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ROOF TRUSS DESIGN FOR INDUSTRIAL BUILDINGS

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ABSTRACT

The roof trusses are mostly depended on the internal forces in the structure, dismember the structure and analyze separate free-body diagrams of individual members or combination of members. In this paper, the design of roof trusses frame, rivet diameters, and area of all members have to be calculated. General design theory of structural analysis, the equilibrium of rigid body, method of joints, tension and compression of members, mechanical properties of materials, design of riveted joints and area of trusses members in the project of Thilawa Zone (1) constructed by PREFAB STEEL Company Limited. This paper deals with the design and analysis of roof truss.

Key Words: *Roof Truss Design, Structural Analysis, Method of Joints, Internal Forces, Materials, Truss.*

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1. INTRODUCTION

A truss is a structure composed of several members joined at their ends so as to form a rigid body. They are used to span greater distances and to carry larger loads than can be done effectively by a single beam or column. Consequently they are of great importance to the engineer who is concerned with structures. They are commonly used to form bridges and to support roofs. Variations on the truss form are also used in large machines. The roof truss is essentially a triangulated system of usually straight interconnected structural elements; it is sometimes referred to as an open web girder. The individual elements are connected at nodes; the connections are often assumed to be nominally pinned. The external forces applied to the system and the reactions at the supports are generally applied at the nodes. When all the members and applied forces are in a same plane, the system is a plane or 2D truss. In a typical single-storey industrial building, trusses are very widely used to serve two main functions:

1. To carry the roof load:
   - Gravity loads (self-weight, roofing and equipment, either on the roof or hung to the structure, snow loads)
   - Actions due to the wind (including uplift due to negative pressure).
2. To provide horizontal stability:
   - Wind girders at roof level, or at intermediate levels if required
   - Vertical bracing in the side walls and/or in the gables.

In order to get a good structural performance, the ratio of span to truss depth should be chosen in the range 10 to 15. The architectural design of the building determines its external geometry and governs the slope given to the top chord of truss. The intended use of the internal space can lead either to the choice of a horizontal bottom chord, or to an inclined internal chord, to allow maximum space to be freed up. To get an efficient layout of the truss members between the chords, the following advisable are the inclination of the diagonal members in relation to the chords should be between 35° and 55, point loads should only be applied at nodes and the orientation of the diagonal members should be such that the longest members are subject to tension (the shorter ones being subject to compression).

For all the types of member sections, it is possible to design either bolted connections or welded connections. Generally, bolted connections are preferred on site. Where bolted connections are used with bolts loaded perpendicular to their shank, it is necessary to evaluate the consequences of slack in connections. In order to reduce these consequences (typically, the increase of the deflections), solutions are available such as use of pre-stressed bolts, or limiting the hole size. [1]

2. TYPE OF TRUSS

The design consideration and calculation of roof truss are mostly dependent upon the internal forces in the structure, dismember the structure and analyze separate free body diagrams of individual members or combination of members. A truss is a structure composed of several members joined at their ends so as to form a rigid body. They are used to span greater distances and to carry larger loads than can be done effectively by a single beam or column. Consequently they are of great importance to the engineer who is concerned with structures. They are commonly used to form bridges and to support roofs. Variations on the truss form are also used in large machines.

2.1 Typical Trusses

Trusses are composed of reasonably slender load-carrying members connected to one another by pin joints, which are at the ends of the members.

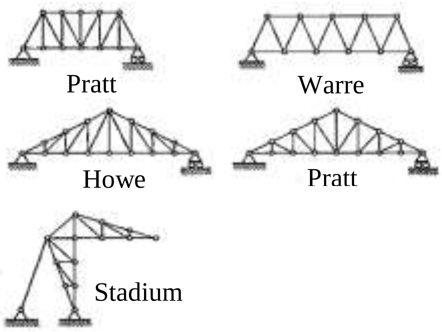

Figure1.Types of truss design

2.2 Truss Assumptions

In the initial analysis of trusses three assumptions are made. These assumptions are usually more or less false but are necessary to allow one to get started. In actual design work it may be necessary to correct for the original assumptions in later stages. The assumptions are:

1. The members are joined by smooth pins at their ends.
2. Loads and reactions act only at the joints.
3. The weights of the members are negligible [2].

