INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume3, Issue4)
Available online at www.ijariit.com

Design of Industrial Steel Building by Limit State Method

Dinesh Kumar Gupta
Al-Falah University Dhauj Faridabad Haryana
structuralaid_2001@yahoo.com

Mirza Aamir Baig
Al-Falah University Dhauj Faridabad Haryana
aamirmirzagarri@gmail.com

***Abstract**: In this project work it is proposed to carry out the design of an industrial steel storage shed by limit state method based on IS 800-2007 (LSM) and comparing the results with the same obtained by working stress method based on IS 800-1984, for a structure with the same dimensions & loading. An industrial shed* of *steel truss of 48m x 16.0m having a bay spacing of 4.0m with a column height of 11m. is considered in the Industrial area of East Delhi. The fink type roof trusses have the span of 16 meters. The structure is modeled in STAAD Pro, analysis and design software. A full 3D model is generated. This project is all about analysis of loads & forces acting on the members of the above structure & their design. Loads acting on the structure are gravity loads (dead & live), Crane Loads, wind loads, and seismic loads calculated using Indian Standard code IS 875-1987 (part I), IS 875-1987 (part II), IS 875-1987 (part III) and the section properties of the specimens are obtained using steel table. In this structure snow loads are not considered as Delhi does not encounter snowfall at all. The main aim of the project is to provide which method is economical and provide more load carrying capacity and high flexural strength.*

***Keywords**: Limit State Method, Working Stress Method, Flexural Strength, Fink Type Roof Trusses, Staad Pro.*

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Any building used by the industry to accommodate the production activity, stock raw materials, stock finished product before supply is known as an industrial building. Roof truss and the portal frame are used to cover and shelter the area of an industrial building. As per the requirement of an industrial building, the suitable kind of roof truss and the portal frame is utilized. A roof truss is designed for dead load, live load, wind load and their combinations as per Indian Standards. An economy of an industrial building depends on the configuration of the structure, type of roof truss and portal frame utilized, forces acting on building and selection of steel sections needed as per force employed.

A Structural steel is a material used for steel construction, which is formed with a specific shape following certain standards of chemical composition and strength. They can also be defined as hot rolled products, with a cross section of special forms like angles, channels and beams/joists. There has been an increasing demand for structural steel for construction purposes in India. Steel has always been more preferred to concrete because steel offers better tension and compression thus resulting in lighter construction. Usually, structural steel uses three-dimensional trusses hence making it larger than its concrete counterpart. As far as the elasticity concerned the Steel follows hooks law very accurately.

1.2 COMPONENT OF AN INDUSTRIAL BUILDING

The elements of industrial buildings are listed below.

1) Purlins
2) Sag rods
3) Principal Rafters
4) Roof Truss
5) Gantry Girders
6) Bracket
7) Column and Column base
8) Girt Rods
9) Bracings

The elements are briefly explained as below.

1.21 Purlins

Beams provided over trusses to support roof coverings are known as Purlins. Purlins spans between top chords of two adjacent roof trusses. When purlin supports the sheeting and rests on rafter then the purlins are placed over panel point of trusses. Purlins can be designed as simple, continuous, or cantilever beams. Purlins are often designed for normal component of forces.

1.22 Sag Rod

These are round sections rods and are fastened to the web or purlin. The roof covering in industrial buildings are not rigid and do not provide proper support. Therefore, sag rods provided between adjacent purlins to extend lateral support for purlins in their weaker direction. A sag rod is designed as a tension member to resist the tangential component of the resultant of the roof load and purlin dead load. The tangential component of the roof load is considered to be acting on the top flange of purlins, here as the normal component and purlin dead load is assumed to act at its centroid. Therefore the sag rod should be placed at a point where the resultant of these forces act

1.23 Principal Rafter

The top chord member of a roof truss is called as a principal rafter. They mainly carry compression but they may be subjected to bending if purlins are not provided at panel points.

1.24 Roof Trusses

Roof trusses are elements of the structure. The members are subjected to direct stresses. Truss members are subjected to direct tension and direct compression. Different members of the truss are shown as in the following figure.

