Evaluation on Seismic Performance of "Dhajji-Dewari" Timber Wall Panel

M. Sushma, Vijayalakshmi Akella, B. K. Raghu Prasad, and G. Deepu

1 Introduction

Vernacular architecture is a major category of architecture which is basically dependent on local needs, local traditions, and locally available construction material [1]. In recent years, technology has disrupted millennia-old building traditions. Several research works and thoughts are developed for the conventional building techniques in urban localities. Whereas, the suburban and rural areas are not taken care in this aspect, which stands as major part of any developing country [2]. UNESCO has emerged in identifying the combination of vernacular techniques with modern materials and technology.

Earthquakes are characterized as the major destructive natural hazard which leads to loss of life, economy, and property. Half-timbered vernacular architectural style popularly known as "Dhajji-Dewari" style of architecture in India combines the finest features of masonry and timber, which offers great resistance against seismic actions [3]. Taking this aspect into consideration, it is of great interest to enhance knowledge on the seismic behavior of such construction typology.

Dhajji-Dewari is the traditional timber-braced frame with random rubble masonry infill construction seen mainly in Kashmir, India. It is noted that vertical posts, horizontal and diagonal bracings are closely packed. The inherent property of timber to be flexible without breaking during an earthquake leads to the exceptional performance of such systems [4].

The research presented in this paper includes experimental evaluation of mechanical properties of timber and timber joints along with numerical investigations conducted on Dhajji-wall in order to compute the seismic capacity of Dhajji-Dewari

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timber-nailed wall panel. The masonry infill is neglected as no significant effect on the peak strength was seen except that of viscous damping. It is seen that wall with masonry infill has higher viscous damping value when compared to wall without infill. Infill just adds on to the initial stiffness of the wall [4]. Hence in the present work, analysis of timber frame is performed neglecting the effect of infill. For the experimental purpose, locally available Acacia wood species is used which has high durability and water-resistant qualities. The experimental work includes the testing of mechanical property of Acacia wood, tension and bending tests on possible tennon-mortise joints in the wall panel. The results obtained from the experiment is applied in the numerical model to perform nonlinear static pushover analysis.

2 Details of Dhajji Wall Panel

Dhajji wall panel considered for analysis has three sets of members with cross-sectional dimensions 4″ × 4″, 2″ × 4″, 4″ × 1″ as shown in Fig. 1. The 4″ × 4″ members are used as main posts and base plate. The 2″ × 4″ members are used as secondary post. The 4″ × 1″ is used as cross bracers. The length and height of the test specimen is taken as 6′5″ and 8′8″, respectively.

For the purpose of connections, nails with diamond pointed ends were used. Main vertical post is connected to top and bottom plate through Type-1 tennon and mortise connections. Secondary vertical post is connected to top and bottom plate through Type-2 tennon and mortise connections as shown in Fig. 2. These tennon and mortise joints were connected by nails designed as per IS: 2366-1983, Indian Standard Code of Practice for Nail-Jointed Timber Construction [5].

The lateral load response of the panel is majorly taken by the connections with respect to vertical posts and bottom plate [4]. Hence to find the capacity of such joints, tension and bending tests are conducted for the Type-1 and Type-2 connections. Member sizes of tennon mortise connection joints is kept same as the wall panel

