A

DISSERTATION

ON

"VERNACULAR BUILDINGS IN UTTARAKHAND AND HIMACHAL"

Submitted by

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this seminar report entitled, **"VERNACULAR BUILDINGS IN UTTARAKHAND AND HIMACHAL"** submitted in the Department of Civil Engineering, IIT Roorkee, is an authentic record of my own work under the guidance of **Dr. SANJAY CHIKERMANE**, Assistant Professor, Department of Civil Engineering, IIT Roorkee, Roorkee.

Dated: 21 May, 2019 **KRISHAN YADAV**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Uttarakhand and Himachal are recognized as being highly vulnerable to earthquakes. In the past the region has been jolted by great earthquakes. People living in earthquake affected areas are generally quick to understand the fundamental premise of earthquake safety, that the key to avoiding loss of human lives lies in ensuring safe construction. This fundamental understanding gave rise to the development of innovative practices to reduce human loss arising from structural collapse.

Vernacular Architecture is the result experience, experimentation and accumulated knowledge of our ancestors which have the all earthquake safety measures. But there is not much work is done to understand this indigenous construction technique. In this report we study about connection details and their strength in kath-kuni structures. As connections plays very important role in performance of any structure.

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1. INTRODUCTION

In the parts of the world away from the influence of urban civil engineering development, a remarkable reliance is seen on the traditional methods of construction without much technical rigor. As with the methods, so with the materials – and hence a prevalent use of materials like mud, timber, stone and masonry is seen in rural house construction. The evolution of these indigenous methods took place in parallel to modern engineering, where dependence came to grow on rules of thumb, traditional modus operandi and passed on knowledge. Features of such localized practices of construction and choice of material were peculiar to the geography, culture and resource availability in the regions concerned.

The Himalayas, being young fold mountains, pose a variety of threats to the population settlements – for instance, these regions are very prone to seismic activity. As a natural part of adaptation of the mankind, a panoply of measures have evolved in the housing methods in these regions, which help resist and withstand such natural threats – to such an extent that houses with multi-storeys are a regular sight in these regions. Many Indian towns in the Himalayan foothills have numerous multi-storeyed structures with unique structural and architectural prospect. Detailed investigations show that this area developed a specific and detailed earthquake-safe construction style within 1000 years. The western-central Himalayas have several localized type of structures which carry elements of earthquake-resistant design.

In the northern states of India in the Himalayan foothills, locally available, rudimentary construction materials like stone, mud and different types of wood have been used for construction for a long time. The kath-kuni style, for example, is characterized by a prevalent use of wood to make the structure robust to bear seismic forces. The Dhajji-diwari style uses timber made diagonal member to reinforce the walls against seismic induced tensile and shear forces.

Isolation of these areas from the reach of modern engineering practices doesn't imply that the techniques involved in the vernacular construction are altogether rudimentary. In fact, a careful perusal of the structural form and the use of materials in different parts of the structure gives an idea that an awareness about the different types of structural effects due to earthquakes has been always present in the locals. The construction procedure is methodical and every step is well laid down in procedures and stages similar to the practices of constructing RC framed houses.

However, the western-central Himalaya's native heritage of aseismic construction techniques is being rapidly lost, replaced by reinforced cement concrete (RCC) construction. This decline is due to a variety of factors, including changing cultural values, demographic and economic transitions, and rural development programmes. While RCC construction can be highly earthquake-resistant, the manner in which this new technology has proliferated in the western-central Himalayas has created vulnerability to earthquake disasters and poses many questions of the sustainability and appropriate use of newer technologies. Indigenous construction techniques still have much to offer in terms of their inherent sustainability and appropriateness.

Gosain and Ayra note that during the 1967 Kashmir earthquake buildings of three to five stories traditional buildings survived while modern RC buildings collapsed. According to Arya, one of the most important reasons for this was the damping of the motion of the building due to induced friction in the wall masonry, when it started cracking with mortar joints and moving forward. Internal damping may be in the order of 20%, compared to 4% in uncracked modern masonry (brick with Portland cement mortar) and 6%-7% after the masonry has cracked. In Himalayan region, rigidity carries the potential for destruction. The more rigid the building is, the stronger it has to be to avoid the fracture. Because the primitive materials and means of construction used in Himalayan region did not provide strength, flexibility was essential.

2. LITERATURE REVIEW

Vernacular architecture imbibes almost all earthquake safety measures, and despite the number of earthquakes it is subjected to it passes the test of time by setting up the firm. But there is limited research to validate the performance of vernacular construction. A better understanding of the structural behaviour of vernacular buildings is the first step in providing trust in this technique, and to identify aspects which are important for the reliable performance of the building system. Analysis by Zanden (2018) on kath-kuni wall shows that the connection plays very important role in kath-kuni structures as one missing kadil connection in third layers governs the whole failure mechanism. So, this project carries forward the work done by Zanden on kath-kuni structures. As it is important to develop evidence-based construction guidelines for this type of structures and exploit the traditional knowledge so that we can improve the performance of modern construction.

In Himachal Pradesh and Uttarakhand different type of indigenous built structures are there like Kath-ki-kunni, Thathara houses, Dhajji Dewari, Taq and koti banal etc. In this report kath-kuni structures are studied their structural features, construction techniques, and connection details.

2.1 KATH-KI-KUNI

In the Kath Kuni style of housing, there are thick load bearing walls connected to each other with timber connections. These connections are of dovetail type, and double horizontal beams are used in these, which are connected in the corners by horizontal dowel bars – all of these made of timber. Dry stone masonry is used to fill the space between the double horizontal beams. Kath Kuni buildings are a typical example of how traditional knowledge has been passed down the years having been used to great advantage, but are being lost out gradually on the present generation.

The lateral force is transferred from the walls lying out of the plane of the force, to the walls that lie in the plane. Members that help in force transfer are the timber beams and the sturdy corner connections.

The dowel and dovetail connection (called kadil and maanwi, respectively in the local language) permits relative rotation internal to the layer. There are no reinforcements provided in the wall in the vertical direction, so it is unrestrained against deformation in this direction.

There is also a great amount of friction present between the stone and timber components in the wall. All these features greatly enhance the ductility of the loaded walls that lie in the plane of seismic forces.

Kath kuni buildings not only perform better than a traditional RC building as far as seismic resistance and thermal insulation are concerned, but they also are have a cultural connotation. While the service life of an RC building is typically in the range of 60 years, Kath Kuni buildings are expected to be in service for a minimum of 200 years. Besides, this building is more *green* – in the sense, it has a much lower footprint on the environment as compared to an RC building. But Kath Kuni buildings are difficult to maintain and expensive – given the present-day scarcity of materials like wood, and the strict legal regulations in obtaining them. It also lacks the modern refurbishments in design. Hence, economically, Kath Kuni buildings don't score well on the scale of feasibility, while on the other hand, they are more sustainable.

The parallel timber beams are connected with dove tail (maanwi) connections, spaced at approximately one meter. These dove tail connections keep the parallel timber beams together.

This type of architecture is found predominantly in central Himachal Pradesh in the Kullu and Mandi districts, and parts of Shimla and Solan districts. This type of architecture is very common in the Kullu valley. Several of the buildings are about 100 years old, and some of the more massive structures, like temples or palaces, are several centuries old. This type of architecture was noticed by officers from the Geological Survey of India after the 1905 Kangra earthquake, who were impressed by the remarkable lack of damage to these buildings.

The investigation shows that this area has developed this elaborate and magnificent earthquake-protected construction style, and that there already existed a prevalent methodology of construction similar to building block work, with a use of locally available building materials like timber logs, stones etc. in good economy. In general, extensive use of wooden beams in multi-storeyed buildings is a quintessential feature of the Rajgarh area.

These buildings have lasted for such multitude of years in the past because of their form and arrangement of components, which indicates that an idea about the chief effects of earthquake, in particular relating to the failure of out of plane walls, was well formed in the minds of the local architects, masons and carpenters who made such buildings. These buildings have some typical earthquake resistant design features. For example, they are regular in plan with proper arrangement of openings and shear walls, the timber beams are integrated throughout the height and width of the structure.

A few salient aseismic features of this type of construction are given below:

i. *Timber tie-bands*: A pair of parallel wooden beams run along the whole length of the walls at regular intervals. They alternate in direction and the alternating pairs are placed at right angles (*Figure 1*). The space between the beams in the pair is usually filled with dry stone masonry, although there are variations depending upon locally available materials. These also form the coursework of the stone masonry in the walls. These beams integrate the superstructure by acting a closed peripheral system of ties, thus providing better robustness against lateral forces.

Figure 1 Corner construction detail of kath-kuni style housing. The timber bands run along both sides of the wall and are connected by pins along their length, and at the corners.

ii. *Interconnection & Corner Reinforcement:* The pair of timber beams are connected to each other at regular intervals along the length of the wall with dowel bars called kadils. Vertical connections at four points of the corner connect the pair of beams meeting at the corners at right angles (*Figure 2*). Thus, the structure is tied in periphery, both along the length and height of the structure. In this manner, the corners are strengthened for vertical distribution of loads, and the described manner of interconnection of the beams also ensures that the wall does not split under high compression. The layout of joints are a testimony to the great craftsmanship of the local carpenters and builders.

