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Optimization of Pre Engineered Buildings

B K Raghu Prasad[1], Sunil kumar[2], Amaranth K[3]
[1] Professor (Retired), Civil Engineering Dept., IISC, Bangalore, Karnataka, India
[2] Student (M Tech), Structural Engineering, TOCE, Bangalore, Karnataka, India
[3] Professor and HOD, Civil Engineering Dept., TOCE, Bangalore, Karnataka, India

ABSTRACT

Pre-engineered buildings have become quite popular in the last few years. The main advantages are speed of construction and good control over quality. However there is not much information on its economy. There are several parameters like the inclination of the gable, spans, bay spacing, which control the cost of the structure. In the present paper the above parameters are varied systematically and in each case the gable frame designed for the common loads DL, LL, EQ, and WL. The quantity in each case is obtained and finally the structure which regulates the lowest quantity of steel is recommended.

Keywords:pre-engineered building, staad pro, working stress method, bay spacing, angle of inclination, span and tapered sections.

I. INTRODUCTION

Pre-engineered buildings (PEB) are steel buildings wherein the framing members and other components are fully fabricated in the factory after designing and brought to the site for assembly, mainly by nut-bolts, thereby resulting into a steel structure of high quality and precision. In conventional steel building, we have site welding involved, which is not the case in using nut-bolt mechanism. These structures use hot rolled tapered sections for primary framing and cold rolled sections (generally “Z” and “C” sections) for secondary framing as per the internal stress requirements, thus reducing wastage of steel and the self-weight of the structure and hence lighter foundations. International codes are referred in their design as per the MBMA (Metal Building Manufacturers Association) standards which are more flexible allowing the use of built - up sections of minimum 3.5 mm thickness against 6 mm as minimum criteria in conventional steel sections .There is use of steel of high strength (345MPa) which prominently speaks about greater strength with judicious use of steel as a result of tapered profile. The tapered section concept was first adopted in U.S.A keeping in mind the bending moment diagram. At locations of high bending moment values, greater resistance is used while less moment encouraged the use of lesser depths. Further unlike the conventional steel sections, where Moment of inertia (I) remains constant, it is not so in case of PEB due to varying depths. As per the formula,” $I = \frac{bd^3}{12}$ “ d(depth) highly affects I value (to the exponential power of 3) and hence to decrease or increase the strength by mere change of depth is quite a logical approach in PEB industry and at the same time leading to economic structures.

II. LITARATURE REVIEW

Concept of Pre engineering buildings is recent in industrial buildings. This methodology is versatile not only due to its quality in pre designing and prefabrication, but also due to its light weight and economy. The concept includes the technique of providing the best possible section according to the optimum requirement. This concept has many advantages over the conventional steel building (CSB). Many papers on comparative study of PEB and CSB concepts have been presented in past, It is reported that PEB structures are more advantageous than CSB structures in terms of cost effectiveness, quality control speed in construction and simplicity in erection. India being one of the fast growing economies, infrastructure development is inevitable. Thus there is wide scope for pre-engineered buildings in India. Thus PEB is an upcoming field in construction industry in India. Some papers have shown in detail the study of PEB design using IS 800 over AISC. As compared to other countries Indian codes for building design are stringent but safer.

III. OBJECTIVE

An attempt is made to optimize the quantity of steel consumption in PEB structures. The various parameters varied are the roof angle (θ), bay spacing (B), and span (S). The structure is analyzed for the usual load combinations as specified in the IS code 875. The parameters which result in the minimum quantity of steel are noted and reported.

IV. SALIENT FEATURES AND IMPORTANT DIMENSIONS

The 7.0m height pre-engineered rigid frame of tapered sections with bolted connections shown in fig 1 is considered for analysis. Analysis is carried out by varying one parameter at a time while keeping other two parameters constants and results are obtained,

Structural Details

1. Height – 7m
2. Ridge angles – 2^{0}.86,6^{0}.5,10^{0}
3. Bay spacing - 5.5,6.5,7.5,8.5
4. span varying – 25,30,40m
5. Grade of steel – 340mpa
6. Type of Soil = soft soil
7. Basic wind speed = 55 m/sec
8. Earthquake zone = III

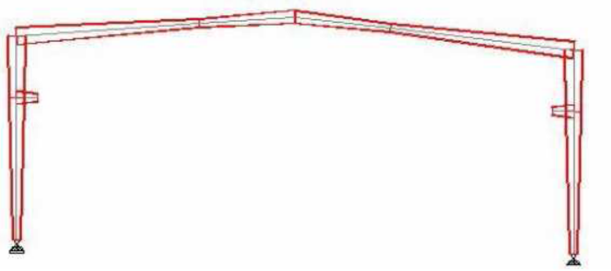

Fig1-: pre-engineered rigid frame.

b) Modeling

Analysis is performed using STAAD PRO V8i. The load combinations as per IS 875 consisting of dead, live, wind and earthquake loads are considered. Static methods are employed for wind and earthquake loads. The parameters as mentioned earlier the roof inclination (θ), bay spacing (B), span (S) are varied i.e at a time one is varied keeping the remaining, two constants. The combination of parameters which give the low quantity of steel are noted.

c) Material

The yield strength of material used for PEB structure is 340Mpa whose density is 7850kg/m^{3} and Young's modulus (E) is 2.0 x10^{11} N/m^{2}.