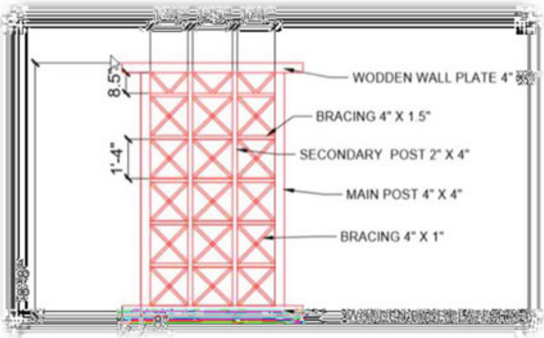


Fig. 1 Cross-sectional dimensions of Dhajji-Dewari wall panel

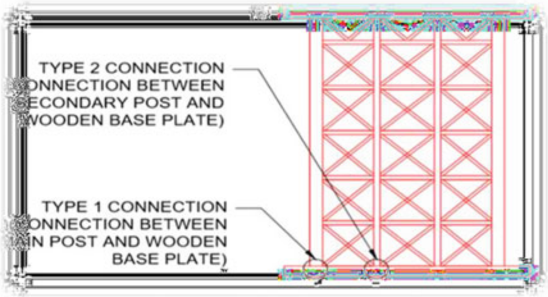


Fig. 2 Type-1 and type-2 connection of timber wall panel

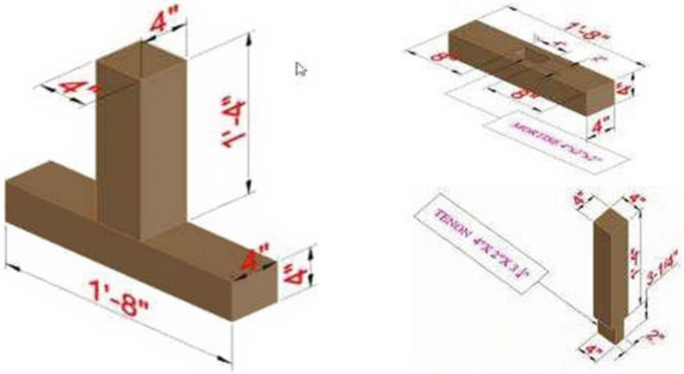


Fig. 3 Joint details of type-1

taken for which height of member is taken as 1′8″. Tenon sizes for Type 1 and Type 2 joint were 4″ × 2″ × 3.25″ and 2″ × 1″× 3.25″. Figures 3 and 4 show joint details of Type-1 and Type-2 connections.

3 Details of Nail-Jointed Timber Construction

Nail with Diamond Pointed edge is used for the joints. As per the codal provision, the length and diameter of the nail used is 100 mm and 4 mm, respectively. Practically nails are arranged in such a way that line of force in the member passes through the centroid of the group of nails transmitting load to it. Nails are driven from opposite faces (adjacent nails are driven alternatively from either face of joint) to strengthen the nail-joint as shown in Figs. 5 and 6. The number of nails calculated as per IS: 2366-1983 for each type of joint is tabulated in Table 1.