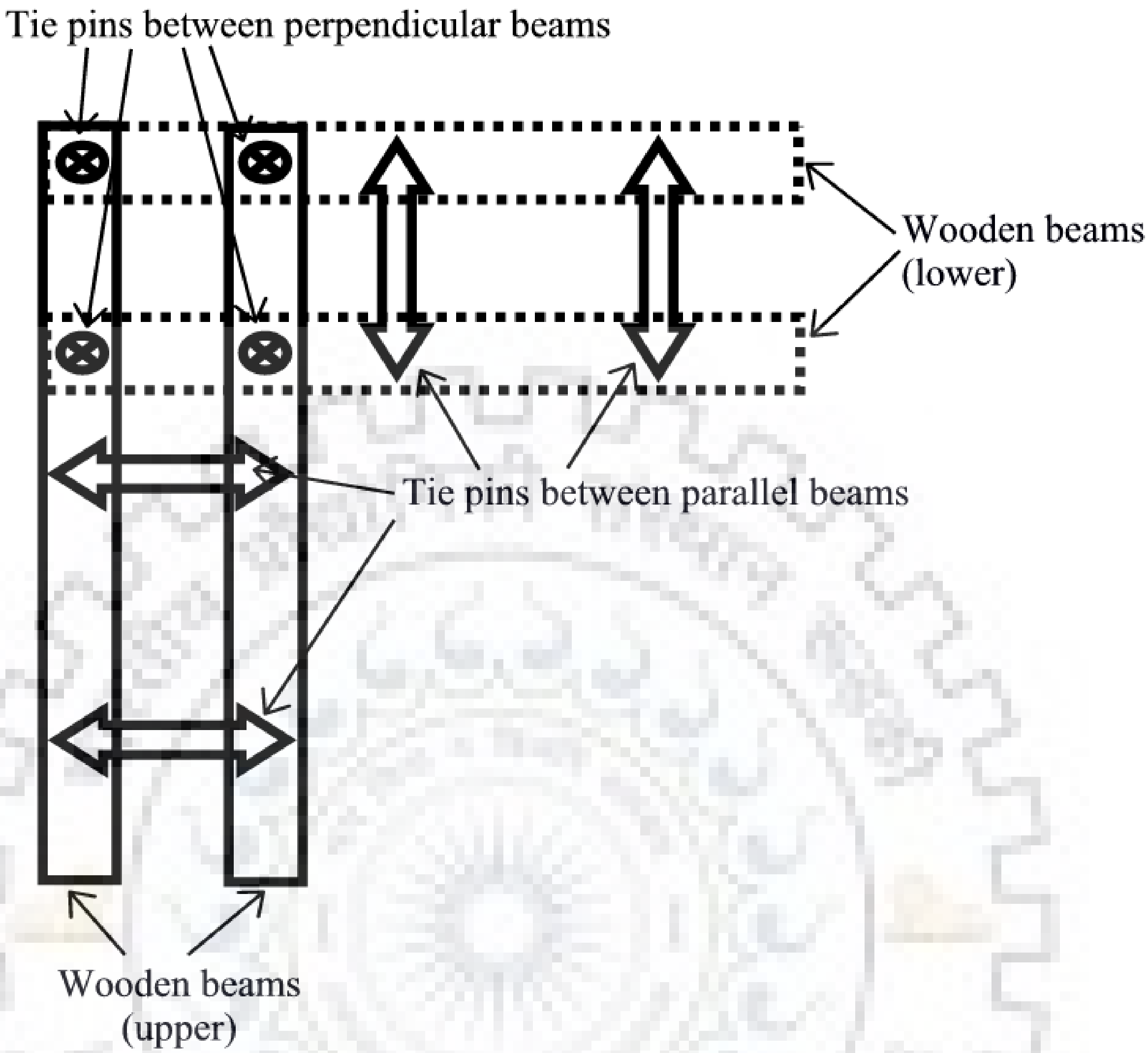


Figure 2 Overhead view of kath-kuni walls. This is a schematic representation of interconnection between parallel and perpendicular/alternating wooden beams.

iii. *Well-dressed stone masonry:* Generally, the walls are made of dry-stone masonry. Long, flat type of stones are used and they are laid in a compact and regular manner so that the load distribution is uniform and no component of the stone masonry is prone to move out of the wall system under the action of vertical loads. For the same reason, it is important for the stones to be well dressed. The walls are very thick compared to those in conventional brick masonry, for example, they are typically 0.4 m thick, but in some cases it may even go as far as 1 m. Apart from reducing the compressive stresses, such thickness also provide thermal insulation which is a chief concern for building design in the cold Himalayan regions.

iv. *Small Openings & Low Storeys:* The regions in the walls above the openings are subjected to high stresses due to the dead load of the wall components above the opening. These regions are also critical for stresses during seismic activity. Hence, the region above the openings, like windows, doors, etc. are reinforced with heavy wooden frames. The openings are not allowed to come in vertical alignment as it makes the wall substantially weak. The frames and doors are also braced diagonally. For creating more stability, low storey heights are used as it helps in lowering the centre of gravity.

v. *Stable Geometry:* The plan of Kath Kuni houses are close to squares in geometry. The ratio of the longer side to the shorter is seldom greater than 1.5. This prevents the longer walls from being too strained, and also keeps minimal the distance between the shear centre and centre of gravity. As the structures gain in height, they are tapered and their bases are wider so that destabilizing moments can be minimized. This approach enables massive kath kuni structures, like the temple of Jungi village in Mandi district (Figure 3), to be very stable.

Figure 3 A temple in Karsog area of Mandi district, H.P. (Rautela, et al., 2011)

vi. Wood surprisingly steers clear of its limitations as a construction material when used in a well-meditated design. Wooden structures have a higher specific strength over concrete and steel structures, i.e. for the same strength, their weight is low. This reduces the inertial forces during seismic activity.

vii. The raised stone pedestal on the foundation consolidates the soil at the base, and a more consolidated soil means better seismic isolation. The wooden plinth beams further diminish the effect of seismic vibrations effects on the upper part of the structure. The flexibility of the structure determines its performance during a given earthquake motion.

3. SCOPE

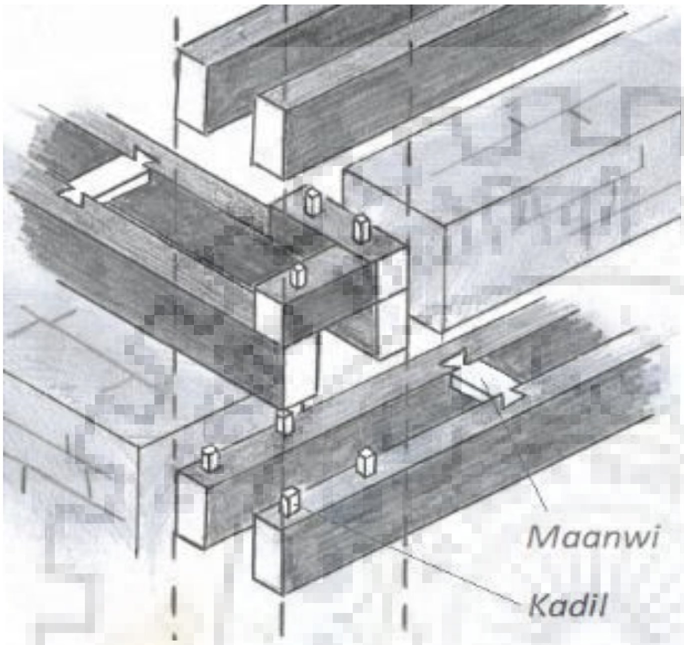


Figure 4 Maannwi and Kadil connections (Zanden, 2018)

Different studies shown that strength of timber wall or any other frame depends on capacity of connections as the quality and engineering details of a connection decides the failure mechanism of timber structure. In kath-kuni structures nails are not used in the connections instead timber dowels called ‘kadils’ used in corners to connect horizontal beams and to connect double horizontal beam timber dovetail connection is used which is called ‘maanwi’.

As (Zanden, 2018) mentioned in her thesis report that *“During the building of the wall, two of the twenty kadil connections in the third layer were accidentally left out. This led to a final failure in this layer, hence the missing kadils triggered other possible failure mechanisms.”*

So, it is evident that connection plays very important role in how structure behaves. If there is slight variation in connection configuration, then capacity of whole structure decreases by very rapidly.

The final dissertation comprises of standard testing of timber and experimental investigations on typical kath-kuni connections to find out their structural capacity and to further understand the behaviour of kath-kuni wall which is tested by zanden.

4. STANDARD TESTING OF TIMBER TO FIND PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

Materials

By (Zanden, 2018) deodar wood is used for testing of kath-kuni walls as it is readily available in Himalayan region. So, for testing of connections also deodar wood is to be used and physical and mechanical properties is to be found out of same.

Following physical and mechanical properties of timber need to be found out under this experimental program: -

i. Moisture content
ii. Specific gravity
iii. Static bending strength under two-point loading
iv. Compressive strength parallel to grain
v. Compressive strength perpendicular to grain
vi. Shear strength parallel to grain
vii. Tensile strength parallel to grain
viii. Tensile strength perpendicular to grain
ix. Cleavage strength parallel to grain

In order to obtain a good average figure, which is truly representative of the species, it is necessary to take samples from green timber as well as from seasoned timber and also sapwood, heartwood and from different parts of the same tree. For standard evaluation of physical and mechanical properties of a species from a locality, at least ten trees are chosen at random from the locality and sampling of material for different test is done. To find these physical and mechanical properties IS 1708 is followed. For each test 10 specimens are used. *Table 1* gives details about the specimens used in testing

Table 1 Specifics of specimens used in testing

Sr. No.	Test	Specimen size	No. of Specimen
1	Bending	50×50×1000	10
2	Compressive ∥	50×50×200	10
3	Compressive ⊥	50×50×150	10
4	Shear ∥	50×50×63	10+10
5	Tensile ∥	50×15×325	10
6	Tensile ⊥	50×50×56	10+10
7	Cleavage ∥	50×50×93	10+10
8	Moisture	50×50×25	Need to be checked of every specimen
9	Specific Gravity	50×50×150	10*

As of now moisture content, specific gravity, compression perpendicular to grain these three tests are completed. There testing procedure and experimental results are explained below: -

4.1 DETERMINATION OF MOISTURE CONTENT

TEST SPECIMEN

After completion of every test moisture content need to be checked. Specimen should be extracted near the place of failure. Section of specimen should be same as tested piece and length is taken as 2.5 cm. In case of shear torn out piece of section 5 X 5 cm need to be taken to determine moisture content. **When only moisture content is to be determined the dimensions shall be taken as 2.5 cm in length and 5 X 5 cm in cross-section.**

PROCEDURE

The specimen need to be weighed with precision of 0.001 gms in a weighing scale and then dried in a well ventilated oven at temperature of 103 ± 2°C. The weight need to be checked at regular intervals. The drying will be considered to be complete when the variation between last two weighings, does not exceed 0.002 gms. The final weight shall be taken as oven dry weight.

* Specimen for compression perpendicular to grain testing are used for this test also

CALCULATION

Weight loss expressed as a percentage of the dry weight of the oven will be taken as the moisture of the test sample. The formula for calculation shall be as given below:

Percentage of moisture content = $\frac{W_1 - W_0}{W_0} \times 100$

where

W_1 = weight of sample at test in gms, and

Wo = oven dry weight of sample in gms.

NOTE 1 – Procedure stated in ASTM D4442-16 is similar to Indian code IS 1708 – 1986.

NOTE 2 – In ASTM time interval between two weighings is specified as 3 hours and it also specifies that all weighings shall be carried out using closed weighing jars.

4.2 DETERMINATION OF SPECIFIC GRAVITY

TEST SPECIMEN

For specific gravity the test specimen is 5 X 5 cm in cross section and 150 mm in length.

PROCEDURE

The specimen shall be weighed precise to 0.001 gms. The dimensions of rectangular specimen shall be measured precise to 0.1 mm and volume shall be computed by multiplying all three dimensions.

CALCULATION

1. Specific gravity shall be computed as follows:

a) Specific gravity at the time of testing = $\frac{W_1}{V_1}$

b) Adjusted specific gravity = $\frac{W_1}{V_1} \times \frac{100}{100+m}$

Where

W_1 = weight in gms of test specimen,

V_1 = volume in cm^3 of test specimen, and

m = percentage moisture content of the test specimen

2. If weight at a given moisture content is required to be calculated, the same shall be calculated as below:
   Weight in kg/m^3 at specified moisture content m =

   (Specific gravity G at moisture content m) X 1000.

RESULTS

Measurements and calculation are shown in Table 2

Table 2 Measurements and calculation for specific gravity and moisture content

Sr. No.	Dimensions (mm)			Weight (gm)	Moisture Content (%)	Specific gravity (kg/m^3)	Adjusted specific gravity (kg/m^3)	Specific gravity at 12% moisture content (kg/m^3)
1	51.55	51.60	153.22	204.127	15.86	500.849	432.288	484.162
2	51.80	51.51	152.75	221.468	16.12	543.386	467.952	524.106
3	49.75	50.00	152.74	194.618	13.11	512.232	452.862	507.206
4	50.16	50.11	151.19	188.342	13.21	495.612	437.781	490.315
5	49.88	50.40	152.19	192.890	13.67	504.158	443.528	496.751
6	50.47	50.05	152.28	180.378	13.18	468.925	414.318	464.036
7	51.19	50.95	151.93	208.949	13.13	527.312	466.111	522.045
8	50.34	49.78	152.47	179.914	14.53	470.882	411.143	460.480
9	51.17	51.51	153.60	216.504	15.50	534.771	463.005	518.566
10	51.72	51.82	152.92	221.840	14.36	541.277	473.310	530.107

The adjusted average specific gravity of all 10 specimen of deodar timber is 446.23 Kg/m^3 and average specific gravity at 12% moisture content is 499.78 Kg/m^3.

