The Most Economical and Optimal Solution for Trusses in Gaza Strip

Ali I. Tayeh

Faculty of Applied Engineering and Urban Planning, University of Palestine, Gaza, Palestine
al2007.i@hotmail.com

Abstract— *Due to siege imposed on Gaza Strip since 2007 and the prevention of importing specific steel sections to the Strip. This situation has led to a change in standard steel prices. It is known that there is a direct correlation between the weight of steel sections and their prices i.e. heavier steel sections are associated with higher prices and vice versa. However, prices of steel sections in Gaza Strip are subject to change according to their availability. In other words, light steel sections can be more expensive than heavier ones.*

The major aim of this research is to investigate the best and most economical steel section to be used in Gaza Strip according to availability and local prices. Throughout this study, steel sections which are permitted to enter Gaza Strip have been used in this work such as L section, T section, I section, Square and Pipe sections. This research is a parametric study of different sections that can be used in the design of Howe roof truss subjected to vertical loads and later identifying the cheapest steel section to be used in Gaza, Palestine.

Keywords— Steel; Howe roof truss; I section; Material cost.

I. INTRODUCTION

A truss, or lattice structure, is a structural assembly of small interconnected elements. Trusses are formed by an interconnected assembly of relatively small elements, which create a lattice arrangement. The overall form, size and shape of the truss are as important as the strength of the individual components, and a wide variety of design options is available. A truss acts like a beam, with bending resisted by the couple created by forces in the top and bottom members. When an I-shaped beam is subjected to simple bending it can be seen that the bulk of resistance to bending moment is offered by a couple consisting of the forces in the flanges multiplied by the distance between them. Accepting that little error is involved in assuming that all resistance to bending is offered in this way, the most efficient system will be one in which the flange forces are reduced to a minimum to save material, and the distance between them is increased accordingly.

Trusses have been used as an effective mean to span for long distances. Nowadays, airport hangars and industrial facilities guarantee the use of a structural member to span larger distances without needing middle supports. This gives open spaces below which are needed for the function of a building. Moreover, shorter spans can use trusses as an architectural characteristic. Examples of these facilities are churches and other religious places.

II. RESEARCH AIM AND OBJECTIVES

The Aim

The major aim of this study is to investigate which steel section is the most economical for use in Gaza Strip by analyzing and designing a simple Howe roof truss carrying only vertical loads.

III. LITERATURE REVIEW

3.1 Truss Mechanics

All trusses are composed of one or more triangles varying in shape and size. Triangles are the simplest, most structurally stable shape. Triangles will retain their shape without the need for intermediate braces or extra supports when lengths of their sides are fixed. For each extra member added to a simple geometric shape, additional bracing is required as is the case with a square, pentagon, etc.'

Due to the geometric arrangement of these triangles within a truss, loads that cause the entire truss to bend are converted into tensile or compressive forces in the members.

Space trusses in which members extend in three dimensions also exist and are suitable for specific applications. Space trusses, also known as space frames, commonly require more hand-analysis or computer analysis time and are less common for long spans, and therefore not included in this report. As well, many space trusses have become proprietary information to the companies spending

https://dx.doi.org/10.22161/ijaers.5.9.12 *ISSN: 2349-6495(P) | 2456-1908(O)*

time and money to research new three-dimensional truss configurations (Chen & Lui, 2005).

One of the largest advantages of a truss is that it uses less material to support a given load.

3.2 Economy in the Design

With any structure, it is in the engineer's best interest to make the most economically efficient structure for the owner, while meeting calculated capacities and mandatory code requirements. This will ensure the building owner is not paying extra for oversized structural components for the given loads.

However with trusses, economy comes in many forms such as material, shop labor, erection and temporary supports, and other miscellaneous items in addition to the engineering design fee.

While all construction materials see some degree of volatility in prices, steel has seen a sharp increase in recent history. This drastic increase in steel prices can be tied to many different factors, but increased demand for steel scrap and other additives is the largest contributor. Steelmaking originally depended strictly on the mining of iron ore. Additionally, steel is an energy intensive material to produce the final steel shapes.

The cost of construction dictates that sections be efficiently designed. The simple principle is to design columns in such a way that the ratio of radius of gyration to the section depth or width is as high as possible, and that the αc (for columns) and αs (for beam-columns) values are as high as possible. Some column sections that are usually employed in practice are shown in Figure (1). If possible, compound sections should be avoided in the interest of economy. However, where heavy loads are to be resisted by the column, the use of compound sections may be the only feasible solution.