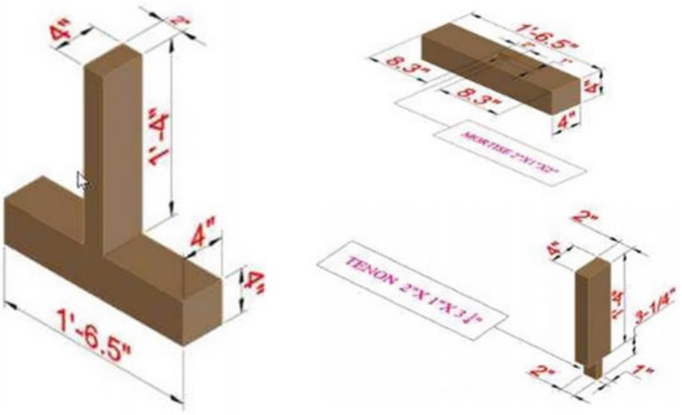


Fig. 4 Joint details of type-2

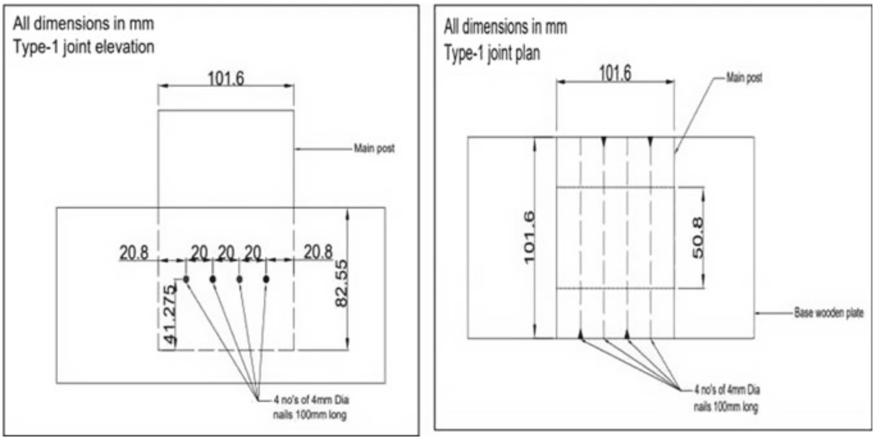


Fig. 5 Elevation and plan view of type-1 joint

4 Test Setup and Procedure to Determine Mechanical Properties of Acacia Wood

4.1 Compressive Strength Parallel to Grain

The timber “Acacia” selected for the present study is tested for compressive strength parallel to grain as shown in Fig. 7 using 20 × 20 mm cross-section and 80 mm in length with a rate of loading 0.8 mm/min as per IS: 1708 (Part 1 to 18)—2005, Methods of Testing of Small Clear Specimens of Timber [6].

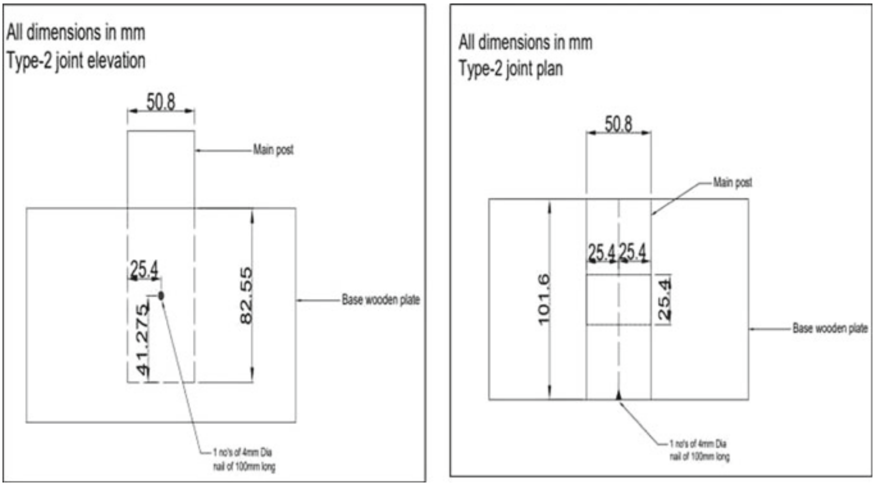


Fig. 6 Elevation and plan view of type-2 joint

Table 1 Number of nails calculated as per IS: 2366-1983

Type of joint	Number of nails
Type 1	4
Type 2	1

Fig. 7 Test setup of compression test parallel to grain

4.2 Tensile Capacity Perpendicular to Grains

The acacia wood specimen of size 50 mm × 50 mm × 56 mm is tested for tension capacity perpendicular to grains as shown in Fig. 8 with a rate of loading 6 mm/min as per IS:1708 (Part 1 to 18)-2005, Methods of Testing of Small Clear Specimens of Timber [6].

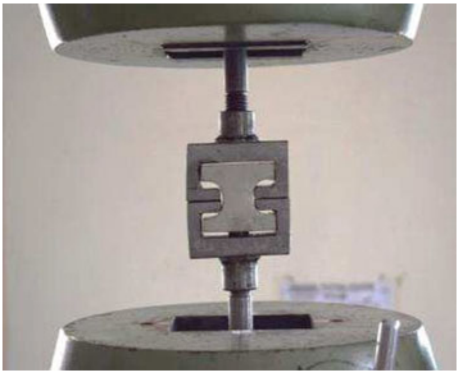


Fig. 8 Test setup of tensile capacity test perpendicular to grain

5 Test Setup and Procedure to Determine Mechanical Properties of Timber Joints

5.1 Bending Test on T-joint

Type-1 and Type-2 timber joints is subjected to bending test. The T-joints is loaded into the loading frame as shown in Fig. 9. Digital Protractor is placed at the connection to find the rotation. This rotation due to force applied is required to quantify the moment carrying capacity of the joint.