4.3 DETERMINATION OF COMPRESSIVE STRENGTH PERPENDICULAR TO GRAIN

TEST SPECIMEN

The test sample has a cross section of 50 x 50 mm and a length of 150 mm. Sampling should be free from defects and faces should move towards the actual radial and touch direction.

PROCEDURE

1. **Placing the Specimen** – The load is applied through a metal bearing plate through a thickness of at least 15 mm in width of 50 mm, at the same distance from the end of the sample on the upper surface of the sample and at the right angle as shown in Figure 5. The load is applied to the radial surface.

Figure 5 Compression Perpendicular to Grain Testing Assembly Showing Load Application Method

2. **Rate of Loading** – The load is applied continuously throughout the test, so that the running head of the test machine continues at a constant speed of 0.01 mm per sec.
3. **Measurement of Load and Deformation** – A small load not more than 50 kg on 5 X 5 X 15 cm specimen will be applied initially to set the specimen. Then the deformation through a dial gauge is measured accurately up to 20 micro meter. Testing is continued till a deformation of 2.5 mm. If a maximum compressive load reaches at low deformation, then it will be recorded with corresponding deformation.

CALCULATION

A curve is drawn between the load and the deformation. Then read the load and deformation at proportionality limit. The load has been recorded on compression 2.5mm also.

Various attributes will be determined by the following formulas:

Table 3 Formulas for compressive strength perpendicular to grain

Sr. No.	Characteristics	Unit	Formula
1	Compressive stress at compression of 2.5 mm	N/mm^2	$\frac{P'}{A}$
2	Compressive stress at max. load	N/mm^2	$\frac{P_0}{A}$
3	Modulus of elasticity in compression perpendicular to grain	N/mm^2	$\frac{Ph}{\Delta A}$

where

P = load at limit of proportionality in N,

A = area of the cross section normal to the direction of load in mm^2 (50 X 50 mm),

P' = load at 2.5 mm compression in N,

P_0 = maximum load if reached at a compression less than 2.5 mm in N,

h = height of the specimen in mm, and

Δ = deformation at the limit of proportionality in mm.

RESULTS

Experimental data for compression perpendicular to grain testing shown in Figure 6 and Figure 7 for all 10 specimens

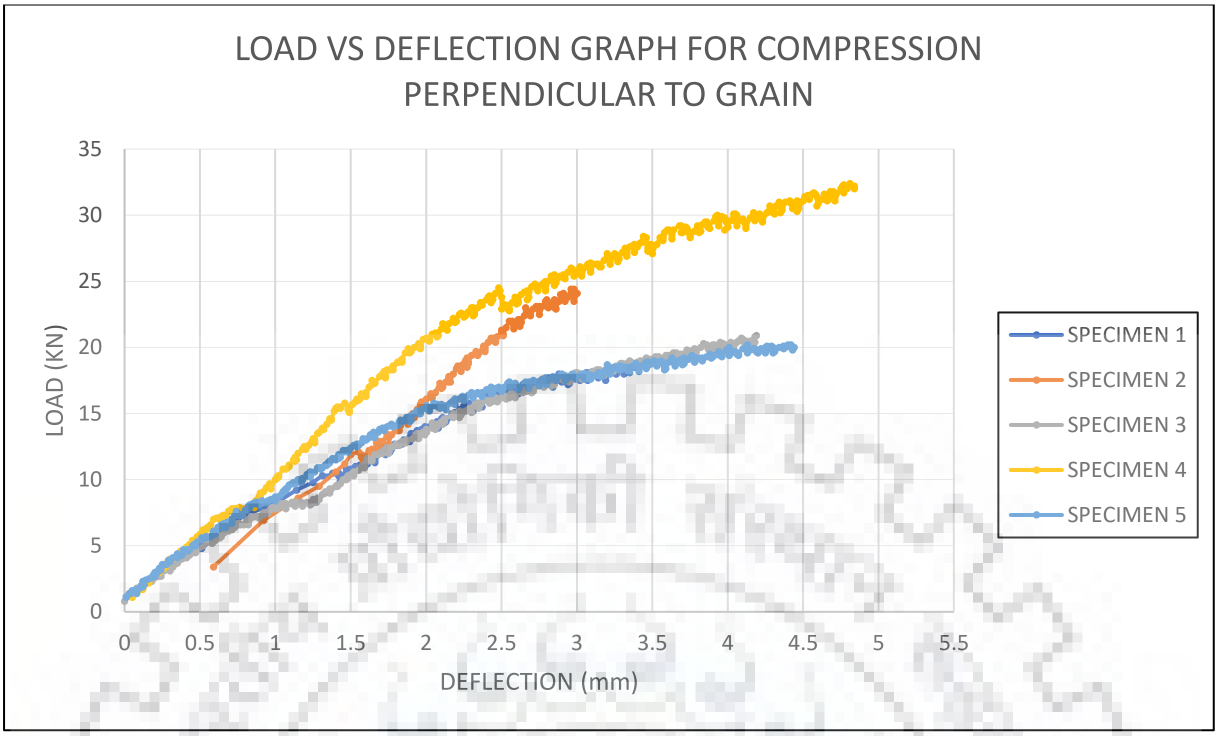


Figure 6 COMPRESSION PERPENDICULAR TO GRAIN LOAD VS DEFLECTION GRAPH SPECIMEN 1-5

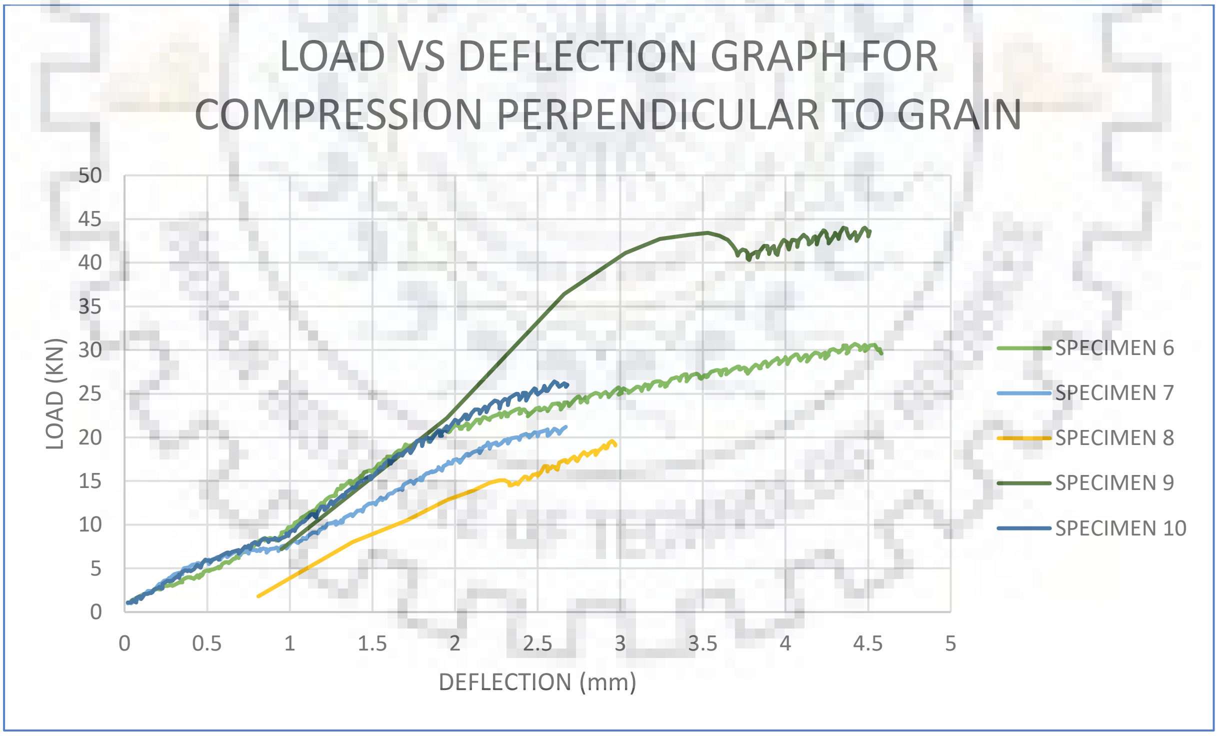


Figure 7 COMPRESSION PERPENDICULAR TO GRAIN LOAD VS DEFLECTION GRAPH SPECIMEN 6-10

Table 4 Results and calculation for compression perpendicular test

Sp No.	Dimension (mm)		Moisture Content (%)	Load At 2.5mm Deflection (KN)	Compressive Stress At 2.5 Mm Deflection (MPa)	Load At Limit Of Proportionality (KN)	Deflection At Limit Of Proportionality (mm)	Modules Of Elasticity (MPa)
1	51.55	51.6	15.86	16.5	6.40	13.5	1.9	141.97
2	51.8	51.51	16.12	21.2	8.23	16.05	2.03	159.02
3	49.75	50	13.11	16.2	6.48	11	1.57	139.43
4	50.16	50.11	13.21	23.8	9.50	14.4	2.1	137.28
5	49.88	50.4	13.67	16.9	6.71	11.5	1.4	162.59
6	50.47	50.05	13.18	23.3	9.31	19.5	1.8	218.48
7	51.19	50.95	13.13	20.5	8.05	10.3	1.3	159.21
8	50.34	49.78	14.53	15.9	6.39	15.1	2.27	134.54
9	51.17	51.51	15.5	36.4	14.13	42.7	3.24	261.84
10	51.72	51.82	14.36	25.1	9.69	15	1.44	207.93

Average compressive strength in perpendicular to grain direction of all 10 specimens is 8.49 MPa but specimen 9 is giving absurdly high value of 14.13 MPa and experimental data shows that rate of loading is also not what we expected so specimen 9 results are to be ignored while calculating average strength in perpendicular to grain direction. So, after ignoring specimen 9 average compressive strength in perpendicular to grain direction is **7.86 MPa.**

4.4 DETERMINATION OF STATIC BENDING STRENGTH UNDER TWO POINT LOADING

TEST SPECIMEN

The test specimen is 5 X 5 cm in cross-section and 1 m in length. Sampling should be free of defects and should not have more than 1 grain slope in 20 parallel to its longitudinal edge.

PROCEDURE

1. **Placing of the Specimen** – The test will be done on a suitable testing machine. The sample will be supported by a rigging in such a way that it will be sufficient free to follow the bending action and will not be controlled by friction. The specimen shall be so placed that the load is applied at two points equidistant from supports through the loading block to the tangential surface nearer to the heart. The distance between points of supports (span) is 90 cm. Distance between application points of load and supports (a) (see Figure 8) will be 15 cm.

