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Finite Element Modeling of Carpet Weaving Loom Structure

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Abstract

Handmade carpet industry needs upgradation in weaving technology to meet the demand of quality carpets and the rate of production. Present looms to weave the carpets are made of wood, which are susceptible to termite attacks. The use of wood also causes deforestation. Moreover, the high tension required in the warps is generated by pulling a rope. This requires about 40-45 minutes by 2 -3 persons. The traditional practice of generating high tension is laborious and demands a change. In order to avoid the above difficulties, an improved metallic loom has been proposed elsewhere which made weaving easy but the cost of loom is high. In the improved loom, worm and worm-wheel, and ratchet-pawl are used to develop tension in the lower beam and to lock the upper beam, respectively. In this paper, finite element analysis of the metallic loom is carried out to determine the critical stresses and deflection in its components so that optimum sizes and shapes of the structural members can be selected.

Keywords: *Carpet loom, Finite element method, and Structure.*

1. Introduction

Handloom weaving of carpets is different in many aspects from the handloom weaving of the fabric [1]. Handloom weaving of fabric almost replaced by sophisticated power looms but not the same has happened to the carpet weaving because of its inherent knotting system and aesthetic values associated with it. The oriental carpet, as shown in Fig. 1, is generally woven on a warp fixed almost vertically in front of the weaver. Required length of warp threads wrapped over upper beam called warp beam that supported by a pair of columns, about 1.8 m high. Tuft of wool or silk inserted between the warp threads, knotted it in with weft and warp, as illustrated in Fig. 2. The process continues along the whole row. Then, the row is pressed using a tool called beater [1]. Carpet knotting continues according to the carpet design. Traditionally, oriental carpets are woven on wooden looms (Fig. 1), which are becoming economically, environmentally and functionally non-viable due to the following reasons [2-3]:

- Life is limited (5-8 years) due to susceptibility to termites and frequent investments are required;
- Deforestation;
- Need rope arrangement to generate high tension in the warps, which is laborious; and
- Over the time the wooden beams bend causing non-uniform tension in the warps. Hence, the carpet quality is affected.

With wooden looms, carpet weaving for large width becomes difficult because greater effort is required to put the warp threads in high tension. Tensioning requires 2 -3 persons who pull a rope to rotate the beams, as shown in Fig. 2. Since there is no mechanical advantage in pulling the rope, the tensioning job is very tedious, and requires about 30-40 minutes. Moreover, in addition to the low life and deforestation, they are prone to accidents due to the damages done by the termites. Existing wooden components have evolved over the years based on the weavers' experiences. There is no literature reporting any systematic design of such components except in by one of the authors of this paper [3]. In order to overcome the problems of existing wooden looms, Saha et al. [3] designed and developed a metallic loom, as shown in Fig. 3, considering all aspects of carpet weaving. The lower beam fitted with a worm and worm-wheel for developing tension in the warp threads. A ratchet-pawl mechanism is used to lock the top (warp) beam. Main components of the metallic loom [3] are shown in Fig. 3, where the upper and lower beams, and two side supports contribute to the 90% of the loom weight and cost. In order to reduce the weight and cost, it is important to know the critical zones of the beams and columns so that their sizes and shapes can be modified. In this pape r finite element analysis of this structure is performed to locate the critical zones, whereas a modified design is proposed in a separate communications [4].

The paper is organized as follows: Section 2 explains the function of the loom and the load modeling. In section 3, finite element model and solution using standard FE tool are presented. Results for a typical metallic carpet loom [3] are reported in Section 4, where they are compared with those of an optimized loom [4].