2.3 Structural Analysis of Plane Truss

A framework composed of members joined at their ends to form a rigid structure. Joints (Connections): Welded, Riveted, Bolted, Pinned.

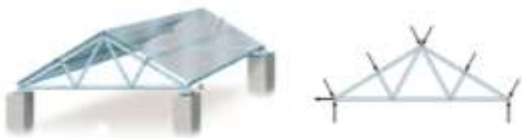

Figure2. Plane Truss

2.4 Forces in Members

The analysis of a force in a member usually involves

1. Draw Free Body Diagram of Truss.
2. Determine external reactions by applying equilibrium equations to the whole truss.
3. Perform the force analysis of the remainder of the truss by Method of Joints.

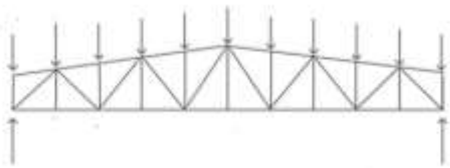

Figure3. Free Body Diagram of Truss

3. RIVETS

Before modern welding techniques came into common use, riveting was one of the most common methods for joining the sheet metal. Since the advent of the new welding techniques and modern machines that form seams on sheet metal, riveted seams are not so common in modern sheet metal work. However, the sheet metal worker will often use rivets on sheet metal too heavy for machine forming and where welding is not practical. Rivets may be made from steel, copper, brass, aluminum or other materials. Standards for rivets sizes and shapes have been put forward by several agencies. Many types of rivets are used in the

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sheet metal shop. The most common types are the tinman's rivets, flathead, snap head (also called roundhead) and pop rivets. The process consists of drilling or punching the plates to be riveted, inserting the rivet, and then closing it by an applied compression force so that it completely fills the hole and forms a rigid joint. A variety of riveted joints is used in construction and fabrication work is making permanent joints. The process consists of drilling or punching the plates to be riveted, inserting the rivet, and then closing it by an applied compression force so that it completely fills the hole and forms a rigid joint [3]. A variety of riveted joints is used in construction and fabrication work is

1. single riveted lap joint;
2. double riveted lap joint;
3. single-strap butt joint;
4. double-strap butt joint.

3.1 Strength of Riveted Joints

A riveted joint is only as strong as its weakest part, and it must be borne in mind that it may fail in one of four ways:

1. shearing of the rivet;
2. crushing of the metal;
3. splitting of the metal;
4. rupture or tearing of the plate.

3.2 Material Properties

Mechanical properties of materials are consideration of such things as material strength, stability, fatigue and brittle fracture etc. Proportional Limit is stress above which stress is no longer proportional to strain. Elastic Limit is the maximum stress that can be applied without resulting in permanent deformation when unloaded. Yield Point is Stress at which there are large increases in strain with little or no increase in stress. Among common structural materials, only steel exhibits this type of response.

Yield Strength is the maximum stress that can be applied without exceeding a specified value of permanent strain (typically .2% = .002 in/in). Ultimate strength is the maximum stress the material can withstand (based on the original area). Modulus of Elasticity is slope of the initial linear portion of the stress-strain diagram. The modulus of elasticity may also be characterized as the "stiffness" or ability of a material to resist deformation within the linear range [4].

3.3 Method of Joints

If a truss is in equilibrium, then each of its joints must be in equilibrium. The method of joints consists of satisfying the equilibrium equations for forces acting on each joint. Recall, that the line of action of force acting on a joint is determined by the geometry of the truss member. The line of action is formed by connecting the two ends of each member with a straight line. Since direction of the force is known, the remaining unknown is the magnitude of the force. The truss is made up of single bars, which are either in compression, tension or no-load. The means of solving force inside of the truss use equilibrium equations at a joint. This method is known as the method of joints. [5]