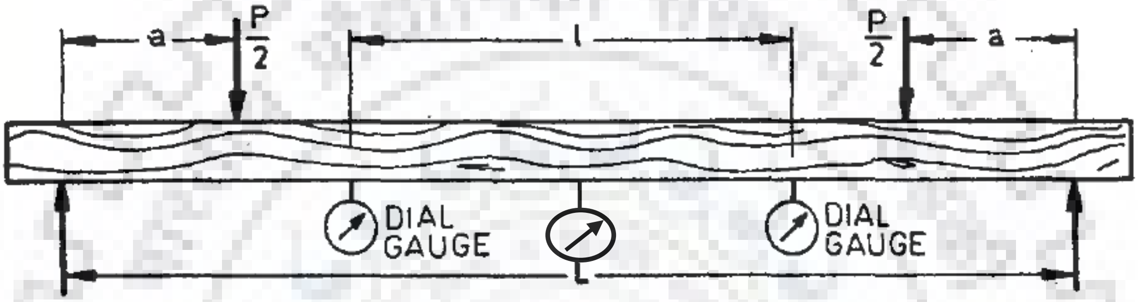


Figure 8 Specimen under the two-point static bending (IS: 1708 (Parts 1 to 18), 1986 (2005))

2. **Rate of Loading -** The load will be applied continuously throughout the test so that the moving head of the test machine moves at a constant speed of 3 mm per minute.
3. **Measurement of Load and Deflection - The Deflection of neutral axis will be measured in the middle interval between the two points** with accuracy of 0.01 mm through a suitable device installed at these two points and having a dial gauge or deflectometer. The distance (l) between these two points (also called as gauge length) will be 400 mm as shown in Figure 9

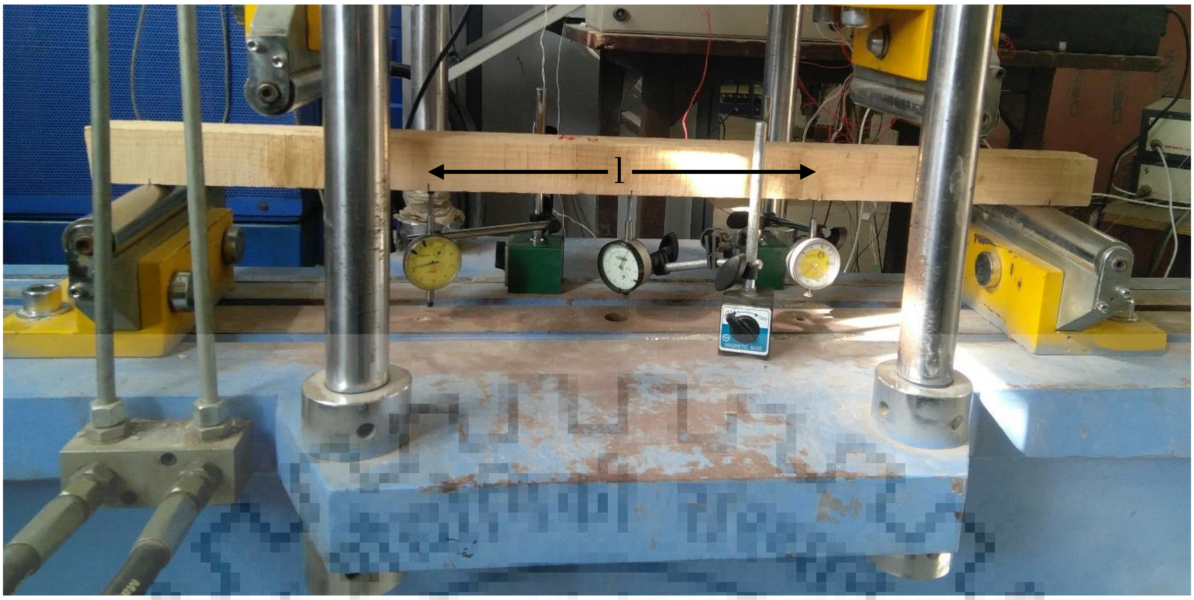


Figure 9 Flexure Test Method

CALCULATION

Various attributes will be determined by the following formulas:

Table 5 Flexure Formulas Two-Point Loading

Sr. No.	Characteristics	Unit	Formula
1	Fiber stress at proportional limit, S'	N/mm^2	$\frac{3Pa}{bh^2}$
2	Modulus of rupture, S_R	N/mm^2	$\frac{3P'a}{bh^2}$
3	Modulus of elasticity, E	N/mm^2	$\frac{3Pal^2}{4bh^3\Delta}$
4	Shear stress at proportionality limit, τ, at ends	N/mm^2	$\frac{3P}{4bh}$
5	Maximum shear stress, τ_{max}, at ends	N/mm^2	$\frac{3P'}{4bh}$

where

P = load in N at limit of proportionality,

P' = maximum load in N,

b = breath of specimen in mm,

h = depth of specimen in mm,

Δ = deflection in mm at the limit of proportionality, **(difference of deflection at gauge length and mid span)**

a = distance between points of application of load and support in mm (150 mm),

l = distance between two fixed points for which deflection is recorded in mm (gauge length) (400 mm), and

L = span in mm (900 mm).

RESULT

Applied load vs deflection in gauge length graph shown in Figure 10 & Figure 11. Due to some technical difficulty in deflection measurement of specimen 1 data of deflection measurement is not shown here for that.

This deodar timber shows brittle failure means there is minute difference between rupture load and limit of proportionality. So, deflection is not measured till rupture load for the safety of dial gauges that’s why we cannot comment on bending stress and shear stress at limit of proportionality. But bending stress and shear stress at failure load is calculated here.

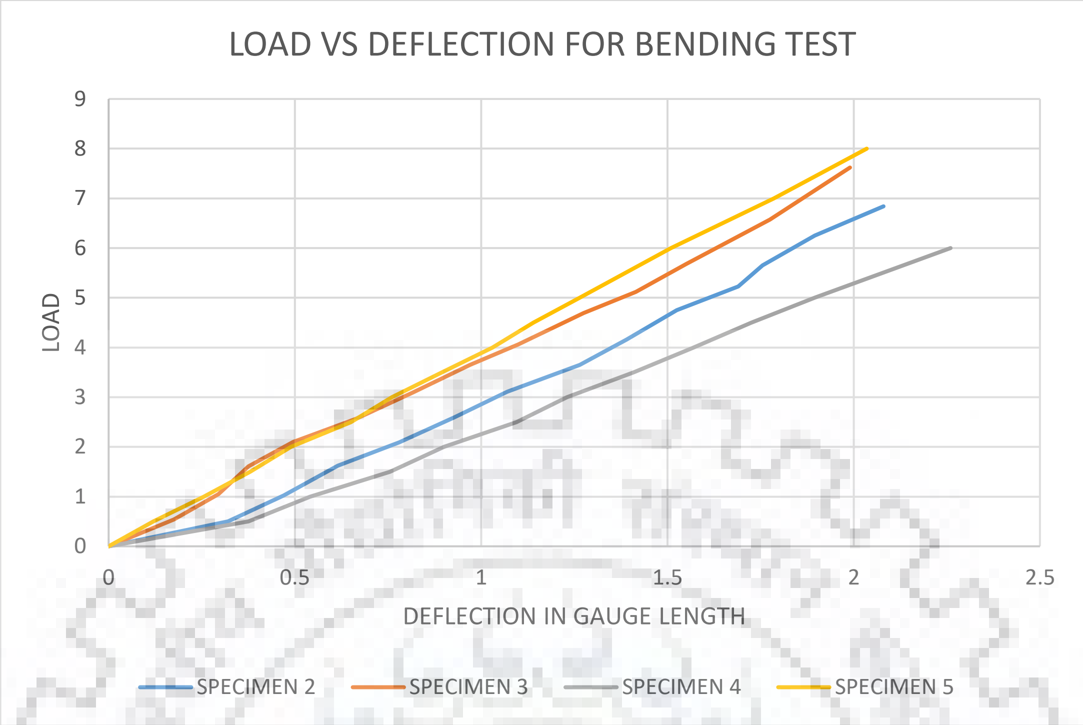


Figure 10 Load vs Deflection for flexure test specimen 2-5

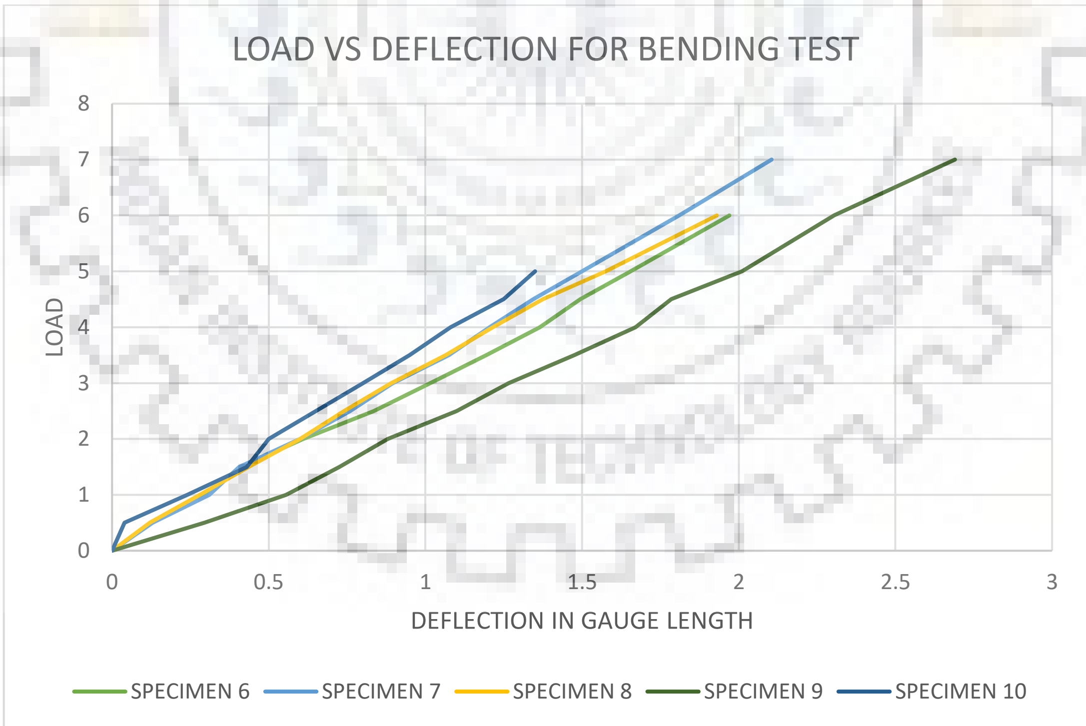


Figure 11 Load vs Deflection for flexure test specimen 6-10

Table 6 Result and calculation for flexure test

Sp. No.	Moisture Content (%)	Max. Load (KN)	Modulus Of Rupture (MPa)	Modulus Of Elasticity (GPa)
1	14.70	6.14	22.10	-
2	14.55	10.58	38.09	52.52
3	15.70	7.68	27.65	56.87
4	13.94	6.40	23.04	42.54
5	13.18	10.91	39.28	57.10
6	12.03	8.60	30.96	43.46
7	13.57	12.21	43.96	47.98
8	14.02	9.01	32.44	44.30
9	-	8.09	29.12	39.57
10	-	14.60	52.56	50.08

Bending stress at failure load is also known as modulus of rupture. Average bending stress at failure for these 10 specimens is 33.92 MPa. While average modulus of elasticity of 9 specimens is 48.27 GPa.