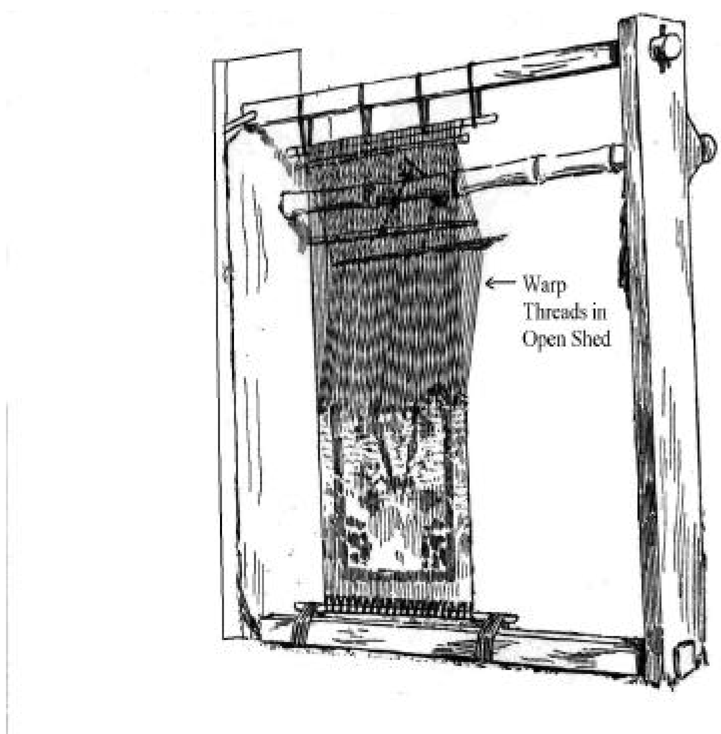
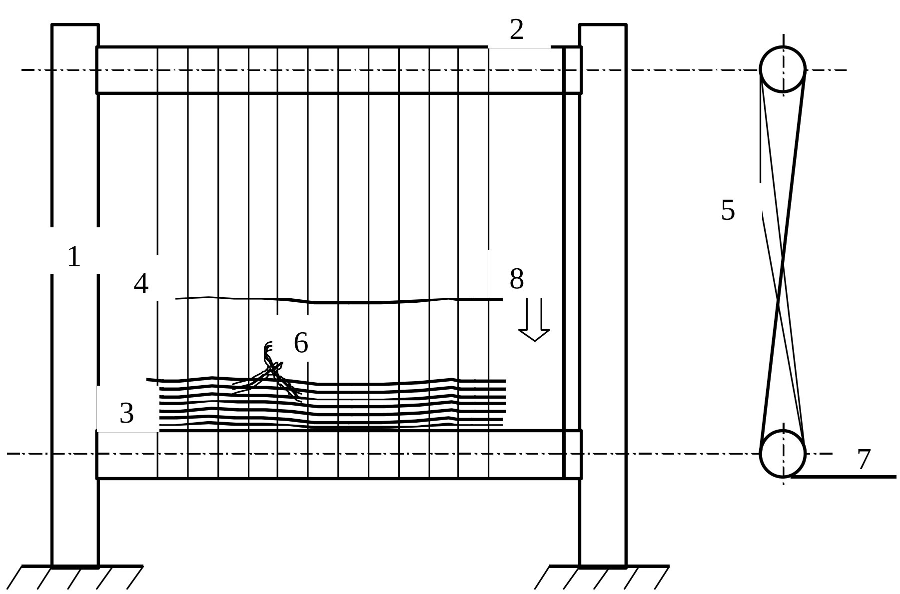


Fig. 1 Traditional oriental wooden handloom



1. Side Support; 2. Upper (Warp) Beam; 3. Lower (Cloth) Beam; 4. Weft Thread; 5.Warp Threads (Open Shed Position); 6. Knotted Turf; 7. Rope for Tensioning; 8. Beating Direction.