1.25 Gantry Girder

Gantry girders are designed as laterally unsupported beams. Overhead traveling cranes are used in industrial buildings to lift and transport heavy jobs, machines, and so on, from one place to another. They may be manually operated or electrically operated overhead travelling crane. A crane consists of a bridge made up of two truss girders which move in the longitudinal direction. To facilitate movement, wheels are attached to the ends of crane girders. These wheels move over rails placed centrally over the girders which are called gantry girders.

1.26 Brackets

Brackets types of connections are made whenever two members to be secured together do not intersect

1.27 Column and Column Base

A column is a structural member which is straight to two equal and opposite compressive forces applied at the ends. Stability plays an important role in the design of compression member because in columns buckling is involved. The problem of determining the column load distribution in an industrial building column is statically indeterminate. To simplify the analysis the column is isolated from the space frame and is analysed as a column subjected to axial load

An industrial building column is subjected to following loads in addition to its self-weight.

1) Dead load from truss
2) Live load on roof truss
3) Crane load
4) Load due to the wind

Steel columns are normally supported by concrete blocks. However, when the load supported by these columns are large and the bearing pressure of concrete from below is insufficient to resist the loads, they may fail. Therefore it is a normal practice to distribute column loads to steel base plate which are placed over these concrete blocks.

CHAPTER 2
OBJECTIVES OF THE PROJECT

The main aim of the study to provide the analysis of practical industrial building by limit state method and also which method is a most economical method and, high bending strength, more load carrying capacity and high flexural strength by analysis of both working stresses and limit state method.

The object of limit state design can be paraphrased as the achievement of an acceptable probability that a part or whole structure will not become unfit for its intended use during its life time owing to collapse, excessive deflection etc. under the action of all loads & load effects. For achieving the design objectives, the design shall be based on characteristic values for material strength and applied loads, which take into account the probability of variations in the material strengths and in the loads to be supported. The characteristic values shall be based on statistical data, if available. Whereas such data is not available, these shall be based on experience. The design values are derived from characteristic values through the use of partial safety factors, both for material strength and for loads. In the absence of special consideration, these factors shall have the values given in this section according to the material, the type of load and the limit state being considered.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

The design Method used is as following:

(i) Working Stress Method (WSM)
(ii) Limit State Design (LSD)

3.11 Working Stress Method (WSM)

This is old systematic analytical design method (IS 800:1984). In this method, stress strain relation is considered linear till the yield stress. To take care of uncertainties in the design, permissible stress is kept as a fraction of yield stress, the ratio of yield stress to working stress itself known as a factor of safety. The members are sized so as to keep the stresses within the permissible value. The allowable stress method of design, the critical combination of loads is found out the members are designed on the basis of working stresses. These stresses should never increase the permissible stresses is considered. The method considers material behaviour is elastic. Thus the permissible stresses may be elaborated in terms of a factor of safety, which takes care of overload or other unknown factors.
Thus, Permissible stress = Yield stress/factor of safety
And, Working stress ≤ Permissible stress

3.12 Limit State Method (LSM)

In the Limit State Design method (IS800:2007), the structure shall be designed to withstand safely all loads likely to act on it throughout its life. It shall also satisfy the serviceability requirements, such as limitations of deflection and vibration and shall not collapse under accidental loads such as from explosions or impact or due to consequences of human error to an extent not originally expected to occur.

The acceptable limit for the safety and serviceability requirements before failure occurs is called a *limit state*. The objective of design is to achieve a structure that will not become unfit for use with acceptable target reliability. In other words, the probability of a limit state being reached during its lifetime should be very low. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states. Steel structures are to be designed and constructed to satisfy the design requirements for stability, strength, serviceability, brittle fracture, fatigue, fire, and durability. The reliability of a design is assured by satisfying the requirements.
Design action ≤ Design strength

3.121 *General Principles of Limit State Design*

The structure should be designed considering the Limit States at which they would become unfit for their intended purpose. For verifying the adequacy of the structure, appropriate partial safety factors, based on semi-probabilistic methods described below shall be used. Two partial safety factors, one applied to forces due to loading and another to the material strength shall be employed.

Partial safety factors to forces allows for;
(a) The possible deviation of the actual behaviour of the structure from that of the analysis and design model,
(b) The deviation of loads from their specified values and
(c) The reduced probability that the various loads acting together will simultaneously reach the characteristic value.

Partial safety factors to the material strength allows for;
(a) The possible deviation of the material in the structure from that assumed in design
(b) The possible reduction in the strength of the material from its characteristic value and
(c) Manufacturing tolerances.
(d) Mode of failure (ductile/brittle).

