT-B) the capacity has increased by about 20%. An increase in load-carrying capacity is as high as ~ 32% for SCLT-S i.e for the CLT column laminated with cold steel sheets. FRP helix has improved the load-carrying capacity by about 23% for SCLT-SH and 25% for SCLT-DH. Although there is a slightly lesser increase in strength (20%) in the case of SCLT-B; however, this is the simplest and cheapest technique for such kind of CLT columns.

Further, load-displacement curves for various SCLT columns have been plotted and a comparison of these load-displacement curves is shown in Figure 6. From this figure, it is observed that both stiffness and ductility of these CLT columns increases as compared to SCLT-0. The maximum stiffness and ductility are observed in the case of SCLT-DH due to confinement by FRP.

Similarly, long columns were tested, loads and corresponding vertical displacements were recorded till failure and a typical failure mode of these columns is shown in Figure 7. From this figure, it is observed that the control column failed by elastic buckling followed by the cracking of timber on the tension side of the specimen, Figure 7(a). LCLT-E columns failed immediately due to the debonding of laminates and fell apart resulted in a brittle failure as such no image has been captured. Similar to control columns, LCLT-B columns failed due to the combined buckling and crushing of timber fibres, Figure 7(b). The specimen initially buckled under the axial load followed by the crushing of fibres on the compression side in the middle area. In the case of LCLT-S columns, the failure occurred due to initial elastic buckling followed by the debonding of steel casing from the timber surface and finally cracking of timber fibres on the compression side, Figure 7(c). Similarly, in the case of LCLT-SH and LCLT-DH, the columns initially buckled elastically followed by the crushing of timber fibres on the compression side in the portion that was not covered by FRP (Figures 7(d) and 7(e)). Due to the wrapping arrangement of FRP cloth around the cross-laminated column, increased the capacity of the columns with large deformations; thus, resulted in a delayed failure. As expected, contrast to the short columns all the long columns failed in buckling first followed by crushing of timber fibres.

(a) (b) (c) (d) (e)

**Figure 7.** Failure patterns of long columns (a) LCLT-0, (b) LCLT-B, (c) LCLT-S, (d) LCLT-SH and (e) LCLT-DH

**TABLE 5.** Increase in load-carrying capacity in short columns

| No. | Designation | Ultimate load (kN) | Compressive stress ($N/mm^2$) | % Increase |
|---|---|---|---|---|
| 1 | SCLT-0 | 204.24 | 20.42 | 0 |
| 2 | SCLT-E | 224.12 | 22.41 | 9.73 |
| 3 | SCLT-B | 244.10 | 24.41 | 19.52 |
| 4 | SCLT-S | 269.10 | 26.91 | 31.76 |
| 5 | SCLT-SH | 251.50 | 25.15 | 23.14 |
| 6 | SCLT-DH | 255.64 | 25.56 | 25.17 |

A comparison of ultimate loads is shown in Figure 8. From this figure it is observed that for the column with cross laminates with epoxy only failed due to separation of laminates due to small buckling effects because of the slenderness effect. Further, it is observed that the compressive strength (overall load-carrying capacity) of all these columns is much lower than the short columns due to the slenderness effect as expected (Table 6). The improvement in load-carrying capacity with different techniques in the case of long columns is shown in Table 6. From this table, it is seen that the increase in load-carrying capacity is insignificant in case of LCLT-B (10%). However, an increase in load carrying capacity is as high as 50% in the case of the double helix CLT column (LCLT-DH). This increase in capacity in LCLT-DH owes to better confinement of laminates by cross FRP. Further, load-displacement curves for these long columns due to various techniques have been plotted and a comparison of these load-displacement curves is shown in Figure 9. From this figure, it is observed that stiffness and ductility increases only when there is sufficient confinement in the cross laminates of these columns, which is maximum in the case of LCLT-DH followed by LCLT-S. Further, it is also observed that LCLT-B has almost the same stiffness as that of LCLT-0 implying that effect of bolting in case of long columns is insignificant.