4.5 DETERMINATION OF COMPRESSIVE STRENGTH PARALLEL TO GRAIN TEST SPECIMEN

The test sample has a cross section of 50 x 50 mm and a length of 200 mm. Sampling should be free from defects and should not have a grain slope of 20 to 1 parallel to its longitudinal edges. The end planes of the sample should be completely at 90 degree angle with the length of the samples. When fibers are broomed at the ends, treatment like a light sanding, brushing of the ends is recommended.

PROCEDURE

1. **Placing the Specimen** - The test will be done on a suitable testing machine. Sample will be placed so that the center of the mobile head is vertical above the center of the cross section of the sample as shown in **Error! Reference source not found.**.

Figure 12 Compression parallel to grain test method

2. **Rate of Loading** - The load will be applied continuously during the test so that the moving head of the test machine moves at a constant speed of 0.01 mm per sec.
3. **Measurement of Load and Deformation** - A load of 250 kg shall initially be applied to set the specimen. Under compression, the deflaction will be correctly measured to 0.002 mm through a suitable compressometer in the central gauge length of 150 mm. Continue reading beyond proportional limits. Final readings will be recorded at maximum load. It would be preferable to remove the compressometer before the maximum load.
4. **Record of Failures** - To achieve satisfactory and uniform results, the machine may continue to cause more damage to the sample body due to continuation of the machine. Compression failures will be recorded according to the presence of the fracture surface.

CALCULATION

Load deformation curves are drawn. Deflection and load at proportionality limit is read accordingly.

Various attributes will be determined by the following formulas:

Table 7 Formulas for compressive strength parallel to grain

Sr. No.	Characteristics	Unit	Formula
1	Compressive stress at proportionality limit	N/mm^2	$\frac{P}{A}$
2	Compressive stress at maximum load	N/mm^2	$\frac{P'}{A}$
3	Modulus of elasticity in compression parallel to grain	N/mm^2	$\frac{PL}{\Delta A}$

where

P = load at the proportionality limit in N,

A = cross sectional area in mm^2,

P' = maximum crushing load in N,

L = gauge length between compressometer points in mm, and

Δ = deformation at the limit of proportionality in mm.

RESULTS

Results and calculation for compression parallel to grain are tabulated in Table 8.

Table 8 Results and Calculation for Compression parallel to grain test.

Sp. No.	Max Load (KN)	Max Compressive Stress (MPa)	Modulus of Elasticity (MPa)
1	77.9	31.16	5256.06
2	95.8	38.32	3705.00
3	60.0	24	4172.04
4	96.5	38.6	4270.02
5	84.2	33.68	2197.38
6	92.2	36.88	3220.20
7	120.3	48.12	6837.00
8	77.8	31.12	2628.18
9	57.5	23	3568.14
10	78.1	31.24	10899.60*
AVG	84.03	33.61	3983.78
St. Dev.	18.47	7.39	1402.65
COV %	21.98	21.98	35.21

* Specimen 10 is not used while calculating modulus of elasticity as it is way off the range with respect to other specimens.

4.6 DETERMINATION OF SHEAR STRENGTH PARALLEL TO GRAIN

TEST SPECIMEN

To produce a defect on the surface of 50 x 50 mm, parallel to grain shear test should be done on 50 x 50 x 63 mm samples with notches according to Figure 13.

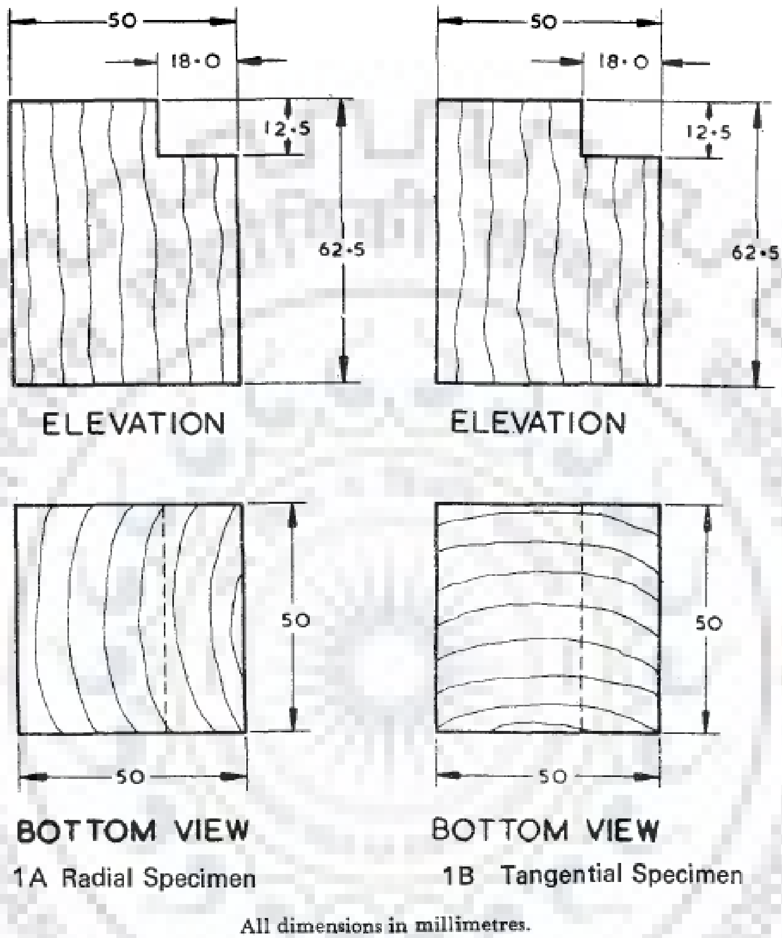


Figure 13 Shear Parallel to Grain Test Specimen.

PROCEDURE

1. **Placing of the specimen** – The test will be done on a suitable test machine with the help of a shear tool on a platform. The sample should be supported on the platform by means of a cross bar so that the edges of the sample should be vertical and part of end surface not to be sheared off rests on support during the whole test. Shear tool should rest in the notch. The shearing direction will be parallel to the longitudinal direction.as shown in Figure 14.

Figure 14 Shear parallel to grain test assembly.

2. **Rate of Loading** — The load will be applied continuously throughout the entire test at the speed speed of 0.007 mm / sec.

RECORDING OF DATA AND CALCULATION

In all cases where the failure spreads to the support surface on the base of the sample, the test should be terminated.

The maximum load required to shear the area will be recorded.

The load divided by the area provides maximum shear stress in the plane in question (radial or tangent).

RESULTS

Results and calculation for shear strength parallel to grain direction on radial plane are tabulated in Table 9. And calculation for shear strength on tangential plane are tabulated in Table 10.

Table 9 Results and Calculation for shear strength parallel to grain direction on radial plane.

Sp. No.	**DIMENSION (mm)**		**Max. Load (KN)**	**Max. Shear Stress (MPa)**
1	49.29	52.18	9.9	3.85
2	49.47	52.29	9.2	3.56
3	50.81	51.61	5.2	1.98
4	51.70	51.75	9.9	3.70
6	49.89	51.62	10.2	3.96
7	50.81	51.59	9.9	3.78
8	50.90	51.59	3.9	1.49
9	49.45	51.66	4.0	1.57
10	50.97	52.04	9.1	3.43

Average Shear strength in parallel to grain direction on radial plane is **3.03 MPa** with COV of 34.19 %.

Table 10 Results and Calculation for shear strength parallel to grain direction on tangential plane.

Sp. No.	**DIMENSION (mm)**		**Max. Load (KN)**	**Max. Shear Stress (MPa)**
1	46.39	52.14	5.6	2.32
2	47.64	52.26	6.8	2.73
3	49.17	51.91	7.8	3.06
4	49.96	52.13	8.6	3.30
5	47.26	52.20	6.6	2.68
6	44.50	51.96	7.0	3.03
7	47.97	52.11	9.2	3.68
8	46.83	52.09	3.9	1.60
9	47.06	51.47	8.3	3.43
10	48.66	51.64	10.4	4.14

Average Shear strength in parallel to grain direction on tangential plane is **3 MPa** with COV of 23.99 %.

Overall average shear strength on both planes is **3.01 MPa.**

4.7 DETERMINATION OF TENSILE STRENGTH PARALLEL TO GRAIN

TEST SPECIMEN

The test sample should have the shape and size as shown in Figure 15. The cross-section of the central portion of the specimen shall be 7 X 7 mm. The gauge length shall be 5 cm. The annual rings at the ends should be perpendicular to the large transverse dimensions.

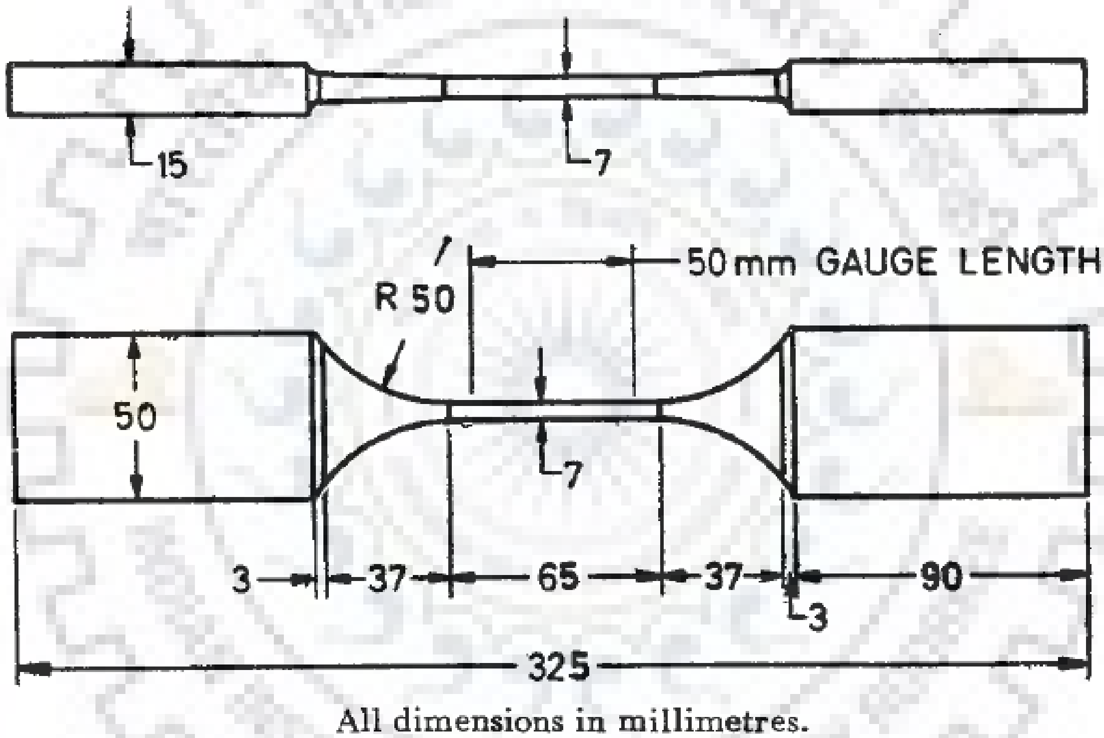


Figure 15 Test Specimen for Tension Parallel to Grain

PROCEDURE

1. **Placing of the Specimen** – Testing can be done on any test machine provided with suitable type of grip to hold the sample firmly without any slippage. The sample should be kept firmly in the grip and the proper elongation measuring device should be connected to the gauge length.
2. **Rate of Loading** – Load will be applied continuously during the test, so that the moving head moves at a constant speed of one millimetre per min.