Fig. 9 T-joints subjected to bending in loading frame

5.2 *Tension Test on T-Joint*

Type 1 and Type 2 timber joints is subjected to tension test as shown in Fig. 10. The T-joints is loaded in Universal Testing Machine. Extensometer is used to measure the displacement at joints. The force with corresponding deformation gives the tensile capacity of joints.

6 Numerical Modelling of Dhajji Wall

The finite element software ANSYS is used for the numerical modeling of the wall chosen. The result obtained from tension and bending elastoplastic curves are assigned to Type-1 and Type-2 connections in the numerical model with a function of "hinge property". At the cross bracings and interior horizontal members, moments are released to replicate the free rotation behavior at connections [7]. Image of the numerical model of wall in ANSYS is shown in Fig. 11. Link element is used to impart the nonlinear property to the linear elements. This non-linear property is induced by giving tension and bending parameters of the experiment to the hinge.

The horizontal main beams and vertical timber post is analyzed as elastic bending elements whereas horizontal bracing elements as a truss element to duplicate the pull-out behavior of joints as demonstrated in the experiment, with a limit on their tensile and compressive strengths. Downward force of 500 N is applied on each vertical post as per the calculation of roof load.

Two nodes having same coordinates for each of the connection between horizontal and vertical timber beams is the procedure used to create plastic hinges. Further link elements is used to connect these two nodes by applying the results of tension and bending test of joints. The node at bottom of the structure which is connected to bottom of horizontal beam is restrained against rotation and transition to model it as