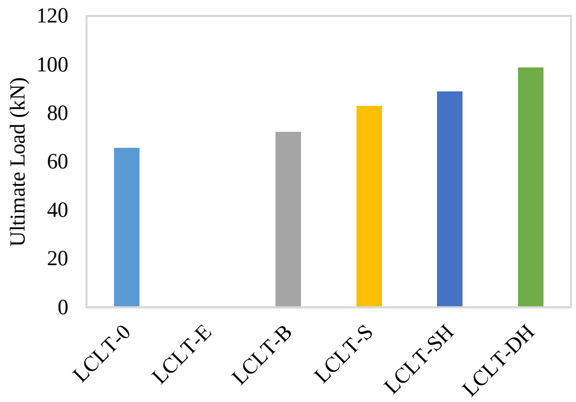


**Figure 8.** Comparison of Ultimate load carrying capacity for Long columns

**TABLE 6.** Increase in load-carrying capacity in long columns

| No. | Designation | Ultimate load (kN) | Compressive stress (N/mm$^2$) | % Increase |
|---|---|---|---|---|
| 1 | LCLT-0 | 65.57 | 11.66 | 0 |
| 2 | LCLT-E | --- | 0.00 | ---- |
| 3 | LCLT-B | 72.21 | 12.84 | 10.13 |
| 4 | LCLT-S | 83 | 14.76 | 26.58 |
| 5 | LCLT-SH | 88.81 | 15.79 | 35.44 |
| 6 | LCLT-DH | 98.77 | 17.56 | 50.63 |

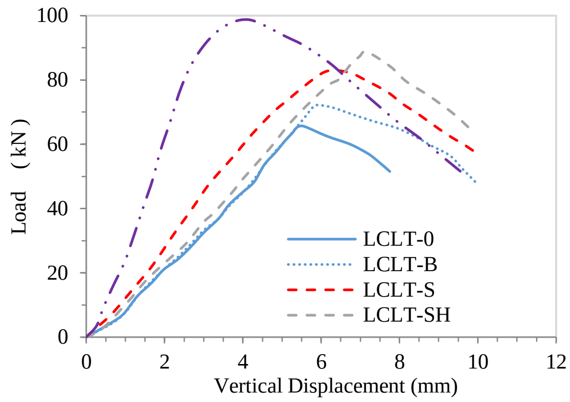


**Figure 9.** Comparison of load-displacement curves of various long columns

## 5. CONCLUSIONS

From the above discussion, it concluded that:

- The use of cross-laminated timber improves the strength, stiffness, and ductility in both short and long type columns.
- In the case of short columns, the improvement in load-carrying capacity and stiffness is more as compared to long columns.
- Simply using epoxy and few bolts in timber laminates increases (SCLT-B) the load-carrying capacity of columns by about 20%. However, in the case of cold form steel SCLT-S this increase is as high as 32%. Maximum stiffness and ductility are achieved in case of double cross helix FRP wrapping columns (SCLT-DH).
- In the case of long columns, the load-carrying capacity is derived by the slenderness of the columns, as such depends upon the confinement of these columns. In the present study maximum improvement in the load-carrying capacity, stiffness and ductility have been observed in the case of double cross helix FRP wrapping columns (LCLT-DH).
- The increase in load-carrying capacity is about 50% in these LCLT-DH columns.

## 6. ACKNOWLEDGMENT

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Persian Abstract

**چکیده**

الوار جدا از اینکه یک ماده ساختمانی ارزان قیمت است، دارای مزایای زیست محیطی بی‌شماری است که آن را به یکی از مصالح ساختمانی بسیار مورد پسند، به ویژه برای سازه‌های مسکونی با بار متوسط تبدیل می‌کند. الوار به دلیل کشت آسان درختان الوار می‌تواند به وفور در دسترس قرار گیرد، بنابراین می‌تواند به عنوان یک ماده ساختمانی کارآمد و پایدار عمل کند، به شرطی که از پتانسیل ساختاری آن کاملاً استفاده شود. در این مطالعه، از روش‌های مختلف بهبود عملکرد برای افزایش ویژگی‌های مقاومت محوری یک نوع چوب (صنوبر) استفاده شده است که به وفور در قسمت شمالی هند موجود است. تکنیک‌های مختلف اتصال / بسته‌بندی برای استفاده از صنوبر به شکل چند لایه، معروف به چوب چند لایه (CLT) استفاده شده است. مشخص شده است که می‌توان در ستون‌های کوتاه CLT به سادگی با پیچ و مهره ورقه ورقه‌ها، به بهبود مقاومت در حدود ۲۰ درصد دست یافت، در حالی که چون این بهبود می‌تواند تا ۳۲ درصد نیز برسد، به شرطی که از ورق‌های فولاد به فرم سرد (CFS) برای تقویت این ستون‌های چوبی استفاده شود. به طور مشابه، در مورد ستون‌های بلند CLT، هنگامی که یک مارپیچ دو طرفه از پارچه پلیمر تقویت شده با الیاف (FRP) برای هدف تقویت استفاده می‌شود، بهبود قدرت ۵۰ درصد حاصل می‌شود. علاوه بر این، این مطالعه با هدف استفاده از برگه‌های کوچک بلا استفاده و در غیر این صورت، ضایعات / قطعه‌های چوبی در ستون‌ها با تکنیک‌های بهبود قدرت برای بهبود عملکرد مقاومت محوری استفاده می‌شود.