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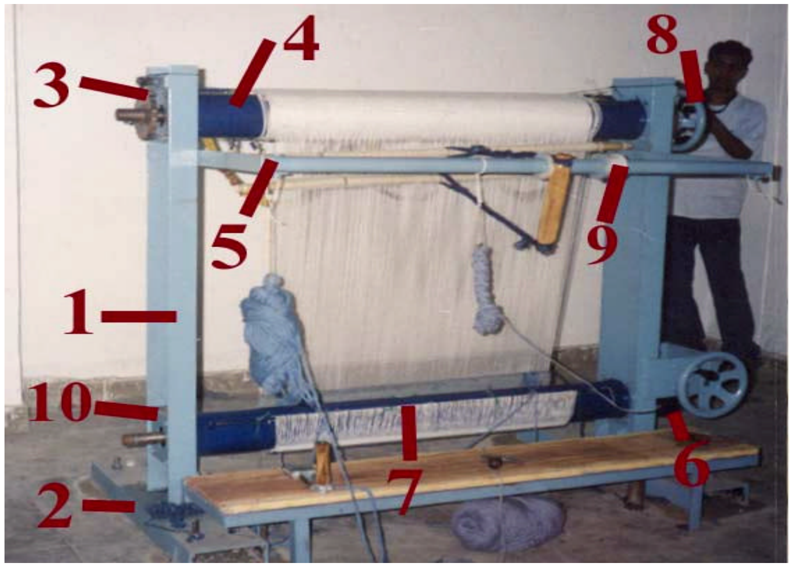
Fig. 2 Schematic diagram of oriental loom with rope tensioning



1. Support Channel; 2. Base Channel; 3. Ratchet and pawl; 4. Upper (Warp) Beam; 5. Shedding Pipe; 6. Tensioning Device; 7. Lower (Cloth) Beam; 8. Handle; 9. Shedding Roller; 10. Bush Bearing.

Fig. 3 Improved carpet loom [3]

2. Loom Components and Their Function

In textile terminology, the part that is used to wind the warp threads and carpet are called beams, namely, the upper (warp) and lower (cloth) beams, 4 and 7 of Fig. 3, respectively. Their function is, however, very complex [5]. Functionally, the warp-beam gradually delivers equal amount of length to all warp threads as the carpet weaving progresses, and maintain proper tension in all the wrap threads. The beam is locked between two let off action to provide proper tension. Still there is a variation in tension of the warp threads during shedding motion, which affects the quality of the carpet. In the improved metallic loom [3], a worm and worm-gear mechanism is used on the right side of the lower beam, 6 of Fig. 3, to provide tension to the warp threads, while a pair of ratchet-pawl, as the left set is indicated with 3 in Fig. 3, is used to lock the upper beam. Among others, two main components of the loom are beams and side columns. The function and constraints of the beams are given in Table 1, which will allow us to model the loom appropriately.

Table 1 Warp and cloth beams' functions and constraints

Function	Constraints
Resist bending and torque	Kinematic: Let off equal length to all warp threads and lock for forward motion during weaving
	Geometric: Length of the beam is greater than the width of carpet
	Strength: Support warp threads tension, and lock torsion without failing
	Stiffness: Less deflection to maintain uniform tension in all the threads

Columns that support both the upper (warp) and lower (cloth) beams are under complex 3-dimensional loading. The left column is indicated by 1 in Fig. 3. The tension in the warp threads is provided by worm and worm-wheel, 6 of Fig. 3, that is attached to the bottom beam. As illustrated in Fig. 4, locking moment, M_L, and axial compressive load, P, act on the column. Additionally, friction force, F_f act on the column due to gradual increase in tension of the wrap threads. Locking moment, M_L, causes beam torsion, which depends on the diameters of the beam and the locking devices, namely, ratchet at the upper beam and the worm-gear at the lower beam. These loads increase simultaneously during tensioning and kinetic friction becomes zero after completing the tensioning.