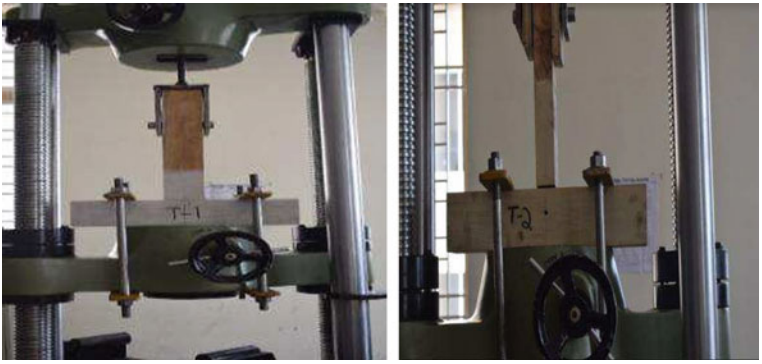


Fig. 10 T-joints subjected to tension test in universal testing machine

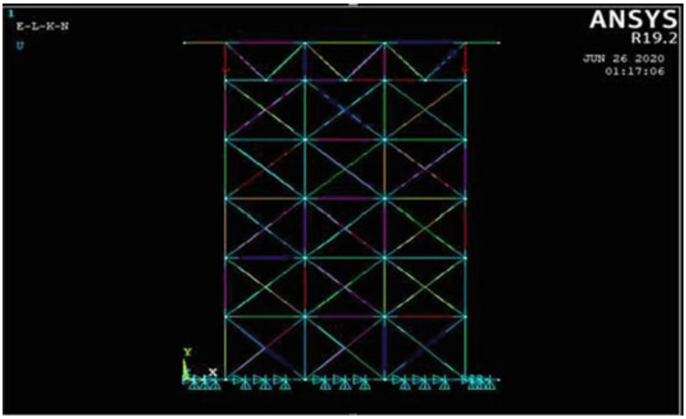


Fig. 11 Numerical model of wall panel in ANSYS

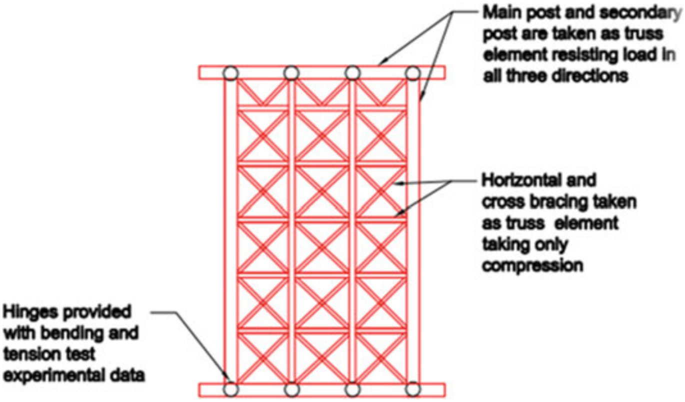


Fig. 12 Details of the element types selected for numerical model

fixed support. Figure 12 represents the pictorial representation of wall panel model with their elemental details.

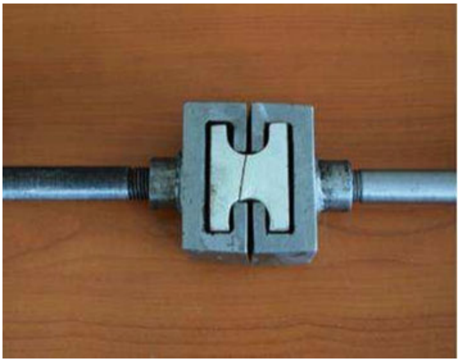
7 Experimental Test Results

7.1 Compressive and Tensile Strength Test on Acacia Wood Specimen

From test conducted on acacia wood specimen based on IS: 1708 (Part 8)-1986, it is observed that compressive strength parallel to grains is 42.5 MPa. It is seen that the

Fig. 13 Failure pattern of Acacia wood test

Fig. 14 Failure pattern of Acacia subjected to compressive strength wood subjected to tensile test



timber specimen subjected to compression parallel to grain failed due to shearing action as shown in Fig. 13. Modulus of elasticity of Acacia is found to be 12,000 MPa. The tensile strength perpendicular to grains is obtained as 5 kN. Failure pattern for timber specimen subjected to tensile strength test perpendicular grain is shown in Fig. 14.

7.2 Tension Test on Type-1 and Type-2 Joint

From the force–displacement graph plotted as shown in Fig. 15, it is observed that the ultimate load taken by Type-1 joint is 17.60 kN and Type-2 joint is 3.90 kN, for which corresponding displacements were 23 mm and 26.3 mm, respectively. The

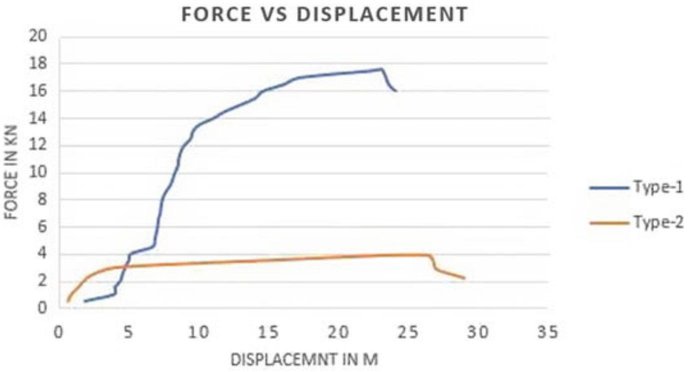


Fig. 15 Force versus displacement plot of type-1 and type-2 joint

ultimate stress obtained with respect to ultimate load for Type-1 joint is 3.4 MPa and Type-2 joint is 3.02 MPa.

7.3 Bending Test on Type-1 and Type-2 Joint

From the moment-rotation graph plotted as shown in Fig. 16, it is observed that the ultimate load taken by Type-1 joint is 0.62 kN and Type-2 joint is 0.49 kN, for which corresponding rotation is 0.0245 rad and 0.1015 rad respectively.