$$\sum F_X = 0 , \sum F_Y = 0 , \sum M_{X,Y} = 0 \qquad (1)$$

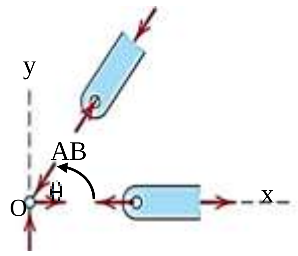

Figure4. Method of Joints

3.4 Free Body Diagram of Joint

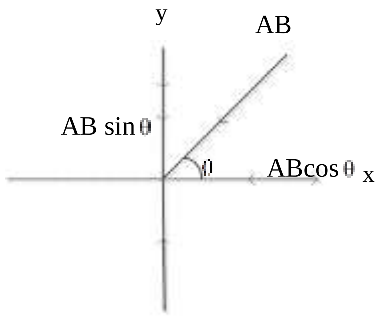

Figure5. Free Body Diagram of Joint

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For Horizontal Force $= AB\cos(\theta)$

For Vertical Force $= AB\sin(\theta)$

$$\text{For Result Force} = \sqrt{F^2_{Horizontal} + F^2_{Vertical}} \quad (2)$$

3.5 Riveted Joint with Eccentric Load

Load applied eccentrically to a group of rivets=Effect of torque or moment + Direct load

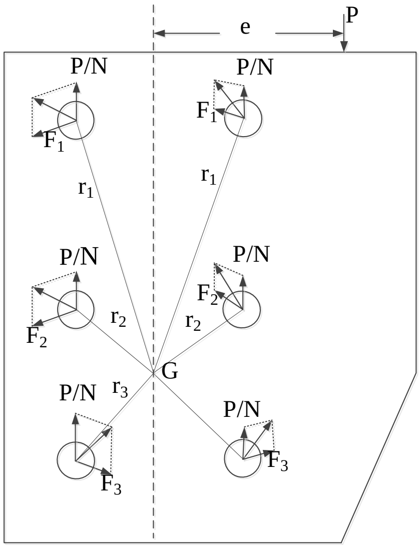

Figure6. Riveted Joint with Eccentric Load

Joints of N rivets are subjected to a moment equal to ($P \times e$). Let it assumed that the moment load on a rivet varies directly with the distance from the center of gravity of a group of rivets and is directly perpendicular to the radius of the center of gravity.

Equations of moment forces F_1, F_2, F_3 may be written;

$$F_1 = Kr_1,\ F_2 = Kr_2,\ F_3 = Kr_3 \quad (3)$$

Where K = constant of proportionality.

Externally applied moment= $\sum$ Product of their forces and their arm to the center of gravity

Hence, $P \times e = N_1F_1r_1 + N_2F_2r_2 + N_3F_3r_3 + ---$

$$P \times e = N_1F_1r_1^2 + N_2F_2r_2^2 + N_3F_3r_3^3 + --- \quad (4)$$

Where, N_1=Number of rivets with radius r_1

N_2= Number of rivets with radius r_2

N_3= Number of rivets with radius r_3

From Equation (4) K is determined.

The value of moment force for each rivet can be determined by multiplying K with the appropriate (r).

Assume that the direct load,

$$\text{Direct Load} = \frac{P}{N} \quad (5)$$

Where,

P=Load on rivets,

N=Number of rivets

Direct load is the same for all rivets of the joint. The vertical sum of the moment force is the resultant force on the rivet. [6]

$$\text{Resultant force on the rivet, } F_R = \sqrt{F^2_{Horizontal} = +F^2_{Vertical}} \quad (6)$$

$$\text{Shear stress in rivet, } S_S = \frac{F_R}{A} \quad (7)$$

where, A=Area of rivet

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4. DIMENSIONS

To design the roof truss frame, the required data are collected in the following

Purlin ((258×200) Section)

D= 258mm, t= 2mm, b=60mm, A=804mm^2, Edge=16mm,

Mass of purlin for 4m = 25.52kg

Mass of Roof for (4×2.8) m^2 = 656.47kg

Mass of Roof truss Frame =2.48 tons (US standard)

2.48ton = 2249.8kg

Weight of purlin for 4m = m $\times$ g

= 25.52 $\times$ 9.81

= 250.3512N

Weight of Roof for (4×2.8) m^2 = m$\times$ g

= 656.47 $\times$ 9.81

= 6439.97N

Total Weight of Roof and Purlin = 250.3512 + 6439.9

= 6.69kN

Weight of Roof truss Frame = m $\times$ g

= 2249.8 $\times$ 9.81

= 22.0753 kN

W = total weight of roof and Purlin on truss = 6.69kN

W_t = weight of roof truss frame = 22.0753KN

4.1 Design Calculation of Roof Truss Frame

As shown in Figure 7, a garage consists of 10 trusses, each spaced 2.8 m. The roof trusses are supported by concrete columns 2.8 m apart. Types of connections are bolted connection for member design and each joint are connected with rivets.