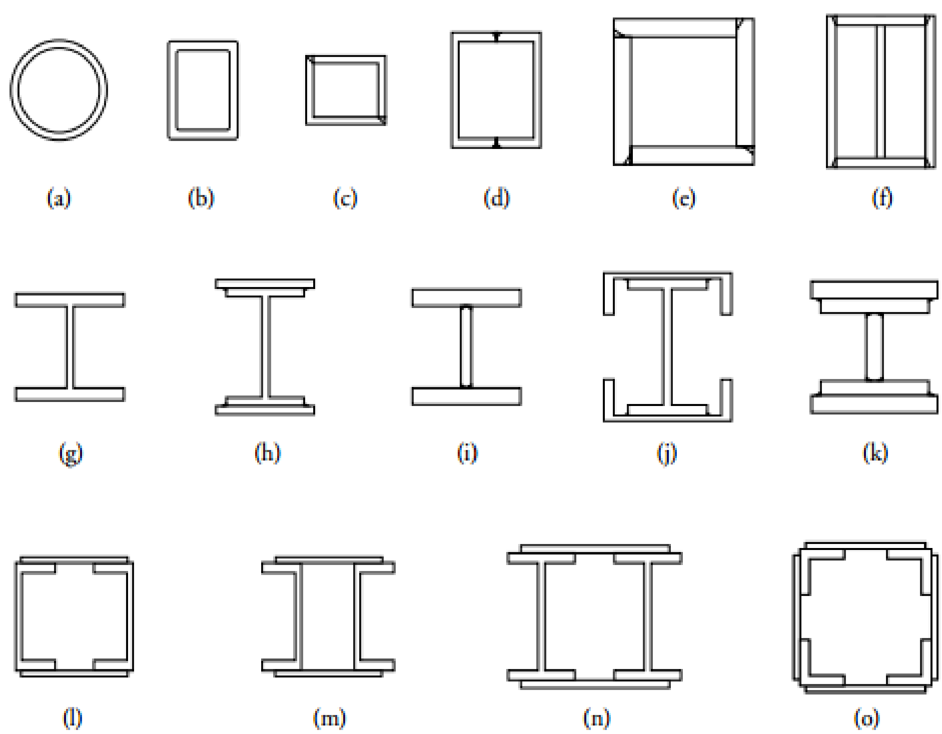

Fig1: Typical compression member sections.

3.3 Tension Members

Tension members are predominantly loaded in axial tension, although inevitably they are often loaded in combined tension and bending. The bending moments may arise from eccentricity of the connections, frame action and self-weight of the members. A simple classification of tension members is presented in Table (1). This table gives an overview of the many types of tension member applications in building construction; it also serves as a directory to subsections covering the particular design aspects.

https://dx.doi.org/10.22161/ijaers.5.9.12 ISSN: 2349-6495(P) | 2456-1908(O)

Table.1: Classification of tension members.

Aspect	Subgroup
(a) Type of construction	
Section type:	
Rigid	I-sections, hollow sections
	Angles and channels
Flexible	Plates, bars
	Steel rods
	Steel wire ropes
Construction	Single section
	Compound sections
(b) By position of restraints	
	End restraints at connections
	End and intermediate restraints
(c) By type of loads	
	Axial tension only
	Combined tension and bending
(d) By load fluctuation	
	Predominantly static loads
	Dynamic loads
	Impact

3.4 Compression Members

Compression members are structural elements that are subjected only to axial compressive forces; that is, the loads are applied along a longitudinal axis through the centroid of the member cross section. The stress can be taken as F = P/A, Where F is considered to be uniform over the entire cross section. This ideal state is never achieved in reality, however, because some eccentricity of the load is inevitable. Bending will result, but it can usually be regarded as secondary and can be neglected if the theoretical loading condition is closely approximated. Bending cannot be neglected if there is computed bending moment. The common type of compression member occurring in building and bridges is the column, a vertical member whose primary function is to support vertical loads. In many instances these members are also called upon to resist bending, and in these cases the member is a beam-column. Compression member are also in trusses and as components of bracing systems. Smaller compression members not classified as columns are sometimes to as struts.

IV. RESEARCH METHODOLOGY

This research shows the analysis and design of a simple Howe roof truss subjected to vertical loading. The aim is to identify the most economical section with respect to factors such as local prices and availability of steel sections in Gaza Strip, Palestine. First, the truss will be sketched on SAP2000 software with the specified height of 9 ft, spacing between joints of 9 ft and vertical factored load of 12 kip. Then, analysis and calculation of internal force in each member will be made using SAP2000 software. After that, design of members can be done and detailed design of two members (tension and compression members) will be demonstrated in this study. Tension and compression members studied along with resulted steel section shapes that can be used and their prices will be shown in tables. Finally, the steel section with the lowest price per unit length will be the most economical section to be used in Gaza, Palestine.