3. **Measurement of Loads and Elongation** – The elongation will be measured accurately at 0.002 mm at appropriate loading intervals, so that the 8-10 reading till proportionality limit is available. The reading will continue beyond the proportional limit and the last reading of the load will be recorded in case of failure. It would be preferable to remove the elongation measuring device before the maximum load is reached.

CALCULATION

Load elongation curve is drawn. Then load and elongation is to be read on the proportionality limit.

Various attributes will be determined by the following formulas:

Table 11 Formulas for tensile strength parallel to grain

Sr. No.	Characteristics	Unit	Formula
1	Tensile stress at proportionality limit	N/mm^2	$\frac{P}{A}$
2	Tensile stress at max load	N/mm^2	$\frac{P'}{A}$
3	Modulus of elasticity in tension parallel to grain	N/mm^2	$\frac{PL}{\Delta\ A}$

Where

P = load at proportionality limit in N,

A = cross sectional area in mm^2,

P' = max load to cause the failure in N,

L = gauge length between extensometer points in mm, and

Δ = deformation at the limit of proportionality in mm.

RESULTS

While testing specimen for tensile load capacity all specimen did not break from centre as shown in Figure 16.

Figure 16 Failure pattern of all specimen

So results of specimens which fail in appropriate manner are tabulated in Table 12.

Table 12 Results and Calculation for Tensile strength parallel to grain direction.

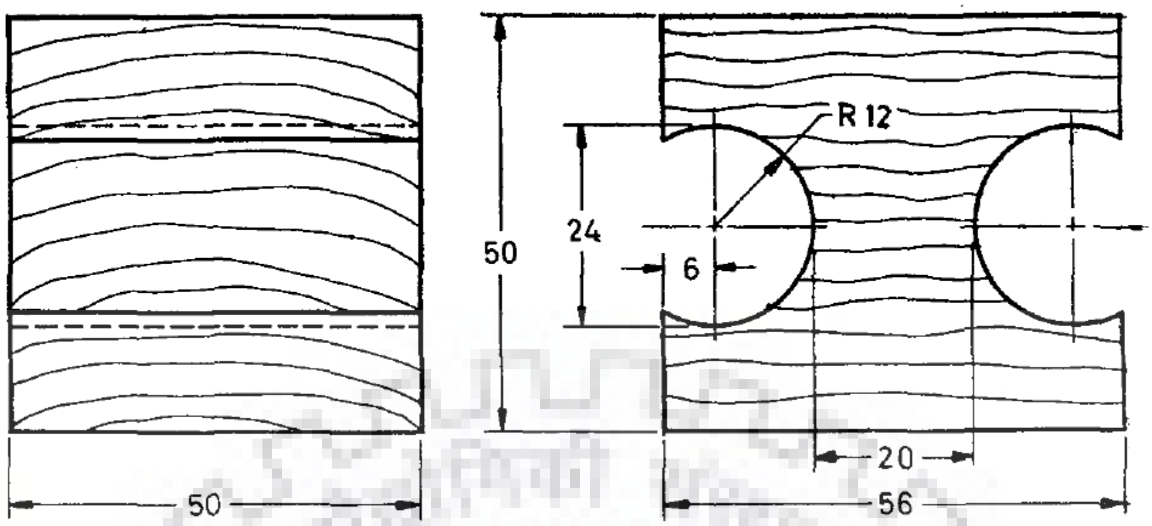
Sp. No.	DIMENSION (mm)		Max Load (KN)	Tensile Strength (MPa)	Modulus Of Elasticity
1	6.60	7.68	4.06	80.18	10619.67
2	6.97	8.37	4.06	69.66	10905.11
3	6.40	8.02	2.24	43.55	8055.76
4	6.98	8.25	2.95	51.17	10626.73
5	7.52	8.33	2.54	40.55	9381.15

Average tensile strength is **57.02 MPa** with COV of 30.16%. While average tensile modulus of elasticity is **9917.68 MPa** with COV of 12.06%.

4.8 DETERMINATION OF TENSILE STRENGTH PERPENDICULAR TO GRAIN

TEST SPECIMEN

The samples of the test should be shaped and sized as shown in Figure 17. The notches shown in Figure 17 should be made to generate a failure in the area of 50 x 20 mm on the radial or tangential surface as desired.



All dimensions in millimetres.

Figure 17 Test Specimen for Tension Perpendicular to Grain

PROCEDURE

1. **Placing of the Specimen** – To test the sample test machine should be equipped with suitable grips. The sample will be kept in the hold as shown in *Figure 18*

Figure 18 Tensile strength perpendicular to grain test assembly

2. **Rate of Loading** - The load will be applied continuously throughout the test, so that the moving head moves at a constant speed of 2.5 mm per min until max load is reached.

RECORDING OF DATA AND CALCULATION

The max load required for failure perpendicular to the grain will be recorded. The load divided by area provides max tensile stress in perpendicular to the grain in the plane in question (tangential or radial).

RESULTS

Results and calculation for tensile strength perpendicular to grain direction on radial plane are tabulated in Table 13. And calculation for tensile strength on tangential plane are tabulated in Table 14.

Table 13 Results and Calculation for tensile strength perpendicular to grain direction on radial plane.

Sp. No.	Dimension (mm)		Failure Load (KN)	Tensile strength perpendicular to grain (MPa)
1	18.11	52.27	11.0	11.62
2	20.06	51.86	11.6	11.15
3	21.84	51.88	10.8	9.53
4	19.81	51.75	11.2	10.93
5	18.24	51.74	11.8	12.50
6	16.13	51.68	13.0	15.60
7	23.29	51.54	11.4	9.50
8	20.93	51.11	11.2	10.47
9	18.02	51.68	10.6	11.38

Average Tensile strength in perpendicular to grain direction on radial plane is **11.41 MPa** with COV of 16.14 %.

Table 14 Results and Calculation for tensile strength perpendicular to grain direction on tangential plane.

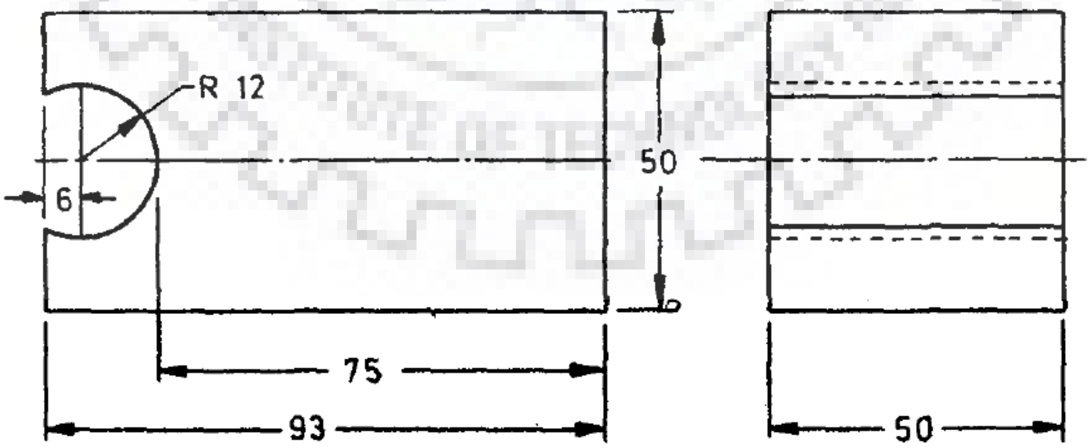
Sp. No.	Dimension (mm)		Failure Load (KN)	Tensile strength perpendicular to grain (MPa)
1	19.33	51.14	11.0	11.13
2	21.68	52.01	11.0	9.76
3	20.65	51.98	10.6	9.88
4	19.06	51.62	10.2	10.37
5	17.31	51.37	8.6	9.67
6	20.58	51.39	10.6	10.02

Average Tensile strength in perpendicular to grain direction on tangential plane is **10.14 MPa** with COV of 5.36 %.

Overall average tensile strength on both planes is **10.9 MPa.**

4.9 DETERMINATION OF CLEAVAGE STRENGTH PARALLEL TO GRAIN TEST SPECIMEN

The test specimen shall have the shape and size as shown in **Error! Reference source not found.**. The notches shown in **Error! Reference source not found.** should be such that the sample fails on the desired radial or tangent surface.



All dimensions in millimetres.

Figure 19 Test Specimen for Cleavage (IS: 1708 (Parts 1 to 18), 1986 (2005))

PROCEDURE

1. **Placing of the Specimen** – Test the sample on a test machine equipped with suitable grips. The specimen shall be placed in the grips as shown in *Figure 20*

Figure 20 Cleavage strength parallel to grain test assembly

2. **Rate of Loading** - The load will be applied continuously throughout the test, so that the moving head can run at a constant speed of 2.5 mm per min until reaching the max load.

RECORDING OF DATA AND CALCULATION

The max load required for failure will be recorded. The load divided by the width gives the max cleavage resistance N/mm in the plane in question (radial or tangential).

RESULTS

Results and calculation for cleavage strength parallel to grain direction on radial plane are tabulated in Table 15. And calculation for cleavage strength on tangential plane are tabulated in Table 16.

Table 15 Results and Calculation for cleavage strength parallel to grain direction on radial plane.

Sp. No.	Dimension (mm)	Failure Load (KN)	Cleavage Strength (N/mm)
1	51.62	9.8	189.85
2	51.24	9.4	183.45
3	51.65	9.0	174.25
4	51.44	9.6	186.63
5	51.38	9.8	190.74
6	51.26	9.6	187.28
7	51.48	8.6	167.06
8	51.82	9.6	185.26
9	51.19	9.4	183.63
10	51.35	9.4	183.06

Average Max. Strength in parallel to grain direction on radial plane is **183.12 N/mm** with COV of 3.97 %.

Table 16 Results and Calculation for cleavage strength parallel to grain direction on tangential plane.

Sp. No.	Dimension (mm)	Failure Load (KN)	Cleavage Strength (N/mm)
1	51.78	9.0	173.81
2	51.38	9.2	179.06
3	51.77	9.0	173.85
4	51.64	9.2	178.16
5	51.89	9.4	181.15
6	51.78	8.8	169.95
7	50.06	9.2	183.78

8	51.52	8.8	170.81
9	51.74	9.4	181.68

Average cleavage strength in parallel to grain direction on tangential plane is **176.92 N/mm** with COV of 2.82 %.

Overall average cleavage strength on both planes is **180.18 N/mm.**

5. SPECIFIC TESTING FOR CONNECTIONS USED IN KATH-KUNI WALLS

In the building studied by Zanden (2018), the corner connections (see *Figure 22*) show differences from the configurations of such connections that have been elucidated in literature (see *Figure 21*). As elaborated, kath kuni structures are connected all along their length and height with dovetail and dowel connections. In the corners, timber beams meeting one over the other at right angles are connected with kadils (timber dowels). Two timber layers, nevertheless, can have different amounts of stone rubble between them; varying from structure to structure. A typical unit in the wall can be said to consist of a timber layer and a stone layer. The height of this unit can be increased by adding timber infill pieces in the corners. Thus, further economy in timber use is achieved without compromising on the integrity of the wall. It is a prevalent practice among kath kuni carpenters to use more stone rubble between the horizontal beams for bigger structures, ostensibly to maximize friction.