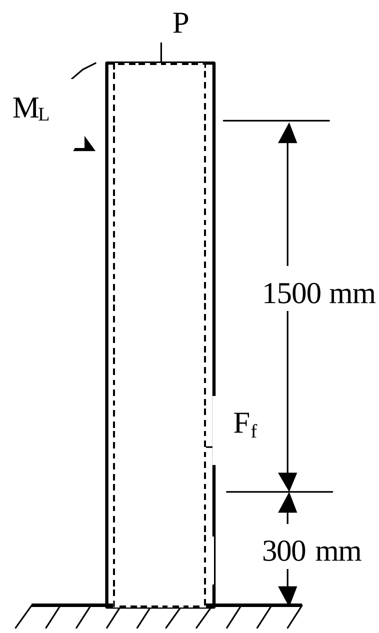


Fig. 4 Schematic diagram of a side support with worm and worm-wheel

2.1 Load Modeling

Warp threads made of cotton yarn were tested for breaking load on Textechono Statimat Me (a textile tester) under standard textile testing conditions [6]. Average force/elongation curves for the warp threads are shown in Fig. 5. Note that unlike conventional ductile metals like steel or aluminum, the cotton yarn does not have any clear yield point. Like a brittle metal, e.g., cast iron, the yield point for cotton is obtained by drawing a tangent line parallel to the line joining the origin to the breaking point [6]. The yield point of the thread occurred slightly below the force, 9.81N (~1000g) at 5 percent elongation. Considering different yarn quality to be used in the loom for which the yield force may lie within the range of 10N to 20N, the design load of 20N for each warp thread is safe. Hence, the safety factor about two is assumed. Since all warp threads are wound uniformly over the upper beam, as shown in Fig. 3, they are modeled as uniformly distributed load.

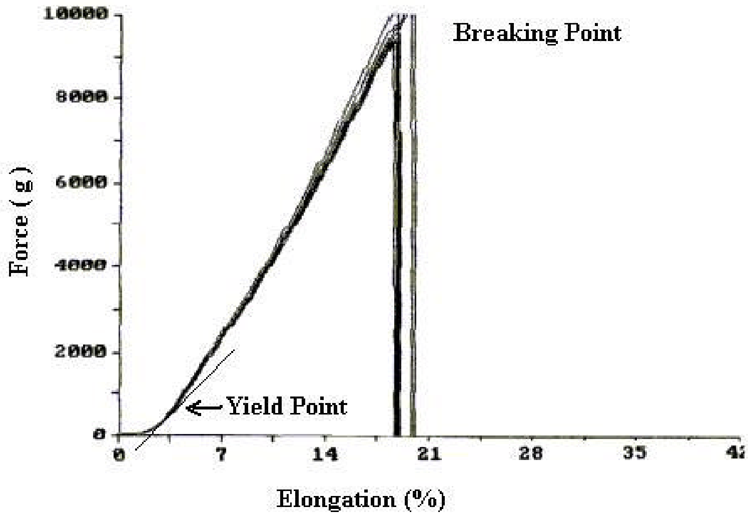


Fig. 5 Tensile test results of warp threads

The load diagram of the upper beam, numbered as 4 in Fig. 3, during weaving is shown in Fig. 6. Since carpet knotting to weave about six-inch carpet takes several days, the structure is subjected to steady loading. The beam is supported on side columns and locked in the plane normal to the plane of the warp threads at A due to the presence of ratchet and pawl, as seen in Fig. 3 from the front.