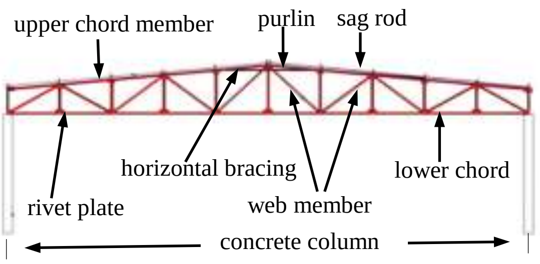

Figure7. Roof Truss Frame Design of Elevation View

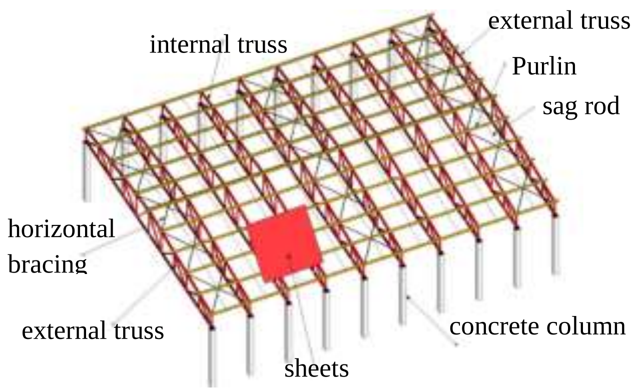

Figure8. Roof Truss Frame Design of 3D View Structural Plan

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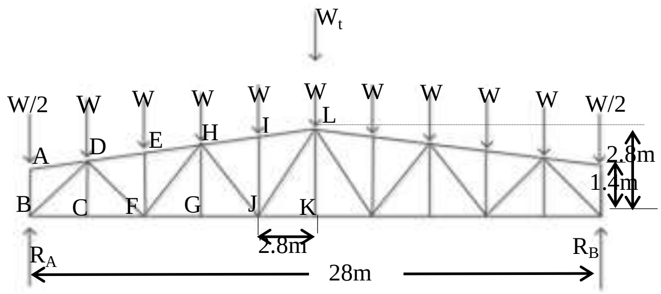

Figure9. Free Body Diagram of Roof Truss Frame

$\sum M_{RA} + = 0$,

$(6.69 \times 2.8) + (6.69 \times 5.6) + (6.69 \times 11.2) + (6.69 \times 14) + (6.69 \times 16.8) + (6.69 \times 19.6) + (6.69 \times 22.4) + (6.69 \times 25.2) + (3.34 \times 28) + (22.0753 \times 14) - (R_A \times 28) = 0$

$R_B = 44.49265\,kN$

$\sum F_y + \uparrow = 0$,

$10W + W_t = R_A + R_B$

$(10 \times 6.69) + 22.0753 = R_A + 44.49265$

$R_A = 44.49265\,kN$

By using the joint method in Figure 4, the following data are calculated in table 1.

Table1. Results of Joint members

Joint	kN	kN	kN
A	AD=0	AB=3.345	
B	BD=79.265	BC=67.767	
C	CF=67.767	BC=67.767	CD=0
D	DE=106.445	DF=-44.53	
E	EH=106.105	EF=10.409	
F	FH=20.559	FH=122.008	
G	GJ=122.008	GF=122.008	GH=0
H	HI=123.297	HJ=-0. 715	
I	IL=123.297	IJ=6.69	
J	JK=128.817	JL=-8.833	
K	JK=128.817	KL=0	