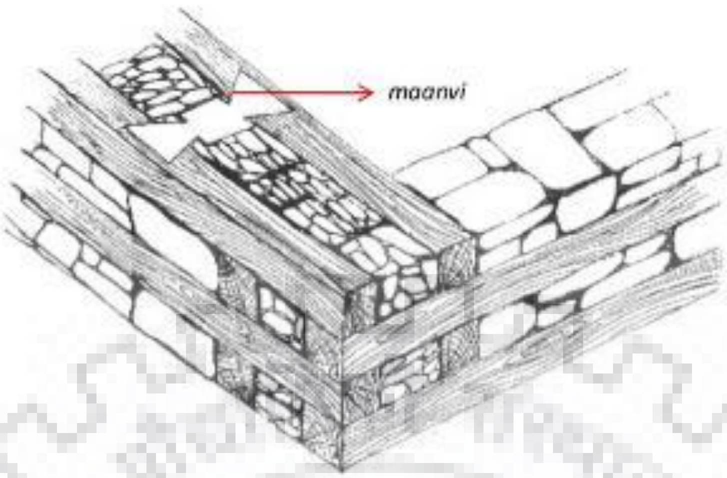


Figure 21 Typical corner connection (Zanden, 2018)

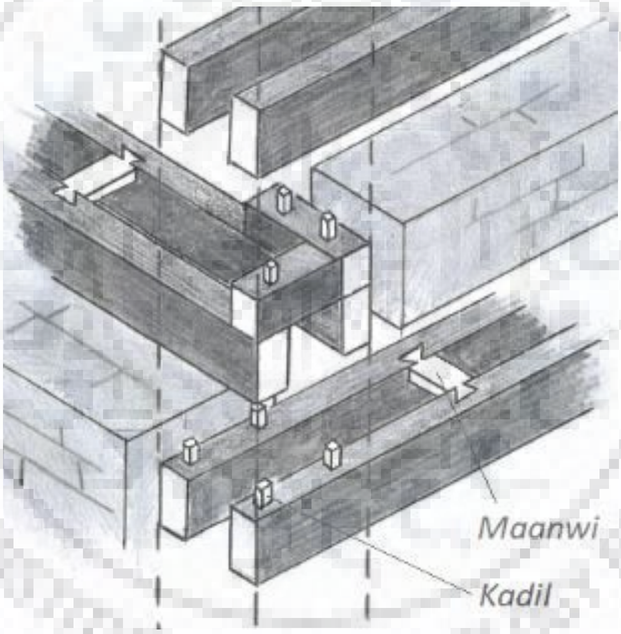


Figure 22 Corner connection in case study building (Zanden, 2018)

Kadils are dowel bars made of timber, square in cross section of approximately 45 x 45 mm width and 90 mm high. In the building studied by (Zanden, 2018), the corner connection has either 3 or 4 kadils per corner in every horizontal plane. On the other hand, for the corner connection used in the temple which is a much more massive structure, invariably 4 kadils per corner in every plane are used for shear transfer.

5.1 Experimental program of maanwi connections

An experimental program on traditional connection used in kath kuni walls was carried to better study the behavior of these buildings. To carry out this experimental program an important connection is used that is called maanwi connection which is a timber dovetail connection. That is used to connect to beams which run parallel to each other.

To comprehend the response of maanwi connection for parallel beams, the deformation patterns and the damage progress was analyzed. To do this study, 4 specimens was tested for the mechanical characterization of traditional joint in kath kuni walls. Pull-out tests have been performed.

SPECIMEN

The specimen used in testing have same geometry as used in kath kuni wall which is tested by (Zanden, 2018). The specimens were fabricated with same type of timber used in kath kuni wall (*deodar*). To carry out this testing we need two components of maanwi connection. One is timber dovetail specimen which is specifically called maanwi. And other component is used to replicate the function of beam so this ideolized beam specimen is called beam in the course of this testing.

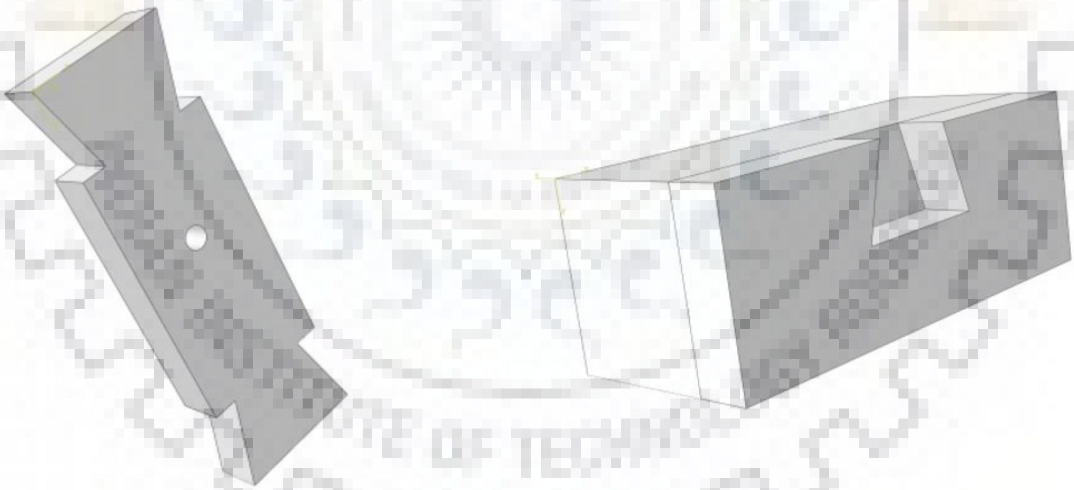


Figure 23 Maanwi and beam components used in testing

Figure 24 Dimensions of test setup

TESTING SETUP

Testing setup is prepared to calculate maanwi strength at one end. As strength on both side of connection should be identical and also whichever end fails first gives the strength of maanwi connection. So, the results of half maanwi connection can be used for as a complete maanwi connection. Here setup and results are discussed according to half maanwi connection.

To fabricate components of setup for this testing mild steel is used. Beam is held between 16mm plates arrangement to held beam is shown in *Figure 25*

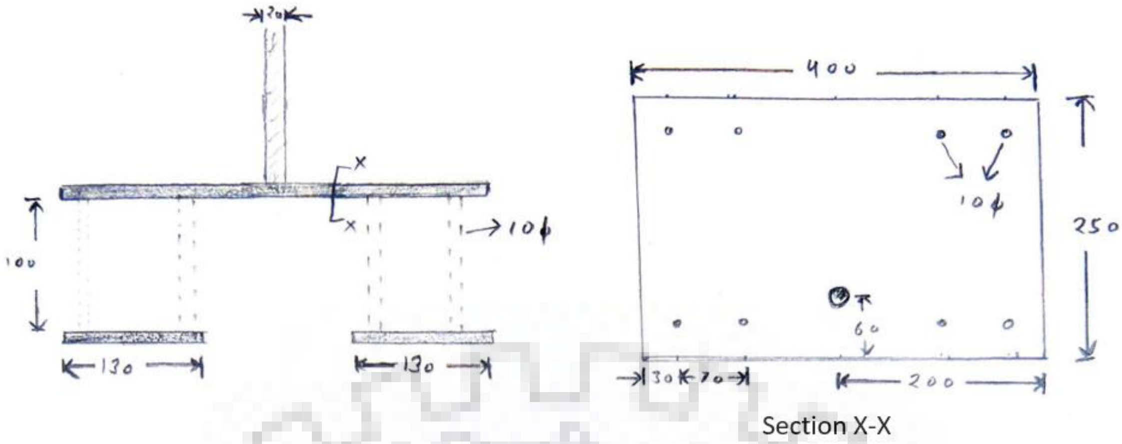


Figure 25 Arrangement to hold beam in position

To hold maanwi a U shape is made with the help of 16 mm plate which have 20 dia mm hole on both parallel plates as shown in Figure 26. In that 20 mm hole a 20 mm steel rod is inserted which coinside with hole in maanwi.

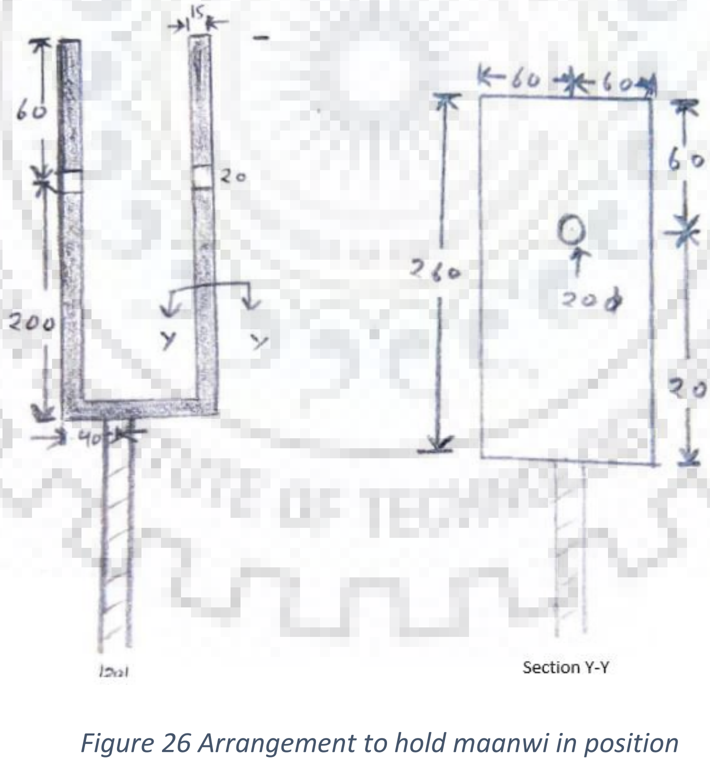


Figure 26 Arrangement to hold maanwi in position

Fabricated component of setup for both maanwi and beam have a steel rod attached to them. Those steel rods are held in the jaws of tensile testing machine and then force applied such that both components move in opposite direction. Test assembly is shown in *Figure 27* & *Figure 28*.

Figure 27 Test Assembly Maanwi

Figure 28 Test Assembly Maanwi

RESULTS

Results of maanwi connection testing are tabulated in Table 17 and Load vs deflection relation is shown in Figure 29.

Table 17 Maanwi connection result

Specimen No.	Failure Load (KN)
1	20
2	17
3	24
4	17.4
Average	19.6

Average capacity of maanwi connection is 19.6 KN.

