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Review of Structural Analysis Program for Study of Trusses

Azhar Uddin Sumit Pahwa

M.Tech Scholar H.O.D, CE Department, AIT, Ujjain AIT, Ujjain, India

Abstract: ***This paper compares and provides a study of various levels of research work done in computational structural analysis. The crust of our review focuses on the analysis of truss, complex or simple because truss is the most widely used and fundamental building block of any structure.***

Keywords: FTTD, FEM, embedded steel frames, trusses

1. Introduction

Composite materials have been used extensively to build truss structures owing to their remarkable properties. Composite truss structures have attracted tremendous research interests due to their superior strength and performances, and have been utilized in the construction of civil structures. Considerable efforts have been placed on the development and analysis of truss bridges, which usually consist of concrete and steel. Research works have been focused on material characteristics, truss joint design, and processing and construction of structural components. In the nineteenth century, composite trusses for aerospace applications were investigated [1-3], which are distinctly different from civil structures regarding materials, strength, stiffness, and weight. The effects of prestressed cables in composite structural system were studied [4]. In recent years, experimental study and numerical analysis have been carried out on composite space trusses with prestressed cables made of steel and compression members made of concrete [5,6]. The performances and characteristics of overall composite truss structures have been studied [7, 8].

Although publication works on composite trusses have been found in the literature, further investigation on systematic design and analysis of composite trusses containing pre-tensioned cables is needed. Unlike theprevious research concentrated on civil structures, thispaper is devoted to the study of light weight high strength composite truss structures, which can be employed inaerospace structures.

The current steel design process consists of two steps, an analysis to determine internal actions such as forces and moments, and a design check for adequate strength, for all individual members and connections. Component-based design is a simplistic process that could be improved to increase efficiency and economy. Advanced analysis completes the analysis and design check in a single step, thereby saving time in the design process. Additionally, advanced analysis directly models factors affecting the structure, such as geometric imperfections and residual stresses, enabling the user to accurately model the structure. Component-based design does not consider the system's ability to redistribute loads, and thus in systems where this is possible the true load carrying capacity is greater than predicted. The current design code uses load and resistance factors to meet a specified level of reliability for each component. As system behavior is different than that of an individual component, the system reliability is not the same as the component reliability. Thus a system resistance factor must be determined in order for the system to meet a target reliability index. Enforcing system reliability will create an economical system which is designed for a specified probability of failure.

2. Analysis of Seismic Performance of the Structure

For dual system of frame-core wall structure, core wall is the key lateral load resistant member bearing more than 80% earthquake shear force. In order to improve the ductility of the core shear walls steel columns of HM340×250×9×14 were embedded at the four corners of the core wall and the intersections of longitudinal and transversal core shear-walls which would also be considered as the second proof to the shear wall in avoidance of potential consecutive collapse owing to the degradation of its vertical bearing capacity from the serious cracking of the concrete under rarely occurring earthquake. On the other hand the embedded steel column also enhance the anchorage of the floor truss/beam. While as, in order to strengthen the inelastic deformation capacity of the longitudinal coupling beams carried steel trusses and ensure the integrity character of the core wall, steel shapes were encased inside the coupling beams, which were connected with embedded steel columns forming the embedded steel frames within the longitudinal core shear-walls.

3. Analysis of Property and Member Variations

3.1 Thickness

ariability of thickness affects the strength of a member as it directly changes the cross sectional area available to resist internal forces due to loading. For this project, it was assumed that each member had a uniform thickness along its length for each of the four sides, but that the value of thickness relative to the nominal was random. The variability of thickness in HSS members was obtained through recently collected data for a report to AISC which characterized dimensional variability in HSS members produced in the US (Christopher M. Foley,

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personal communication, February 7, 2011). This report contains data on the variation of several dimensional measurements, however only thickness data was utilized in this project. Samples were obtained from three HSS manufactures in the US for 6 typical cross sections, ranging in size from 12”x6” to 3”x3” and thicknesses from 5/8” to 3/16”. There were a total of 28 samples measured and sample lengths ranged from 11 to 13 inches. Thickness measurements were taken at 16 locations around the cross section: 3 along each face and 1 at each corner at 1 inch from both ends of each specimen.