The aim of the design is to decide shape, size and connection details of the members so that the structure being designed will perform satisfactorily during its intended life. With an appropriate degree of safety, the structure should

- Sustain all loads expected on it.
- Sustain deformations during and after construction.
- Should have adequate durability.
- Should have adequate resistance to misuse and fire.
- The structure should be stable and have alternate load paths to prevent overall collapse under accidental loading.

3.2 LOADS ON THE STEEL INDUSTRIAL SHED

The shed structures are subjected to a dead load, live load, crane load, wind load and seismic load etc.

3.21 Dead Load (DL)

The dead loads of the truss include a dead load of roofing materials, purlins, trusses and bracing system.

3.22 Live Load (LL)

The Live load on sloping roofs with inclination up to 10 degrees is taken as 0.75KN/m2 of the plan area. For roofs with slopes more than 10degree, The Live load is taken 0.75kN/m2 – (0.02 KN/m2 for every degree increase in slope over 10 degrees), subject to a minimum of 0.4 KN/m2.

3.23 Wind Load (WL)

Wind load on the roof trusses, unless the roof slope is too high, would be usually uplift force perpendicular to the roof, due to suction effect of the wind blowing over the roof. Hence the wind load on roof truss usually acts opposite to the gravity load, and its magnitude can be larger than gravity loads, causing a reversal of forces in truss members. The horizontal and vertical bracings employed in single and multi-storey buildings are used primarily to resist the wind and other lateral loads. These bracings minimize the differential deflection between the different frames due to crane surge in industrial buildings. They also provide lateral support to columns in small and tall buildings, thus increasing the buckling strength. Wind load is the most critical load on an industrial building.

Wind force (F) = (Cpe – Cpi) A Pd

3.24Load Combinations

From IS 800-2007, we find load factor is 1.5 for case (i) whereas for load case (ii) it is 0.9 for DL and LL and 1.5 for WL. Hence the factored force in the member is to be found for

i) 1.5 (DL + LL)
ii) 0.9 (DL + LL) + 1.5 WL at 0°
iii) 0.9 (DL + LL) + 1.5 WL at 90°

From IS 800-1984, Load combinations for design purposes shall be the one that produces maximum forces and effects from the following combinations of loads.
i) DL + LL
ii) DL + LL + WL /EL
iii) DL + WL/EL
iv) DL + LL + CL
v) DL + LL + CL + WL /EL
vi) 0.75* (DL + LL + WL /EL)
vi) 0.75* (DL + LL +CL + WL /EL)

3.3 DESIGN ACTIONS –

The design Action, Q_d, is expressed as

$$Q_d = \sum_k \gamma_{fk} \; Q_{ck}$$

Where

γ_{fk} = partial safety factor for loads, given in Table to account for

3.31 Partial Safety Factors for Loads, γ_F, For Limit States

Table 1

3.4

Combination	**Limit State of Strength**					**Limit state of Serviceability**			
	DL	**LL**		**WL/ EL**	**AL**	**DL**	**LL**		**WL/ EL**
		Leading	Accompanying (CL, SL etc.)				Leading	Accompanying (CL etc.)	
DL+LL+CL	1.5	1.5	1.05	—	—	1.0	1.0	1.0	—
DL+LL+CL+ WL/EL	1.2 1.2	1.2 1.2	1.05 0.53	0.6 1.2	—	1.0	0.8	0.8	0.8
DL+WL/EL	1.5 (0.9)*	—	—	1.5	—	1.0	—	—	1.0
DL+ER	1.2 (0.9)	1.2	—	—	—	—	—	—	—
DL+LL+AL	1.0	0.35	0.35	—	1.0	—	—	—	—

* This value is to be considered when stability against overturning or stress reversal is critical
Abbreviations: DL= Dead Load,LL= Imposed Load (Live Loads),WL= Wind Load, SL= Snow Load,
CL= Crane Load (Vertical/horizontal), AL=Accidental Load, ER= Erection Load, EL= Earthquake Load.