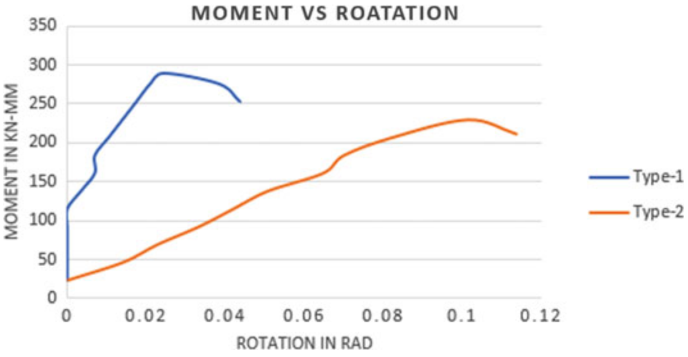


Fig. 16 Moment versus rotation of type-1 and type-2 joint

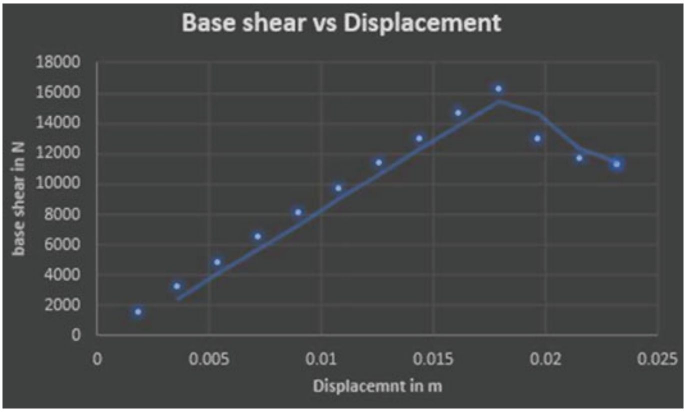


Fig. 17 Base shear versus displacement graph for Dhajji-Dewari wall panel

8 Numerical Analysis of Wall Panel

Dhajji-Dewari wall panel considered for the study is subjected to pushover analysis. Properties of Acacia wood and joints obtained from experiment are assigned. The tension and bending results obtained from testing Type-1 and Type-2 is provided to the respective hinge.

Base shear versus displacement curve of the wall is plotted. The lateral capacity of the wall is found to be 20 kN. Maximum displacement is found to be 17.9 mm for the lateral load of 20 kN. Load, displacement, and base shear of the panel is shown in Fig. 17. The maximum displacement of the wall panel is shown in Fig. 18.

At 22 kN lateral load, the maximum compressive stress in horizontal bracing is 6.98 MPa and cross bracings is 7.46 MPa, which does not exceed the experimental results. Even though corner joints failed, bracings intact even at lateral load of 20 kN. The stress in horizontal and cross bracings is shown in Fig. 19.

When the lateral load of 22 kN is applied, the stress in type-1 joint is 4.3 MPa in the numerical model which exceeds the maximum stress of type-1 joint 3.4 MPa obtained from test results. Hence the failure of panel initiates at type-1 joint when the lateral load is more than 20 kN. The stress concentration in the frame elements is shown in Fig. 20 proves that the panel fails with the failure of Type-1 joint.

9 Conclusions

When the nails were provided with sufficient edge and pitch distance as per IS: 2366-1983, Code of Practice for Nail-Jointed Timber Construction, it was seen that nails failed during tensile capacity test and not the timber. The lateral capacity of wall was found to be 20 kN for the designed joints. Numerical analysis observations