This load vs deflection graph shown in figure shows that maanwi has plastic failure but actually embedment of beam fails due to cleavage failure and they are not able to separate from beam as beam is hold between the plates. If beam is not confined then this will be a brittle failure and be idolized as shown in Figure 30

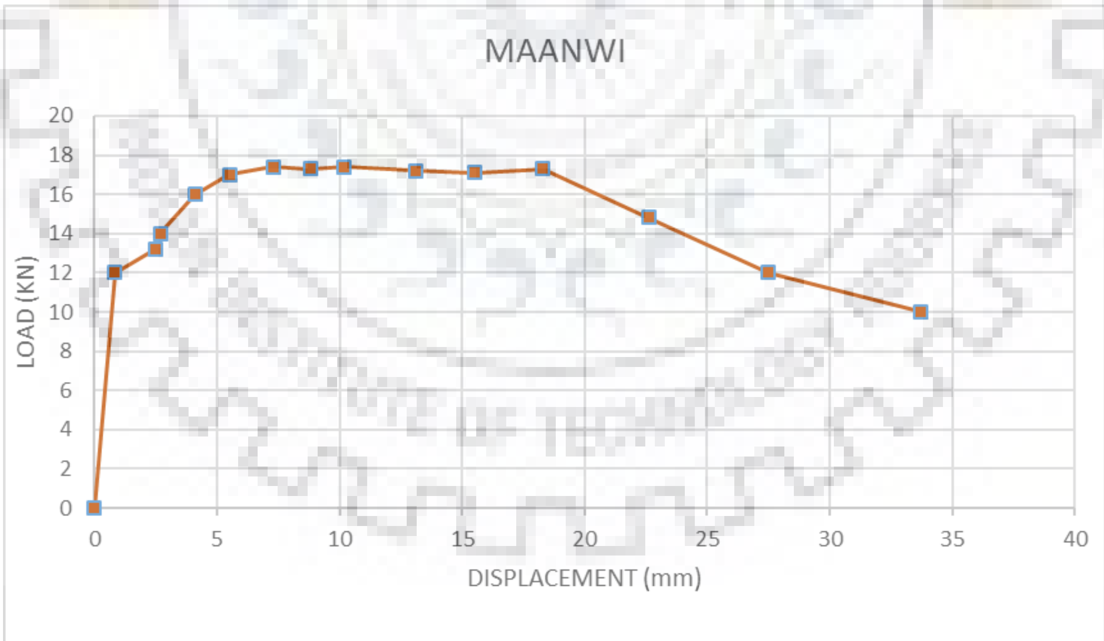


Figure 29 Maanwi Load vs Deflection curve

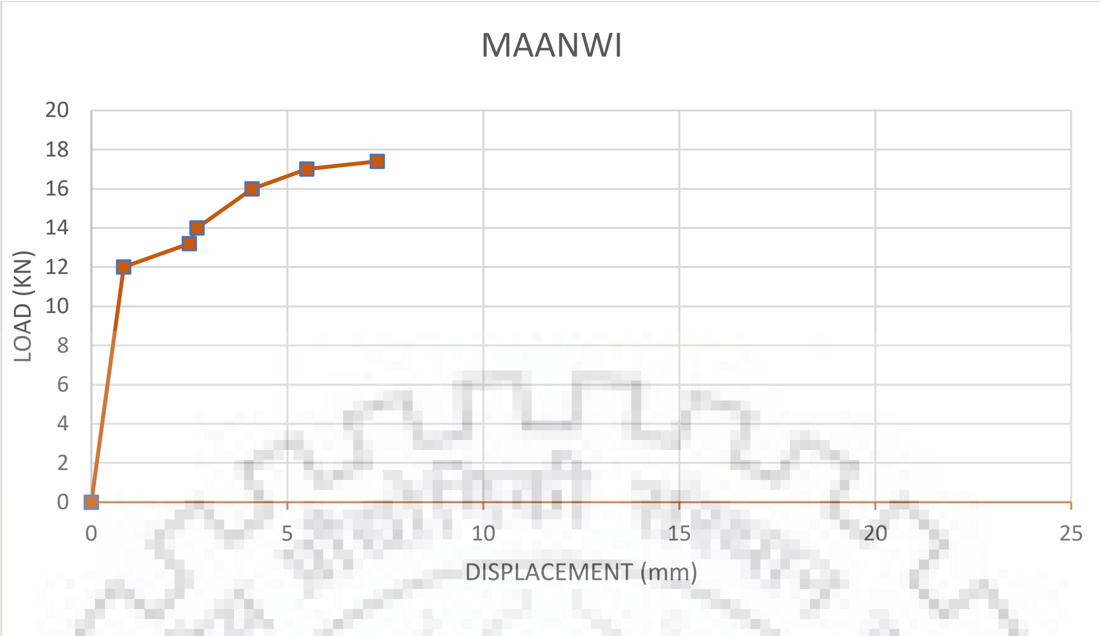


Figure 30 Idolized Load vs Deflection curve

In this testing it is evident that maanwi does not fail but beam fails. And that is also a cleavage failure as cleavage strength of timber is 180.18 N/mm and thickness of maanwi is 50 mm and to fail in cleavage both sides need to be failed as load is going to be distributed. So, cleavage length will be considered as 100 mm which is two times of thickness of maanwi. So cleavage strength comes out as 18 KN and average strength of maanwi is 19.6 KN. As there is no significant variation in both values so conclusion that failure of maanwi connection is due to beam failure in cleavage is accurate.

6. CONCLUSION

Basic strength parameters of deodar timber is first determined to check to analytical models used by Zanden(2018). Then using that basic parameters strength of maanwi and kadil is computed and to validate her model then strength of maanwi connection is determined.

Basic mechanical parameters are summarized here:

As first we get the density of deodar timber at 12% moisture content that is 499.78 Kg/m^3. Then in table all strength parameters are summarized:

Table 18 Strength parameters

Sr No.	Strength parameter	Strength (Mpa)	Modulas of Elasticity (Mpa)

1	Compressive Strength perpendicular to grain	7.86	162.27
2	Compressive Strength parallel to grain	33.61	3983.78
3	Flexural strength	33.92	48270.00
4	Shear strength parallel to grain	3.01	-
5	Tensile strength parallel to grain	57.02	9917.68
6	Tensile strength perpendicular to grain	10.90	-
7	Cleavage strength	180.18	-

Strength of maanwi connection comes out as 19.6 KN during lab testing.

6.1 RECOMMANDATION

Kath kuni wall which is tested by marloes have kadil connection in alternative layer as 6 and 8 no. so there it become obvious that failure is govern by layer which have 6 kadil connections. So for better strength 8 no. of kadil connections should be used in every layer.

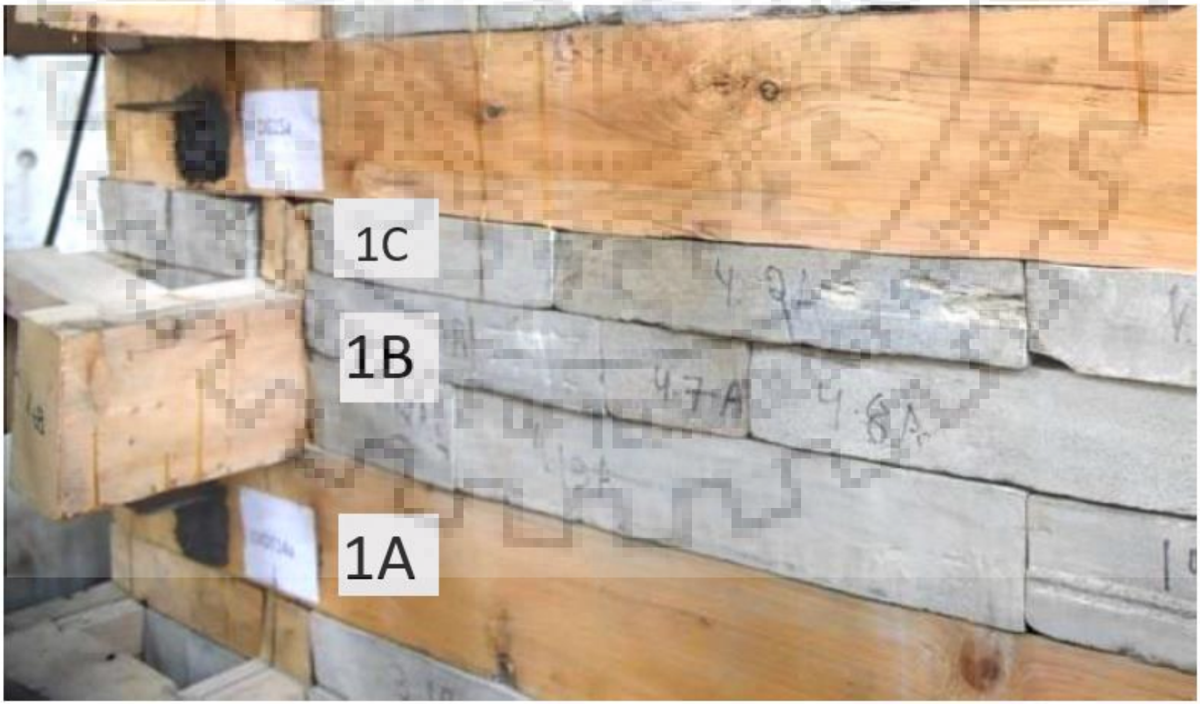


Figure 31 Layer characterization

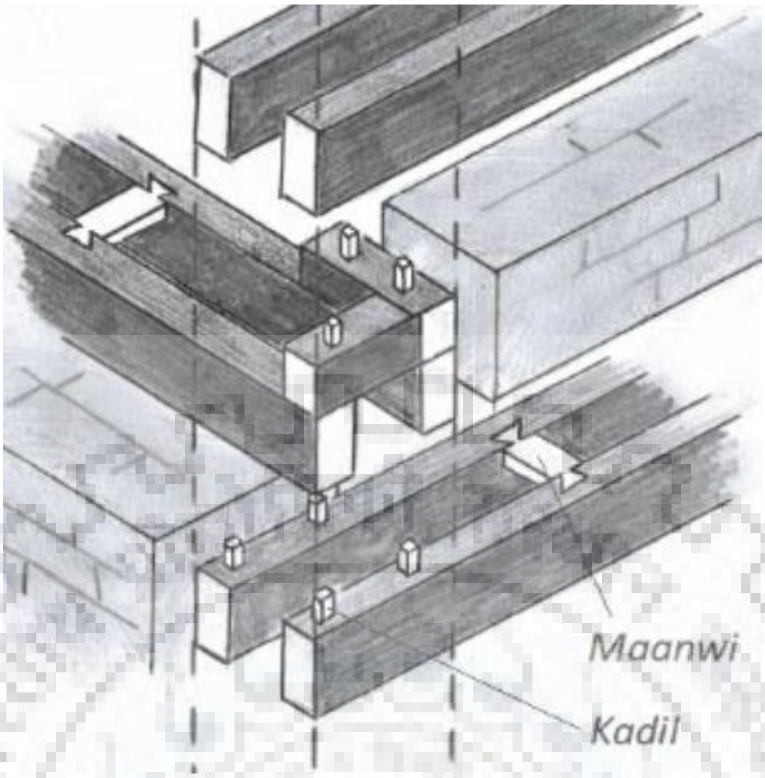


Figure 32 Maanwi kadil connections

As shown in **Error! Reference source not found.** there is discontinuity in timber connections in vertical direction. To simplify explaining process we call different timber layer as 1A, 1B and 1C. 1A is connected to 1B using 8 no. of kadil connection and creating box type configuration. But 1B and 1C are connected by 6 kadil connections. In 1C it makes L type configuration on one side and it will make L type configuration on other side in 2C. The L shape in layer 1C is made up by one longitudinal timber member and one member in lateral direction. The member in lateral direction is connected by two kadil connection and it is connecting member for beams in alternate direction. The member in longitudinal direction is connected by one kadil connection and it is not connected to lateral member in horizonal direction. By that lateral member can rotate when subjected to horizontal loads. As when lateral member rotates the upper beam lifts up and friction strength got reduced. On opposite side of longitudinal member there is stone piece is placed which doesn't have any structural part to play. That is used to just fill the gap in vertical direction.

So, my recommendation is that on opposite direction also a timber member should be used in longitudinal direction. Also, there should be a horizontal connection between longitudinal and lateral member so that lateral member does not rotate. So that friction capacity will not reduce.

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