DESIGN STRENGTH

The Design Strength, S_d, is obtained as given below from ultimate strength, S_u and partial safety factors for materials, γ_m.

$$S_d = S_u / \gamma_m$$

Where partial safety factor for materials, γ_m, account for

3.41 Partial Safety Factor for Materials, γ_M

Table 2

Sl. No	***Definition***	***Partial Safety Factor***	
1	Resistance, governed by yielding γ_{m0}	1.10	
2	Resistance of member to buckling γ_{m0}	1.10	
3	Resistance, governed by ultimate stress γ_{m1}	1.25	
4	Resistance of connection γ_{m1}	Shop Fabrications	Field Fabrications

	(i) Bolts-Friction Type, γ_{mf} (ii) Bolts-Bearing Type, γ_{mb} (iii) Rivets (iv) Welds	1.25 1.25 1.25 1.25	1.25 1.25 1.25 1.50

3.5 RESEARCH ELABORATION

Design data of Industrial shed

The building is located in industrial area of Parparganj Delhi

Span of the roof truss	=	16	m.
Spacing of the truss (span of purlin)	=	4	m.
Height of column	=	11	m.
Length of building	=	48	m.
Rise of the truss	=	4	m.
Slope of the roof (Θ)	=	26.56	degree
Length along the slopping roof	=	8.94	m.
Let us place the purlin at panel points.			
Length of each panel (c/c spacing of purlin)	=	2.235	m.

3.51 Dead Load: (Ref. IS: 875 PART 1) 1987

Weight of roof covering (AC sheeting)	=	171	N/sq.m.
Self-Weight of purlin	=	202	N/m.
Weight of wind bracing	=	12	N/sq.m.
Self-Weight of trusses (span / 3 +5)10	=	103.33	N/sq.m.
say		110	N/sq.m.
Total dead load on purlin	=	183	N/sq.m.
Load at each intermediate purlin due to dead load	=	409	N/m.
Load at each end purlin due to dead load	=	205	N/m.
Load at each intermediate panel due to dead load (Wd)	=	3427	N.
Load at each end panel due to dead load	=	2118	N.

3.52 Live Load: (Ref. IS: 875 PART 2) 1987

Live load = 750 – 20 x (26.56˚ – 10˚)	=	418.8	N/sq.m.
Load at each intermediate purlin due to live load	=	936.02	N/m.
Load at each end purlin due to live load	=	468.01	N/m.
Load at each intermediate panel due to live load	=	3744.07	N.
Load at each end panel due to living load	=	1872.04	N.

3.53 Wind Loads: (Ref. IS: 875 PART 3) 1987

Let us assume the life of the industrial building to be 50 years and the land to be plain and surrounded by small buildings.

Risk coefficient (k1) taken from IS 875- 1975 (life of building 50 years)	=	1	
Terrains category (k2) taken from IS 875- 1975 (Terrine category "3" class "B")	=	0.89	
Topography factor (k3) taken from IS 875- 1975 (plain ground of Delhi)	=	1	
Basic wind speed (Vb) Delhi	=	47	m/sec
Design wind speed (Vz) = k1 x k2 x k3 x Vb	=	41.83	m/sec
Design wind pressure P_d = (0.6 x Vz ^{2})	=	1049.85	N/sq.m.
	=	1.05	KN/sq.m.

An internal pressure coefficient depends upon the degree of permeability of cladding to the flow of air. The internal air pressure may be positive or negative depending on the direction of flow of air in relation to the opening in the building. Building with small opening 0-5% the internal pressure coefficient + 0.2 or -0.2, Building with medium opening 5 – 20 % an internal pressure coefficient + 0.5 or -0.5 , Building with large opening above 20 % an internal pressure coefficient + 0.7 or -0.7 .

An external pressure coefficient depends upon the height and width ratio wind ward and lee ward given in condition IS 875 -1975. Part III

h/w = 0.6875

Building Height Ratio = ½ < h/w <3/2

For wind blowing normal to ridge

Cp_e (windward side) = -0.37

Cp_e (leeward side) = -0.50

For normal permeability of wind in building

Cp_i = 0.2

OR -0.2

For wind blowing parallel to ridge

Cp_e (for 1/4 length of building both windward & leeward side) = -0.8

Cp_e (for middle half building both windward & leeward side) = -0.731

Therefore maximum applied wind load on each intermediate panal point

$(Cp_e – Cp_i)$ x A x P_d

(windward side) = -5.63 KN.

(leeward side) = -9.39 KN.

maximum applied wind load on each end panal point

(windward side) = -2.82 KN.