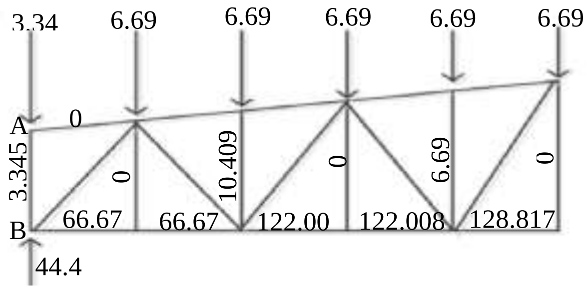

Figure10. Force Diagram of Roof Truss Frame

4.2. Design Calculation of Rivet Diameter

Maximum force and load are acting on joint J. Rivet of joint J have 18 holes, 400 mm base, 240 mm wide and 22 mm thickness. Rivet joint J connected 5 chords. Rivet plate are made up of wrought iron.

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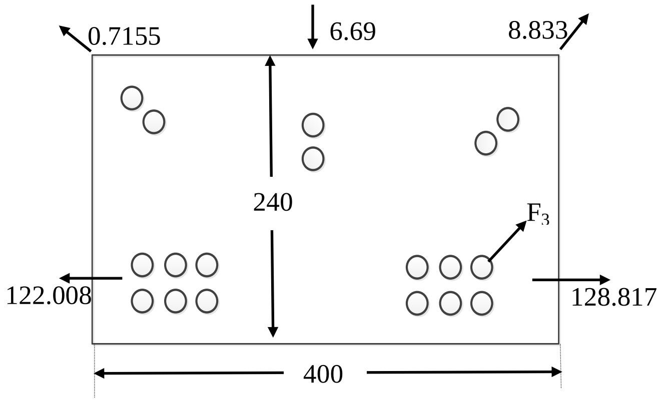

Figure11. Rivet Plate

Direct Force, $F = \frac{P}{N}$

$$= \frac{6.69}{17} = 0.393 \text{ kN}$$

Taking movement about the left row of

$$\bar{x} = \frac{2\times(2+47+92+153+217+262)+32+172+308+273}{17}$$

$= 147.235$ mm

Taking movement about the bottom row of rivet,

$$\bar{y} = \frac{(35\times 6)+126+171+133+165+138+166}{17}$$

$= 65.235$ mm

$$\text{External applied moment} = \sum \begin{matrix}\text{Product of their forces and} \\ \text{their arm to the center of gravity}\end{matrix}$$

$$P\times e = F_1N_1r_1 + F_2N_2r_2 + ---- + F_{17}N_{17}r_{17}$$

$$P\times e = k(N_1r_1^2 + N_2r_2^2 + ---- + N_{17}r_{17}^2)$$

$$6.69\times 10^3 \times (195-147) = k\,(r_1^2 + r_2^2 + --- + r_{17}^2)$$

k = 0.4395

The most heavy load rivet at F_3,

$F = k\times r_3$,

$= 0.4395\,(\sqrt{20^2 + 118^2}\,)$

$= 52.60$ kN

$F_{horizontal} = F\cos\theta$

$= 52.6 \times (118/119.68)$

$= 51.86$ kN

$F_{vertical} = F\sin\theta$

$= 52.6 \times (20/119.68)$

$= 8.79$ kN

Total vertical force,

$F_{vertical} + \text{Direct force} = 8.79 + 0.393$

$= 9.183$ kN

Horizontal force,

$F_{horizontal} = 51.86$ kN

Resultant force,

$F_R = \sqrt{F_{horizontal}^2 + F_{vetrical}^2}$,

$= \sqrt{8.79^2 + 51.86^2}$

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$= 52.599$ kN

F_R = Stress of material x Area , Stress of wrought iron , $S_S = 262000.8\ \text{kN/m}^2$

$F_R = S_S \times A$,

$$52.599 = 262000.8 \times \frac{\pi}{4} \times D^2$$

D = 0.0159 m

D =15.9 mm

4.3. Design Calculation of Area of Members

Roof truss consists of each of joint members such as bottom chords, top chords, and internal members, incline members and connected with rivet plates. Each of members is used ASTM-36 steel, M1010 steel, 1080 steel and 1020 steel.