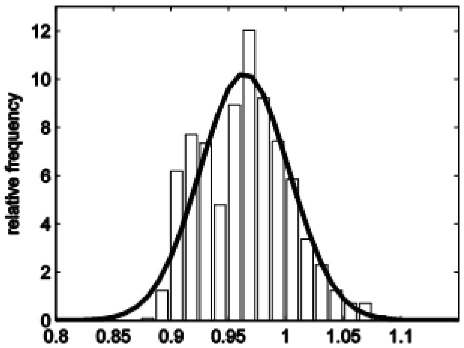

Figure 3.1: Histogram and normal PDF fit of HSS wall thickness

3.2 Analysis of Young’s Modulus and Yield Stress

Material properties such as Young’s modulus, E, and yield stress, Fy, affect the strength of structural members by varying at which stress they begin to experience plastic deformations and at which strain this occurs

3.3 Implementation in Models

Latin hypercube sampling was employed to reproduce values of thickness, Young’s modulus, and yield stress for chord and web members for all simulations. In the 2D models, all chord members were correlated, and all web members were correlated. This reflects how chord members and web members come from the same batch and have similar properties. Additionally, if all n members were uncorrelated, the variability would be much smaller than a single member’s variability as shown below (Eq. 3.1) where V is the coefficient of variation.

$$V_{system} = \frac{V_{member}}{\sqrt{n}} \quad (3.1)$$

In the 3D models, all chord members in a truss were orrelated and all web members in a truss were correlated, however the members were not correlated between trusses. Thus the 3D model was a system of independent trusses, and system behavior was observed through the simulations of systems of independent trusses.

4. Analysis of Plane Truss Structure

The proposed truss structure is 72 ft with 18 ft height. The proposed truss structure is composed of two materials: steel and aluminum. The modulus of elasticity of steel is 29,000 ksi and the modulus of elasticity of aluminum is 10,000 ksi. The structural configuration of proposed structure can be seen in Figure 2. Figure 3 shows the analytical model of plane truss structure. The main data input to the MATLAB program are joint data, support data, material property data, cross-sectional property data, member data and load data. Joint data of the proposed plane truss consists of the total number of joints, NJ, and the global coordinates of each joint. There are six joints in the proposed truss. The position of each joint is specified by means of the global coordinates of the joint. Joint coordinates are stored in a joint coordinate matrix, COORD of order NJ × 2. Support data are stored in the form of a matrix MSUP of order NS × (NCJT+1) and this matrix is called a support data matrix. In the proposed plane truss, the number of joints that are attached to supports, NS, is three. For a plane truss, the number of degree of freedom of a free joint, NCJT, is two. The joint numbers and their corresponding directions of restraints are defined in the support data matrix. The directions of restraints of each support joint are specified by using two-digit code, 0 or 1. If the joint is free to translate, it is defined as 0 and if the joint is restrained, 1 is selected. Material property data are defined by storing modulus of elasticity of each aterial used in the structure in a elastic modulus vector, EM. The number of rows of EM is equal to the number of materials used in the plane truss, NMP. In this proposed truss structure, two materials; namely, steel and aluminum are used and so NMP is two. The steel is arbitrarily assigned to be material number 1 and the aluminum is arbitrarily assigned to be material number 2. In cross-sectional property data, the cross-sectional areas are stored in a cross-sectional property vector, CP. The number of rows of CP is equal to the number of different crosssection types used for the truss members, NCP. There are three different cross-section types in this proposed truss so NCP is three.

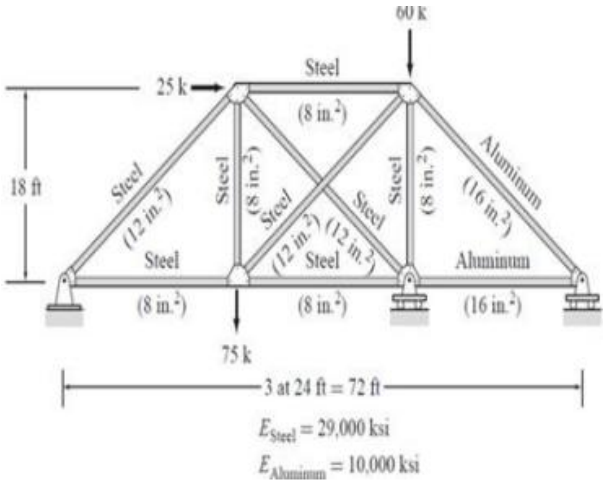

Figure 2: Proposed Truss Structure.