(leeward side) = -4.69 KN.

Therefore maximum applied wind load on each intermediate purlin

(windward side) = -1.41 KN/m.

(leeward side) = -2.35 KN/m.

maximum permissible wind load on each end purlin

(windward side) = -0.70 KN/m.

(leeward side) = -1.17 KN/m.

3.531 ***For wind blowing normal to ridge***

maximum applied wind load on each intermediate purlin

(windward side) = -1.34 KN/m.

(leeward side) = -1.64 KN/m.

maximum permissible wind load on each end purlin

(windward side) = -0.67 KN/m.

(leeward side) = -0.82 KN/m.

3.532 ***For wind blowing parallel to ridge***

maximum applied wind load on each intermediate purlin

(windward side) = -2.35 KN/m.

(leeward side) = -2.35 KN/m.

maximum permissible wind load on each end purlin

(windward side) = -1.17 KN/m.

(leeward side) = -1.17 KN/m.

3.533 ***External Pressure Coefficients For Walls***

L/W = 3

3/2 < L/w < 4

For wind blowing normal to ridge

Cp_e (windward side) = 0.7

Cp_e (leeward side) = -0.30

Cp_e (both width sides) = -0.70

For wind blowing parallel to ridge

Cp_e (for length of building both side) = -0.5

Cp_e (for width windward side) = 0.7

Cp_e (for width leeward side) = -0.1

Local Cp_e for corner of walls = -1.1

For normal permeability of the wind in building

Cp_i = 0.2

OR -0.2

Therefore Max Local Cpnet at the wall edge = -1.3

3.5331 *For wind blowing normal to ridge*

Therefore maximum applied wind load on each intermediate column in length

(windward side) = 3.78 KN/m.

(leeward side) = -2.10 KN/m.

Load on one before corner column = -5.46 KN/m.

Load on corner column = -2.73 KN/m.

maximum applied wind load on each intermediate column in both width

(middle column) = -5.20 KN/m.

(corner column) = -2.60 KN/m.

3.5332 *For Wind Blowing Parallel To Ridge*

Load for length of building both side = -2.94 KN/m.

Load on one before corner column = -3.05 KN/m.

(corner column) = -1.53 KN/m.

for width windward side = 5.67 KN/m.

(corner column) = 2.83 KN/m.

for width leeward side = -1.57 KN/m.

(corner column) = -0.79 KN/m.

3.54 Crane Load

Weight of crane girder /truss = 180 kN

Crane capacity = 200 kN

Weight of crabe and motor = 50 kN

Span of crane girder truss = 15 m.

Minimum hook approach = 1.2 m.

C/C Spacing of the Gantry columns = 4 m.

maximum reaction at nearest gantry girder = (180x7.5 + 250x13.8)/15

R_A = 320 kN

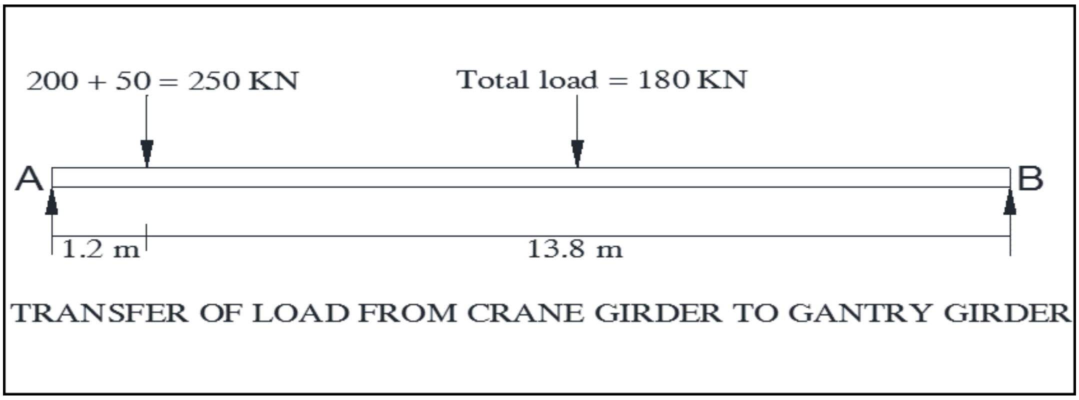

Figure No.1

maximum vertical static wheel load = 160 KN

Taking the impact factor for an electrically operated traveling crane as per IS 875 as 25%