4.1 THEORETICAL INVESTIGATION OF SIMPLE HOWE ROOF TRUSS

4.1.1 Analysis and Design of Howe Roof Truss

This is the truss used for the study, the height of truss is 9 ft and spacing between joints is 9 ft (12@9 = 108) as shown in Figure (2).

The load is factored loads equal to 12 kip.

https://dx.doi.org/10.22161/ijaers.5.9.12 *ISSN: 2349-6495(P) | 2456-1908(O)*

Truss analyzed by SAP2000

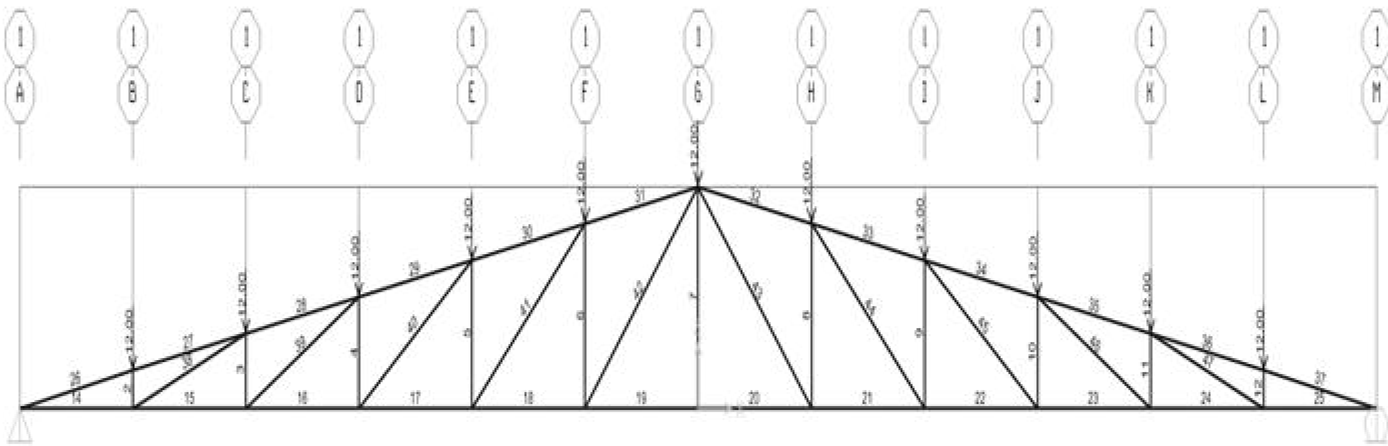

Fig.2: Howe roof truss used in this study.

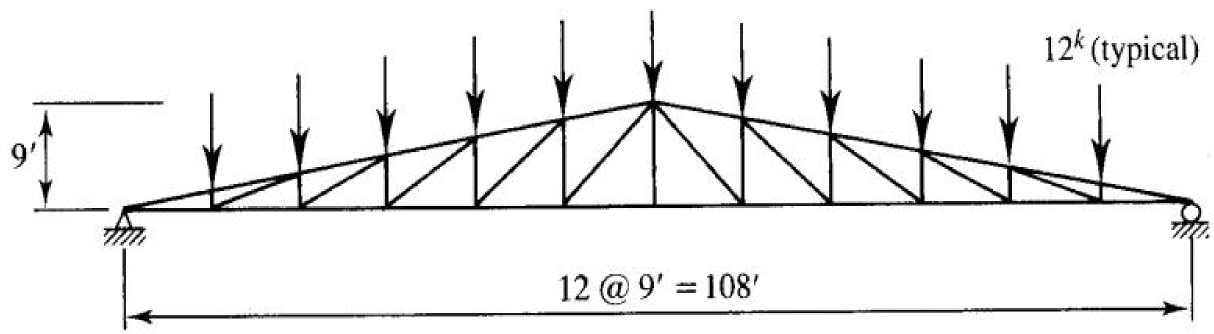

Fig.3: Howe roof truss analysis using SAP2000 software.

Table.2: Internal force and classification of members.