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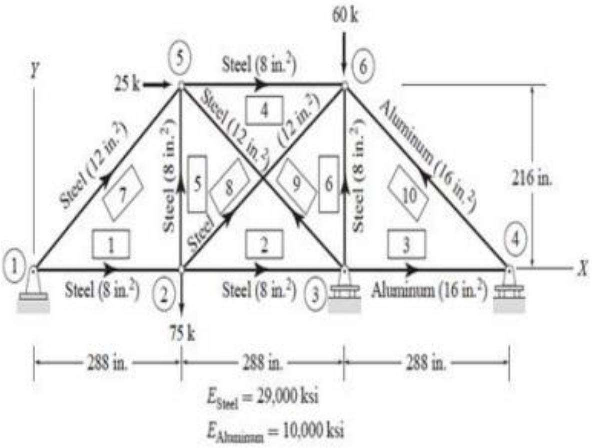

Figure 3: Analytical Model of Proposed Truss structure**.**

The cross-sectional areas of three types are 8 in.2, 12 in.2and 16 in.2 respectively. The numbers 1, 2 and 3 are selected as the cross-section type number for each area. Member data includes the total number of members of the truss, NM, and the beginning joint number, the end joint number, the material number and the cross-section type number for each member. Since the proposed truss has ten members, NM is ten. These member data are stored in the form of a member data matrix, MPRP of order NM × 4. Load data contains the number of joints that are subjected to external loads, NJL, and their joint numbers and the magnitudes of the force components in the X and Y directions. The numbers of the loaded joints are stored in an integer vector, JP. The number of rows of JP is equal to NJL. As the proposed truss has three joints that are subjected to external loads of 75 k, 25 k and 60 k, NJL is three. The magnitudes of forces and thecorresponding load components in the X and Y directions are stored in a load data matrix, PJ of order NJL × NCJT.

5. Analysis of Residual Stresses

The formation of cold-formed hollow sections produces a complex distribution of residual stresses. The sections are formed by uncoiling and leveling sheets of steel. hey are next roll formed into tubes and seamwelded, then sized into the required shape (Li at al., 2008). Specifically there are two methods for forming rectangular hollow sections, one by directly forming the rectangular section from the sheet, the other byforming a circle cross section from the sheet, then forming the circle into the final rectangular cross section (Li et al., 2009). The processes of uncoiling and leveling, roll-forming, and sizing produce residual stresses in both the longitudinal and circumferential directions, which affect the strength of the tubes (Kato and Aoki, 1978). To model residual stress in the FE models, data was separated into longitudinal and transverse components. Residual stress distributions through the thickness and around the cross section and magnitudes of the residual stresses were determined based on models and experimental data found in literature.

5.1 Longitudinal

There were several models in the literature for longitudinal residual stress in HSS. The distributions were similar, but the model proposed by Davison and Birkemoe (1982) was chosen for its simplicity in defining anequation to represent the distribution. They experimentally measured residual stresses from coupons and determined a model to reflect the data and theory. Davison and Birkemoe (1982) determined that there aretwo residual stress gradients in the longitudinal direction, one across the tube face and around the cross section, denoted as membrane, and the other perpendicular to the tube face through the material thickness, denoted as bending. "The perimeter (membrane) residual stress gradient represents the variation in the mean value of the longitudinal residual stress [and] the through thickness (bending) residual stress gradient is the deviation from this mean value normal to the perimeter through the material thickness" (Davison and Birkemoe, 1982). In their model, bending is symmetrical through the thickness, with tension at the outer face and compression at the inner face (Figure 5-1(a)), and membrane residual stress is constant through thethickness (Figure 5-1(b)). They found that the maximum magnitude of through thickness residual stresses wasless for coupons taken from the corners than for coupons taken from the flats (Davison and Birkemoe, 1982).Key and Hancock (1993) also confirmed that longitudinal bending through thickness residual stresses were smaller in magnitude in the corner than flats, specifically that the corners have half the value as the flats(Figure 5.3(a)). The numbers reflecting the location along the cross-section is depicted in Figure 5-2.Membrane residual stresses vary linearly along the cross section (Figure 5.3(b)). The stress magnitudes are equal for the flats and corners, but vary from maximum tensile stress at the flat centerline to maximum compressive stress at the corner (Davison and Birkemoe, 1982). The distributions through the thickness andacross the section produce no net force as shown in Eq. (5.1) where σb is the bending residual stress and σm is the membrane residual stress.