Wheel load with impact factor = 200 KN

3.541 *Maximum shear force at gantry support*

For maximum shear force, the wheel load shall be placed as shown in figure

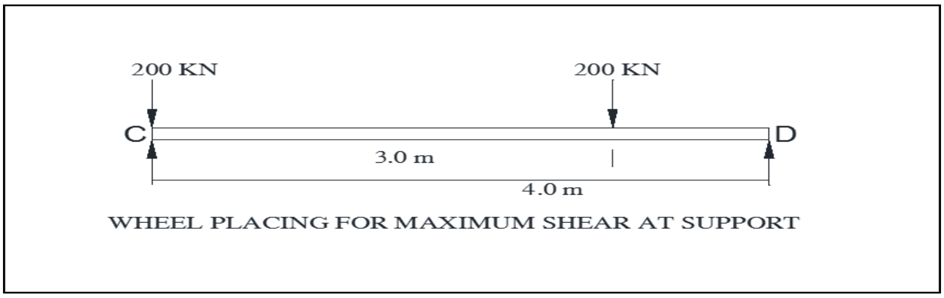

Figure No.2 Maximum shear force at gantry support

maximum shear force R_C	=	250	kN
Self-weight of gantry girder (Approx.)	=	10	kN
Therefore maximum shear force at gantry support	=	255	kN
Therefore minimum shear force at gantry support	=	155	kN

3.542 ***Lateral forces***

lateral force transverse to the rails	=	25	kN
lateral force on each wheel	=	12.5	kN
maximum horizontal reaction	=	15.9	kN