Maximum tension of bottom chords at joint JK,

F=128.817 kN

ASTM -36 STEEL are used,

Yield strength of ASTM -36 STEEL =248 MPa

Factor of safety for member JK = 2.3

$$\sigma_{allow} = \frac{\text{Yield stress}}{\text{Factor of safety}}$$

$$= \frac{248}{2.3}$$

=107.8 MPa

$$\text{Required area} = \frac{\text{Load to be transmitted}}{\text{Allowable stress}}$$

$$= \frac{128.817 \times 10^3}{107.8 \times 10^6}$$

$$= 1195\ \text{mm}^2$$

Maximum tension of top chord at joint IL,

F=123.297 kN

M1080 STEEL are used,

Yield strength of ASTM -36 STEEL =220.44 MPa

Factor of safety for member IL = 2.5

$$\sigma_{allow} = \frac{\text{Yield stress}}{\text{Factor of safety}}$$

$$= \frac{220.44}{2.5}$$

= 88.2 MPa

$$\text{Required area} = \frac{\text{Load to be transmitted}}{\text{Allowable stress}}$$

$$= \frac{123.297 \times 10^3}{88.2 \times 10^6}$$

$$= 1398\ \text{mm}^2$$

Maximum tension of vertical chord of internal member at joint EF,

F=10.409 kN

ASTM -36 STEEL are used,

Yield strength of ASTM -36 STEEL =248 MPa

Factor of safety for member EF = 9

$$\sigma_{allow} = \frac{\text{Yield stress}}{\text{Factor of safety}}$$

$$= \frac{248}{9}$$

= 27.6 MPa

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$$\text{Required area} = \frac{\text{Load to be transmitted}}{\text{Allowable stress}}$$

$$= \frac{10.409 \times 10^3}{27.6 \times 10^6}$$

$$= 377\text{mm}^2$$

Maximum tension of incline member at joint BD,
F=79.265 kN, M1010 STEEL are used,
Yield strength of ASTM -36 STEEL =179.11 MPa
Factor of safety for member BD = 4.5

$$\sigma_{allow} = \frac{\text{Yield stress}}{\text{Factor of safety}}$$

$$= \frac{179.11}{4.5}$$

$= 39.8$ MPa

$$\text{Required area} = \frac{\text{Load to be transmitted}}{\text{Allowable stress}}$$

$$= \frac{79.265 \times 10^3}{39.8 \times 10^6}$$

$$= 1991.6\,\text{mm}^2$$

Maximum compression of incline member at joint DF,
F=44.53 kN
ASTM -36 STEEL are used,
Yield strength of ASTM -36 STEEL =248 MPa
Factor of safety for member DF = 3.5,

$$\sigma_{allow} = \frac{\text{Yield stress}}{\text{Factor of safety}}$$

$$= \frac{248}{3.5}$$

$= 70.9$ MPa

$$\text{Required area} = \frac{\text{Load to be transmitted}}{\text{Allowable stress}}$$

$$= \frac{44.53 \times 10^3}{70.9 \times 10^6}$$

$$= 628\,\text{mm}^2$$

5. CONCLUSION

This publication provides guidance on the design of trusses for single-storey buildings. The use of the truss form of construction allows buildings of all sizes and shapes to be constructed. The document explains that both 2D and 3D truss forms can be used. The 2D form of truss is essentially a beam and is used to supporting a building roof, spanning up to 28 meters for large industrial buildings. The 3D form of truss can be used to cover large areas without intermediate supports; this form is often used for large exhibition halls. The detailed guidance in this document relates mainly to 2D truss structures composed of rolled profiles but the principles are generally applicable to all forms of truss structure. The detailed design of trusses is illustrated by three sections. There are structural analysis of truss plane, rivet joint with eccentric load and design for axial load and direct load by reference. This Section summarizes the general requirements and the topics covered in subsequent. Fully detailed calculations for verification of a gusset plate connection and a chord splice are given in Appendices A. This paper deals with the design and analysis of roof truss. These are design calculation of rivet diameter and area of roof truss members, the explanations theory background of rivet diameter and area of roof truss members and to perform the force diagram of roof truss frame design, rivet diameter and area of roof truss members.

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