$$\int(\sigma_b+\sigma_m)\,dA=0$$

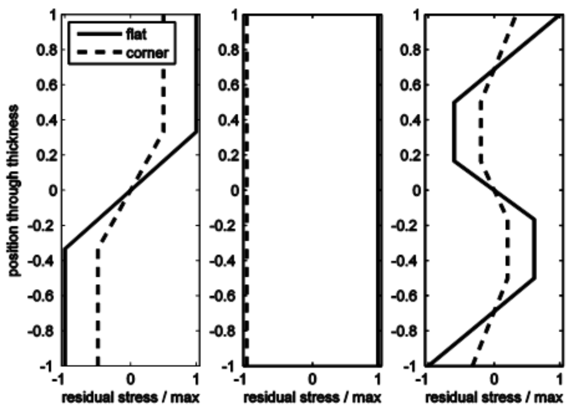

Figure 5.1: Through thickness residual stress distribution for (a) longitudinal bending, (b) longitudinal membrane, and (c) transverse

5.2 Transverse

Traverse residual stress data for HSS members in the literature was minimal. The distribution proposed by Key and Hancock (1993) was chosen to model transverse residual stresses (Figure 5-1(c)), which consists of tension at the outer surface and compression at the inner surface for the

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bending component, and zero for the membrane component. The relationship between values at the outer surfaces to values on the plateaus was determined by enforcing the requirement of no net force on the section. This resulted in the stress on the plateau being equal to 0.61 times the surface stress. Data from Li et al. (2008), which was determined experimentally by X-ray diffraction, shows that the transverse residual stresses in the corners is a third of the transverse residual stresses in the flats.

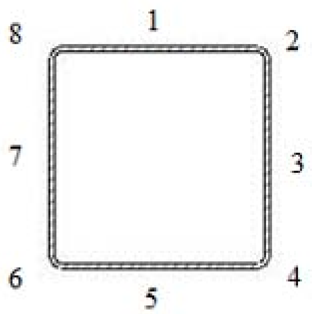

Figure 5.2: Square HSS numbered cross section points

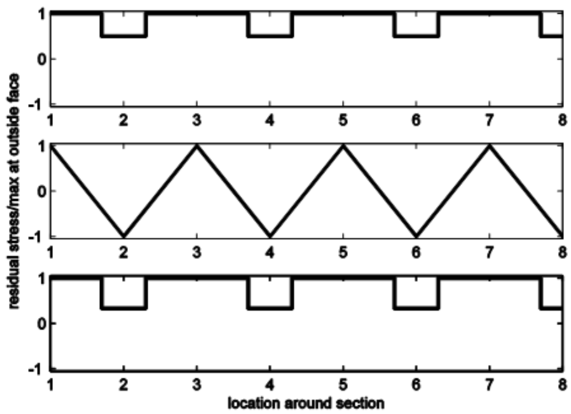

Figure 5.3: Residual stress distribution around cross-section at outside face for (a) longitudinal bending, (b) longitudinal membrane, and (c) transverse

6. Analysis of Determinate Trusses

The trusses are classified as determinate and n determinate. They are also classified as simple, compound and complex trusses. We have plane and space trusses. The joints of the trusses are idealized for the purpose of analysis. In case of plane trusses the joints are assumed to be hinged or pin connected. In case of space trusses ball and socket joint is assumed which is called universal joint. If members are connected to a hinge in a plane or universal joint in space, the system is equivalent to m members rigidly connected at the node with hinges or socketed balls in (m-1) number of members at the nodes as shown in figure 6.1. In other words it can be said that the members are allowed to rotate freely at the nodes. The degree of freedom at node is 2 for plane truss (linear displacements in x and y directions) and 3 for space truss (linear displacements in x,y and z directions). The plane truss requires supports equivalent of three reactions and determinate space truss requires supports equivalent of six reactions in such a manner that supporting system is stable and should not turn into a mechanism. For this it is essential that reactions should not be concurrent and parallel so that system will not rotate and move. As regards loads they are assumed to act on the joints or points of concurrency of members. If load is acting on member it is replaced with equivalent loads applied to joints to which it is connected. Here the member discharges two functions that is function of direct force member in truss and flexural member to transmit its load to joints. For this member the two effects are combined to obtain final internal stress resultants in this member.