Member No.	Load(Kips)	Tension/Compression
2, 12	12	C
3,11	18	C
4,10	24	C
5,9	30	C
6,8	36	C
7	0	-
14,25	396	T
15,24	360	T
16,23	324	T
17,22	288	T
18,21	252	T
19,20	216	T
26,37	401.46	C
27,36	401.46	C
28,35	365	C
29,34	328.5	C

30,33	292	C
31,32	255.5	C
38,47	38	T
39,46	40.3	T
40,45	43.3	T
41,44	46.86	T
42,43	50.1	T

Design of Member with "A36 Steel, Fy = 36 ksi, Fu = 58 ksi"

Design of Tension Member

The maximum value for tension member is 396 Kips

$$\emptyset_c P_n \geq P_U \;\rightarrow\; 0.9F_y A_g \geq P_U \;\rightarrow A_g = \frac{P_u}{0.9F_y} \quad \text{required}$$

To avoid fracture

$$0.75F_U A_e \geq P_U \;\rightarrow A_e \geq \frac{P_u}{0.75F_y}$$

$$\text{Required } A_g = \frac{P_u}{0.9F_y} = \frac{396 \text{ Kips}}{0.9 * 36 \text{ Ksi}} = 12.23 \text{ in}^2$$

$$A_e = \frac{P_u}{0.75F_u} = \frac{396 \text{ Kips}}{0.75 * 58 \text{ Ksi}} = 9.11 \text{ in}^2$$

$\therefore$ Area Required $= 12.23 \text{ in}^2$

From steel manual, the section W14 $*$ 43 with $A_g = 12.6 \text{ in}^2$ and $A_e = 9.45 \text{ in}^2$ can be aduqate for load.

All sections that are summarized in table below can be adequate, but we need the cheapest section.

Table.3: Sections that can be used along with their area and cost.

Section Name	A_g and A_e (in^2)	Shape	Cost ($/ft)
W14*43	$A_g = 12.6\ in^2$ and $A_e = 9.45\ in^2$	I shape	41.37
L8*8*1 7/8	$A_g = 13.1\ in^2$ and $A_e = 9.83\ in^2$	L shape	40.25
WT12*42	$A_g = 12.4\ in^2$ and $A_e = 9.3\ in^2$	T shape	38.42
HSS 8*8*1/2	$\boldsymbol{A_g = 13.5\ in^2}$ **and** $\boldsymbol{A_e = 10.1\ in^2}$	**Square shape**	**36.95**
HSS 14 *0.312	$A_g = 12.5\ in^2$ and $A_e = 9.38\ in^2$	Pipe	38.43
S15*42.9	$A_g = 12.6\ in^2$ and $A_e = 9.45\ in^2$	I shape	39.15
HP10*42	$A_g = 12.4\ in^2$ and $A_e = 9.3\ in^2$	I shape	44.38
MC18*42.7	$A_g = 12.6\ in^2$ and $A_e = 9.45\ in^2$	[shape	42.78
C15*50	$A_g = 14.7\ in^2$ and $A_e = 11.02\ in^2$	[shape	39.64
ST10*43	$A_g = 12.7\ in^2$ and $A_e = 9.5\ in^2$	T shape	43.34

Design of Compression Member

The maximum value for compression member is 401.46 Kips with length of member is 9.12 ft

$$\text{Assume } F_{cr} = \frac{2}{3}F_y = \frac{2}{3} * 36 = 24 \text{ ksi}$$

$$\text{Required } A_g = \frac{P_u}{0.85F_{cr}} = \frac{396 \text{ Kips}}{0.85 * 24 \text{ Ksi}} = 19.68 \text{ in}^2$$

Try W12 $*$ 72 with ($\mathbf{A_g = 21.1in^2}$, $\mathbf{r_{min} = 3.04\ in}$)

$A_g = 21.1\text{in}^2 > A = 19.68\text{in}^2 \rightarrow$ ok

$$\frac{KL}{r_{min}} = \frac{1 * 9.12(12)}{3.04} = 36 < 200 \rightarrow ok$$

$$\lambda_c = \frac{kl}{r\pi}\sqrt{\frac{F_y}{E}} = \frac{36}{\pi}\sqrt{\frac{36}{29000}} = 0.4 < 1.5$$

Use AISC Equation [E2 − 2]

$$F_{cr} = \left(0.658^{\lambda^2}\right)F_y = \left(0.658^{0.4^2}\right)36 = 33.67 \text{ Ksi}$$

https://dx.doi.org/10.22161/ijaers.5.9.12 **ISSN: 2349-6495(P) | 2456-1908(O)**

$$\emptyset_c P_n = \emptyset_c * A_g * F_{cr} = 0.85 * 21.1 * 33.67$$
$$= 603.87 \text{ Kips } > 401.67\ Kips \ \rightarrow ok$$