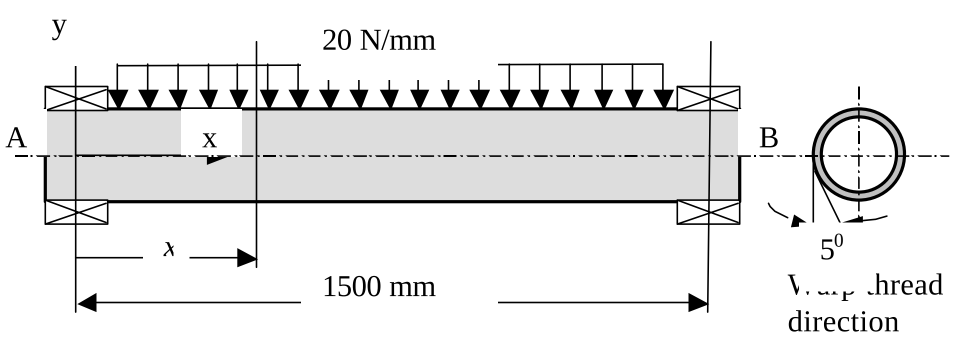


Fig. 6 Load diagram of the Upper (Warp) Beam

3. Finite Element Modeling

The upper and lower beams resist the thread load of 20 N/mm at 5 degree from the vertical plane, Fig. 6. This is equivalent to the loads at the beam axis shown in Table2, whereas the beam and column sizes are shown in Table 3. Uniaxial finite elements are appropriate for such components. Distance between the nodes, i.e., the length of uniaxial elements, is chosen as 100mm which is about 6 percent of the length/height of beam/column. The distance between the nodes is decided by the accuracy needed. Elements of the beam whose the cross-section is hollow circular are chosen as Pipe16 of ANSYS 7 and those for the columns whose the cross-section is hollow square Beam4 is selected. Both the elements, Pipe16 and Beam4, have the capability to provide tension, compression, torsion and bending. They allow six degree-of-freedom at each node, i.e, three transnational and three rotational, as explained in Table 4 [7]. The load is applied at each node of the beam. Note that the load carried by the corner nodes of the beam is half of that of the middle ones [8].

Table 2 Load per 100 mm length on beams

Components	F_y (N)	F_z (N)	M_x (N-mm)
Upper Beam	-1992.4	174.3	117800
Lower Beam	1992.4	174.3	117800

F_y: Force along Y; F_z: Force along Z; M_x: Moment about X.

Table 3 Sizes of the beams and columns [4]

Components	Cross-section	Size (mm)	Length/height (mm)
Beam	Hollow circular	OD=117.8 Wall thickness=3.8	1500
Column	Hollow square	Out side width=78.31 Wall thickness=1.41	1800

Table 4 Nodal DOF and load

Components	Type of element	Node DOF	No. of nodes	Middle nodal loads	Corner nodal load
Beam	Pipe16	6-DOF: UX, UY, UZ, ROTX, ROTY, ROTZ	16	F_x= -1992.4 N F_z= 174.3 N M_x= -117800 N-mm	F_x= -1992.4/2 N F_z= 174.3/2 N M_x= 117800/2 N-mm
Column	Beam4	6-DOF: UX, UY, UZ, ROTX, ROTY, ROTZ	18		

Now, the joint constraints are looked into. Joints at 3 and 6, Fig. 3, respectively, connect the beam to the column using bush bearings. However, the ratchet-pawl and the worm and worm-gear are used to lock the beams while tensioning needs to be developed. Thus, these joints are assumed to be fixed to the columns. The joints, 8 and 10 of Fig. 3, are simply bush bearings whose width is less in comparison to the length of the beam. Hence, they are modeled as cylindrical j oints of 2-DOF, i.e., the beam end is free to translate along and rotate about the beam axis. Due to less width of the bearing, the stiffness of the two rotational constraints is very low. Alternatively, these joints impose constraints on the translation normal to the warp thread plane. Hence, the transnational stiffness perpendicular to the beam axis is assumed to be very high. An element Combin7 [7] is chosen for this application. The Combin7 is the three-dimensional joint having joint flexibility (stiffness), friction, damping, and certain control features. In order to use this element as the bush bearing connection between the beam and column the following stiffness values used:

x-y translational stiffness (k_1)= 10^9 N/m
z-direction stiffness(k_2) = 0 N/m
Rot-x and Rot-y stiffness (k_3)= 0 N/m

where x, y, z are the local axes of the Combin7. Note that the z -axis of the Combin7 coincide with the axis of rotation of the beam, i.e., global x axis. The lower ends of both the columns are grounded. So, these joints are assumed to be rigid.

4. Results

The finite element model is developed and solved in Ansys7 [7]. The vector diagram of the deflection of the loom is shown in Fig. 6, in which the maximum deflection, 18.97mm, occurs at the joint number 8 of Fig. 3. The corresponding, von-Mises effective stress contour diagram is shown in Fig. 7. The maximum stress of 146.48 MPa is induced at the middle nodes of the beam. Moreover, the stress of 235.91 MPa is induced at the joint 6 of the column, i.e., at the gear end of Fig. 3. In [4], the maximum stresses were computed analytically by assuming the beams as simply supported, and columns as fixed-free end. Thus, the values were higher compared to those obtained using the FE tool, i.e., ANSYS 7 as indicated in Table 5.