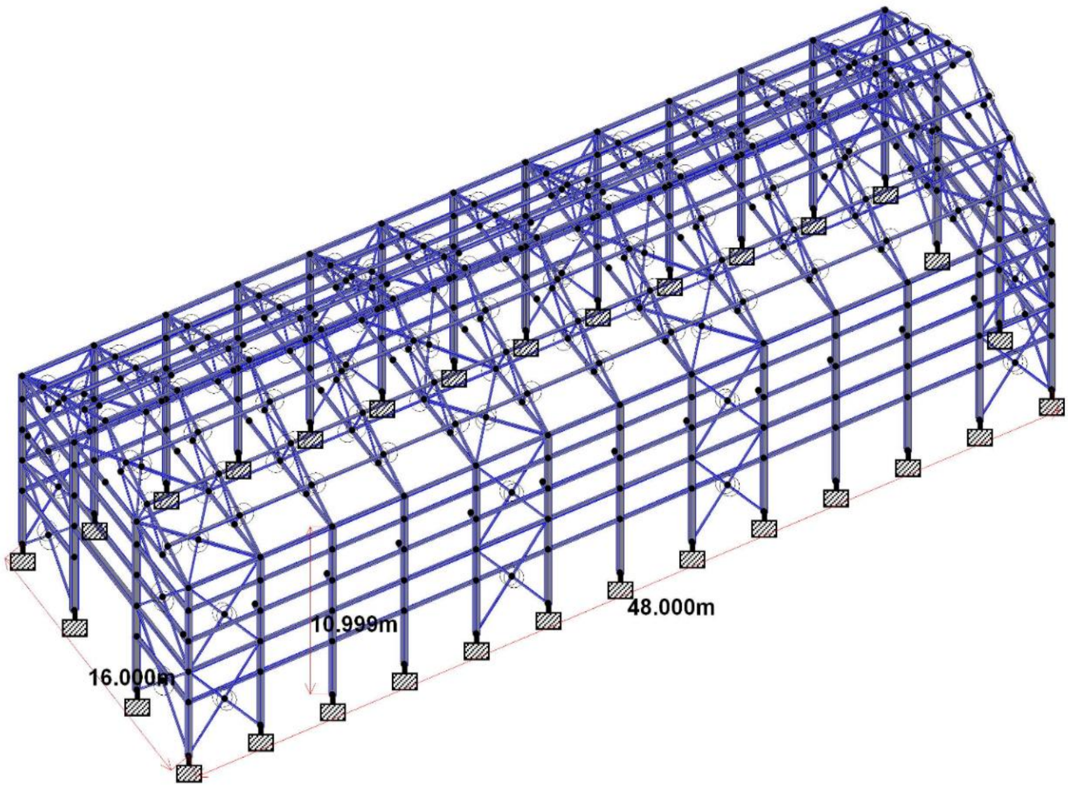

Figure No.3 STAAD Pro. MODEL

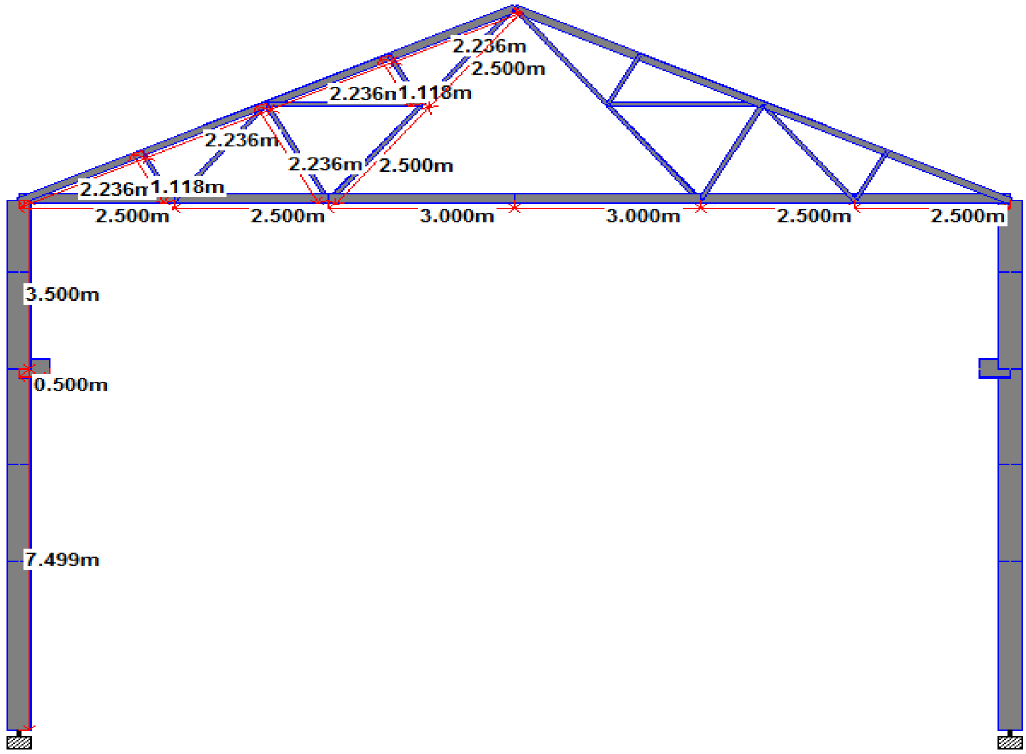

Figure No.4 Internal main frame with crane brackets

CHAPTER 4
RESULT ANALYSIS

4.1 COMPARATIVE TABLE OF DIFFERENT PARAMETER

Table 3

S. No.		LSM			WSM		
1	**Shear Force**	Max Fx	Max Fy	Max Fz	Max Fx	Max Fy	Max Fz
		374.30	268.51	14.29	399.50	255.61	18.28
2	**Bending Moment**	Max Mx	Max My	Max Mz	Max Mx	Max My	Max Mz
		0.14	15.65	228.66	0.10	20.23	187.50
3	**Reaction**	X	Y	Z	X	Y	Z
		56.67	442.81	57.59	67.22	490.16	40.45

4.2 ESTIMATE OF MATERIAL:

4.21 Steel quantity required by LSM

Profile	Length(Meter)	Weight(Kg)
ST ISWB400	354.98	23636.111
ST ISWB175	624.00	13735.415
LD ISA200X100X10	208.00	9515.400
LD ISA150X75X10	232.55	7869.714
LD ISA90X65X6	96.00	1355.117
LD ISA75X50X5	376.28	3548.901
ST ISMB225	192.00	5970.938
ST ISWB200H	104.00	5409.440
LD ISA90X60X6	336.54	4566.013
ST ISMC150	160.14	2671.942
	TOTAL =	**78278.992**