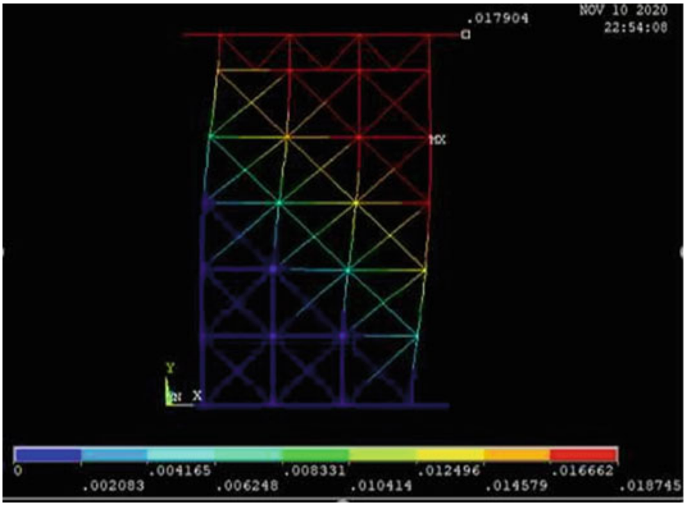


Fig. 18 Maximum displacement of Dhajji-Dewari wall panel

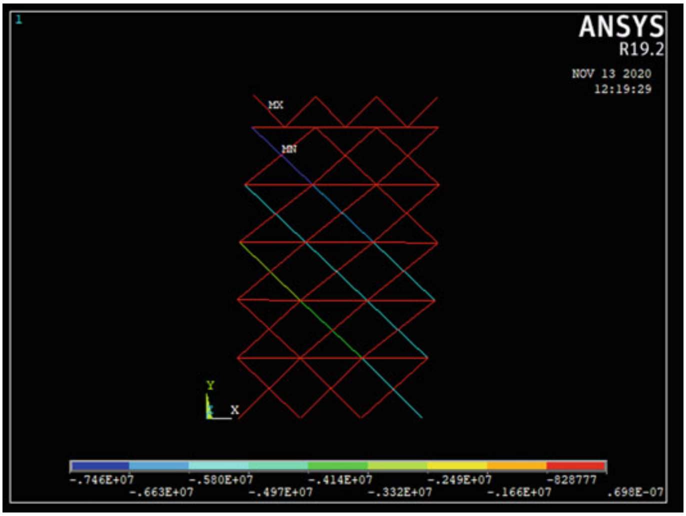


Fig. 19 Stress in horizontal and cross bracings at 22 kN lateral load on wall panel

have demonstrated large deformability of Dhajji wall panel under lateral load. The displacement of the wall panel is found to be 17.9 mm which is within the maximum allowable deflection of L/120 as per International Code Council. Bracings being a member under compression gave good resistance even at the ultimate load. Maximum stress concentration with a value of 4.3 MPa was seen in the joint that connected main vertical post to top and bottom of the panel. The failure at this joint led to the

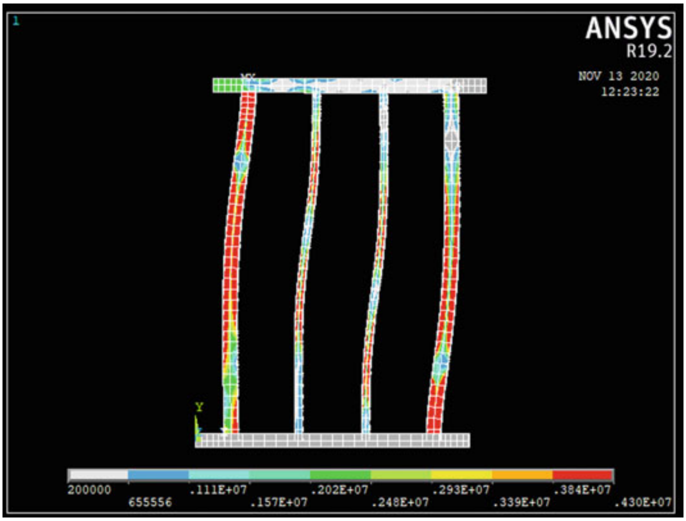


Fig. 20 Stress concentration in Dhajji-Dewari wall panel

failure of the timber wall panel. Dhajji-Dewari wall panel showed inelastic deformation without reaching its breaking point. This behavior is responsible for good performance of the Dhajji-Dewari structures in case of an earthquake. Such style of vernacular architecture with traditional construction techniques and materials should be embraced and rediscovered. With little care and research these structures can be engineered to perform better.

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