Table 5 Comparision of FE solutions

Componets	Max. deflection	Max. von-Mises effective	Max. analytical

		stresses (ANSYS 7)	stresses [4]
Beam	18.97 mm	146.48 MPa	150 MPa
Column	18.97 mm	235.91 MPa	240 MPa

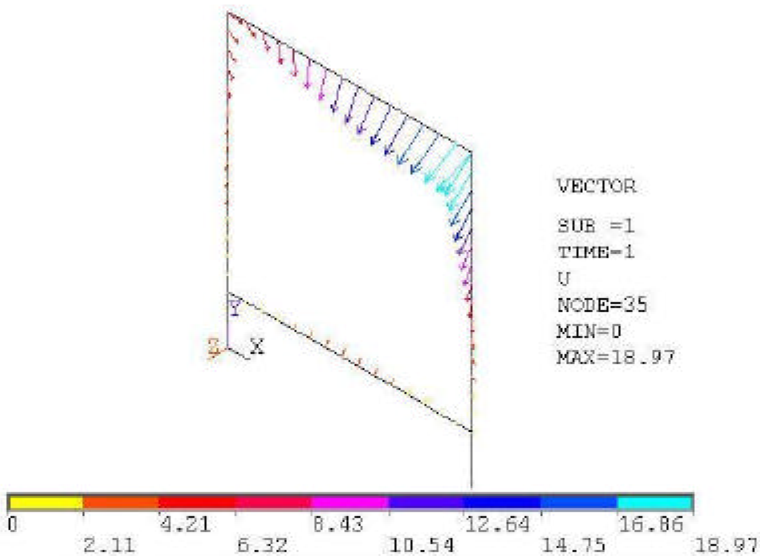


Fig. 6 Vector deflection in the loom

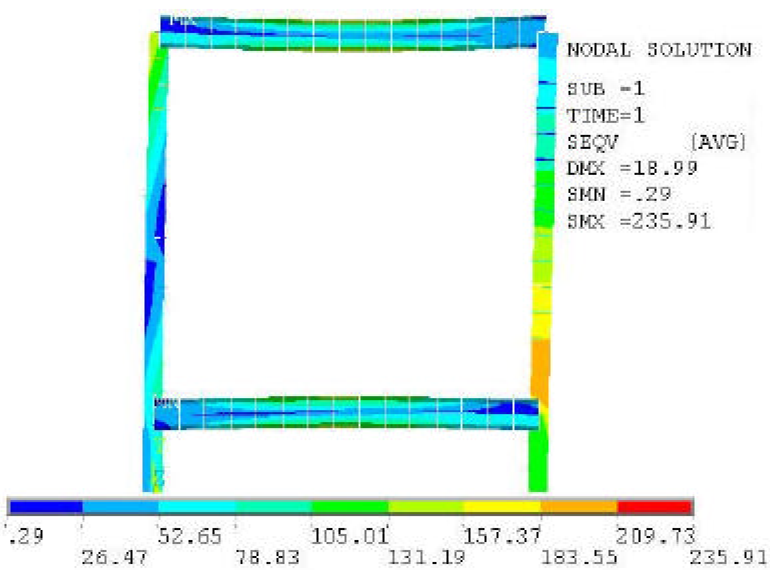


Fig. 7 The von-Mises effective stress contours in the beams and columns

5 Conclusions

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A metallic carpet loom developed to overcome the difficulties of the existing wooden looms is reported in Saha et al. [3]. In order to reduce its weight and cost, optimization of its critical components, namely, the beams and columns are carried out in [4]. For realistic estimation of the loads, tensile test of the warp thread was conducted to obtain the load-deformation curve. Finite element analysis (FEA) of the components is carried out in this paper to verify the stress and deflection results used for the optimized [4]. FEA is critical when the realistic conditions are difficult to implement in analytical form [4], as was for the connection between beam and columns. The FE model results are comparable with those from the analytical equations [4].

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