Check W12 ∗ 65 $(\mathbf{A_g = 19.1in^2}, \mathbf{r_{min} = 3.04\ in})$ **"The next lightest"**

$$\frac{KL}{r_{min}} = \frac{1 * 9.12(12)}{3.02} = 36.23 < 200 \ \rightarrow ok$$

$$\lambda_c = \frac{kl}{r\pi}\sqrt{\frac{F_y}{E}} = \frac{36.23}{\pi}\sqrt{\frac{36}{29000}} = 0.406 < 1.5$$

Use AISC Equation [E2 − 2]

$$F_{cr} = \left(0.658^{\lambda^2}\right)F_y = \left(0.658^{0.406^2}\right)36 = 33.66 \text{ Ksi}$$

$$\emptyset_c P_n = \emptyset_c * A_g * F_{cr} = 0.85 * 19.1 * 33.66$$
$$= 546.47 \text{ Kips } > 401.67\ Kips \ \rightarrow ok$$

Check W12 ∗ 53 $(\mathbf{A_g = 15.6in^2}, \mathbf{r_{min} = 2.48\ in})$ **"The next lightest"**

$$\frac{KL}{r_{min}} = \frac{1 * 9.12(12)}{2.48} = 44.13 < 200 \ \rightarrow ok$$

$$\lambda_c = \frac{kl}{r\pi}\sqrt{\frac{F_y}{E}} = \frac{44.13}{\pi}\sqrt{\frac{36}{29000}} = 0.495 < 1.5$$

Use AISC Equation [E2 − 2]

$$F_{cr} = \left(0.658^{\lambda^2}\right)F_y = \left(0.658^{0.495^2}\right)36 = 32.50 \text{ Ksi}$$

$$\emptyset_c P_n = \emptyset_c * A_g * F_{cr} = 0.85 * 15.6 * 32.50$$
$$= 430.95 \text{ Kips } > 401.67\ Kips \ \rightarrow ok$$

This shaped is not listed in the column load tables; the width-thickness ratio must be checked:

$$\frac{b_f}{2t_f} = 8.69 < 0.56\sqrt{\frac{E}{F_y}} = 0.56\sqrt{\frac{29000}{36}} = 15.89 \quad (ok)$$

$$\frac{h}{t_w} = 28.1 < 1.49\sqrt{\frac{E}{F_y}} = 1.49\sqrt{\frac{29000}{36}} = 42 \quad (ok)$$

All sections that are summarized in table below can be adequate, but we need the cheapest section.

Table.4: Sections that can be used along with their shape and cost.

Section Name	$\emptyset_c P_n\,(Kips)$	Shape	Cost ($/ft)
W12*53	430	I shape	45.12
S20*75	421.311	I shape	52.15
HP12*53	439.12	I shape	44.39
C15*50	439.57	[shape	39.13
L8*8*1	415	L shape	40.7
WT9*53	434.5	i shape	43.67
HSS 8*8*5/8	**467**	**Square**	**37.55**
HSS10.000	402.37	Pipe shape	38.23

V. RESULTS AND DISCUSSION

Conclusion

The result of this research demonstrated that using square shaped steel section (**HSS 8*8*5/8** for maximum internal force of compression member and **HSS 8*8*1/2** for maximum internal force of tension member) is the most economical among other sections according to availability, material cost and transport in Gaza Strip, Palestine.

REFERENCES

[1] American Institute of Steel Construction (ASIC), (2010a). Specifications for Structural Steel Buildings, Chicago, IL.

[2] American Institute of Steel Construction (AISC), (2010b) Steel Construction Manual, Chicago, IL.

[3] Carter, C. J., & Schlafly, T. D. (2008, March). $ave More Money. Modern Steel Construction.

[4] Chen, W., & Lui, E. M. (Eds.). (2005). Handbook of Structural Engineering. New York: CRC Press.

[5] Chen, W., & Lui, E. M. (Eds.). (2006). Principles of Structural Design. New York: CRC Press.

[6] Sanchita.S.Nawale, Sangram Chalukya, and Dr.S.V.Admane "Comparative Analysis and Bending Behavior of Cold form Steel with Hot Rolled Steel Section." American Journal of Engineering Research (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-03, Issue-05, pp-255-261(2013)

[7] Thornton, W., & Lini, P. (2011, July). The Whitmore Section. Modern Steel Construction.