4.22 Steel quantity required by WSM

Profile	Length(Meter)	Weight(Kg)
ST ISHB450	298.98	25996.933
ST ISWB175	624.00	13735.415
LD ISA200X100X12	208.00	11340.271
LD ISA150X75X10	232.55	7869.714
LD ISA90X65X6	96.00	1355.117
LD ISA75X50X6	376.28	4220.952
ST ISMB250	192.00	7159.110
ST ISWB400	56.00	3728.549
ST ISWB200H	104.00	5409.440
LD ISA100X75X6	336.54	5325.257
ST ISMC150H	160.14	2835.019
	TOTAL =	**88975.778**

4.3 COMPARISON OF WEIGHT BY WORKING STRESS METHOD AND LIMIT STATE METHOD OF DESIGN

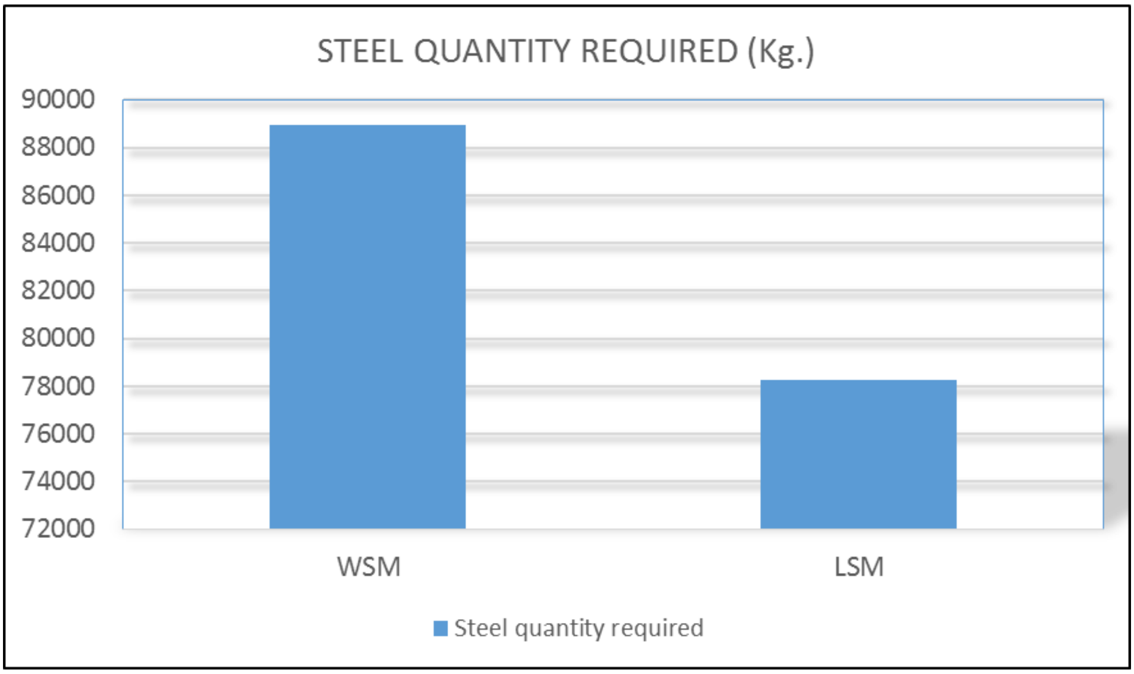

Figure No.5 Comparison Required Steel Quantity

4.4 CONCLUSION

From the above results, we can observe that the sections designed using Limit State Method are more economical than the sections that are designed by Working Stress Method. In this study, the total roofing load configuration is same in both the working stress and limit state method. But the area of the section is approximately 12% less needed for limit state method in comparison to the working stress method. In IS 800 (1984) the local buckling is avoided by specifying b/t limits. Hence we don't consider local buckling. However, In IS 800 (2007), the local buckling is the first aspect as far as the beam design is concerned (by using section classification). The section designed as per LSD is having more reserve capacity for BM and SF as compared to WSM.

In this study with the help of the results obtained, we can conclude that limit state method is more reliable and economical than the working stress method for designing structure. The results of the limit state method of bending moment and load carrying capacity are higher than working stress method. The limit states provide a checklist of the basic structural requirements for which design calculations may be required. Limit states to design, provide consistent safety and serviceability.

ACKNOWLEDGMENT

I express my deep gratitude to **Mr. Mirza Aamir Baig,** Assistant Professor, and Department of Civil Engineering, Al-Falah University guide for the initiative, motivation, and guidance provided during the course of this work.

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