The truss is said to be just rigid or determinate if removal of any one member destroys its rigidity and turns it into a mechanism. It is said to be over rigid or indeterminate if removal of member does not destroy its rigidity.

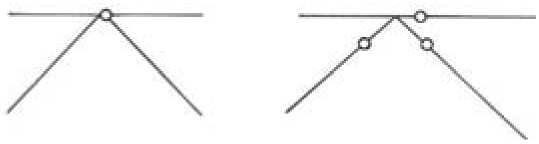

Figure 6.1: hinged joint of truss

6.1 Plane truss

The stable and just rigid or determinate smallest plane truss as shown in Fig.9.3. comprises of a triangle with three nodes and three members. Two members and a pin joint are added to expand the truss. Total number of non-parallel and non-concurrent links or reactive forces required to support j number of joints is 3. Total number of unknowns is number of member forces and reactions at the supports. Number of available equations is 2j. Therefore for determinate plane truss system:

$$\mathbf{(m + 3) = 2j}$$

$$\mathbf{m = (2j - 3)}$$

Hinge support is equivalent of two reactions or links and roller support is equivalent of one reaction or link.

7. Finite Element Analysis of Composite Truss Structures

Various 2D and 3D composite truss structures will be first proposed, and two typical configurations are shown in Figures 7.1 and 7.2. The procedure of finite element simulation is similar to conventional approach. Based onthe characteristics of structural members, they can be simulated as beams (compression-tension-bending element), bars (compression-tension element), and cables tension-only element). It is known that the element type of ANSYS LINK10 is capable of dealing with tensiononly property of cable structures. Equivalent material properties of structural members are applied. For example, the honeycomb sandwich panel will be approximated as orthotropic materials. Joints are assumed to be perfectly connected to truss members. Since this kind of finiteelement models involves tension-only elements, nonlinear solver of ANSYS will be applied. Convergent solution will be obtained under specified sub step settings. Once displacements are solved, the unreformed and deformed configurations of the truss can be generated (Figure7.3).

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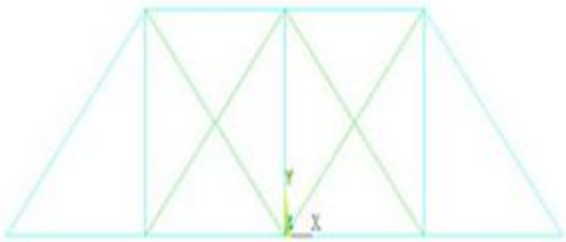

Figure 7.1: Schematic of a 2D truss

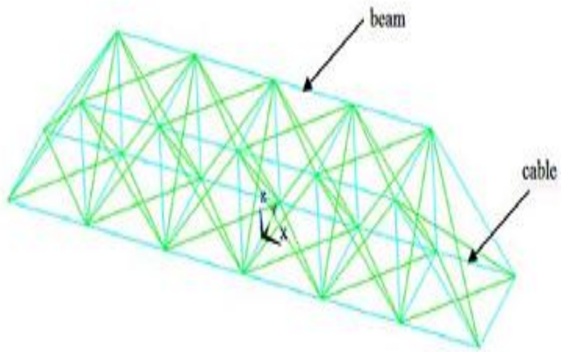

Figure 7.2: Schematic of a 3D composite truss

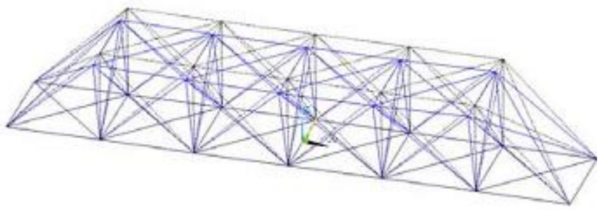

Figure 7.3: Undeformed and deformed configurations

8. Conclusion

In this research paper we have seen various techniques and details regarding the analysis of truss , some of them are , study of vibrations in a structure , analysis of Young's modulus , analysis fo planar trusses , analysis by means of FEM . We have also seen that finite element method have been used for the analysis of complex trusses and hence require more computational resources which are hard to get for everybody. On the other hand matrix based analysis of trusses yield a better overall performance and thus is more suited for day to day analysis of the program. Hence we propose a structural analysis program which will have all the above features and in addition to that a graphical user interface will be there for easy visualization . Plus the software thus designed could also be used for the study of trusses at undergraduate level for easy visualizations.

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