V. RESULTS AND DISCUSSION

Table 1				S = 25m
MAX VALUE OF BASE REACTION AT EXTREME COLUMN (kN)				
θ\B	5.5m	6.5m	7.5m	8.5m
2^{0}.86	145.065	170.507	189.51	220.082
6^{0}.5	146.193	172.273	196.89	221.763
10^{0}	148.268	175.148	198.644	223.691

In the table- 1, it may be noted that a maximum value of base reaction at an extreme column occurs for a roof angle of 10^{0} and a bay spacing of 8.5m. The base reaction does not seem to vary much with the roof angle, while it increases marginally with the bay spacing. The largest base reaction is 223.691kN when θ = 2^{0}.86 for a bay spacing 8.5m.

Table 2				S = 25m
MAXIMUM VALUE OF MOMENT AT BEAM COLUMN JUNCTION(kNm)				
θ\B	5.5m	6.5m	7.5m	8.5m
2^{0}.86	527.12	679.42	679.42	852.4
6^{0}.5	542.16	643.55	717.49	772.33
10^{0}	544.82	625.5	712.55	811.94

In table- 2 the maximum value moments are tabulated for various inclinations of roof angle (θ) and bay spacing (B). It can be similarly observed that the max moments at the beam column junction increases with the bay spacing. The largest moment is 811.94kNm when θ = 2^{0}.86 for a bay spacing 8.5m.

Table 3				S = 25m
MAXIMUM VALUE OF MOMENT AT RIDGE OF RAFTER(kNm)				
θ\B	5.5m	6.5m	7.5m	8.5m
$2^{0}.86$	37.74	52.16	36.98	35.645
$6^{0}.5$	32.51	29.42	62.52	76.3
10^{0}	46.88	64.74	78.03	82.05

In the table – 3 the maximum value of moments are tabulated for various inclinations of angle (θ) and bay spacing (B). It can be similarly observed that the maximum moment at ridge of rafter increases with definite pattern also such that as bay spacing increases the moment also increases and for $\theta = 10^{0}$ as ridge angle increases the moment increases for all bay spacing's. The largest moment is 82.05 when $\theta = 10^{0}$ and bay spacing is 8.5m.

Table 4				S = 25m
MAXIMUM VALUE OF HORIZONTALDISPLACEMENT AT BEAM COLUMN JUNCTION(mm)				
θ\B	5.5m	6.5m	7.5m	8.5m
$2^{0}.86$	19.19	16.227	17.466	16.415
$6^{0}.5$	14.545	8.731	11.063	12.443
10^{0}	14.105	8.026	9.595	10.568

In table - 4 maximum values of displacement at beam column junction are tabulated for various inclinations of angle (θ) and bay spacing (B).It can be similarly observed that as the roof angle increases the displacement decreases while it does not have a variation in a definite pattern as bay spacing increases. The largest displacement is 19.19mm when $\theta = 2^{0}.86$ for a bay spacing 5.5m.

Table 5				S = 25m
MAXIMUM VALUE OF HORIZONTAL DISPLACEMENT AT RIDGE OF RAFTER(mm)				
θ\B	5.5m	6.5m	7.5m	8.5m
$2^{0}.86$	19.19	16.227	17.466	16.415
$6^{0}.5$	11.378	8.731	11.063	12.443
10^{0}	14.105	8.026	9.072	10.568

In table - 5 maximum values of displacement at ridge of rafter are tabulated for various angles of inclinations (θ) and bay spacing (B). It can be observed that as the roof angle and bay spacing increase the displacement does not have a definite pattern. The largest displacement is 19.19mm when $\theta = 2^{0}.86$ and bay spacing 5.5m.

Table 6				S = 25m
MAXIMUM VALUE OF VERTICAL DEFLECTION AT RIDGE OF RAFTER(mm)				
θ\B	5.5m	6.5m	7.5m	8.5m
$2^{0}.86$	43.392	39.126	41.287	39.256
$6^{0}.5$	41.96	31.816	37.978	42.124
10^{0}	43.279	28.306	32.22	36.701

From table - 6 maximum values of vertical deflection at ridge of rafter are tabulated for various inclinations of angle (θ) and bay spacing (B). It can be observed that as the angle of roof and bay spacing increase. The displacement does not have a definite pattern. The largest deflection is 43.392mm when $\theta = 2^{0}.86$ and bay spacing is 5.5m.

Table 7				S = 25m
STEEL CONSUMPTION(kg/m^{2})				
θ\B	5.5m	6.5m	7.5m	8.5m
$2^{0}.86$	23.20	22.05	20.62	19.32
$6^{0}.5$	23.74	23.12	21.11	19.81
10^{0}	24.87	24.77	21.09	19.74

It may be seen from the table 7 that for a frame span 25m as the angle (θ) increases consumption of steel increases while along bay spacing consumption of steel quantity decreases as the bay spacing increases. The minimum consumption of steel from table 7 is 19.32kg/$m^2$when θ = 2^0.86 and bay spacing is 8.5m.

Table 7a				S = 25m
MOMENT INTERACTION RATIO				
θ\B	5.5m	6.5m	7.5m	8.5m
2^0.86	0.911-0.954	0.904-0.916	0.885-0.951	0.934-0.979
6^0.5	0.948-0.978	0.917-0.997	0.904-0.949	0.922-0.965
10^0	0.897-0.967	0.859-0.945	0.929-0.964	0.912-0.991

Table 7a, 8a and 9a give the interaction ratio which should be always less than unity for a safe design. It is maintained at a value of about 0.9 and above for economy but keeping the same always less than unity.

Table 8				S = 30m
STEEL CONSUMPTION(kg/m^2)				
θ\B	5.5m	6.5m	7.5m	8.5m
2^0.86	38.61	35.25	33.26	28.03
6^0.5	29.29	25.90	22.25	24.19
10^0	27.49	26.26	24.94	22.94

It may be seen from the table 8 that for a frame span 30m as the angle (θ) increases consumption of steelseverally decreases, while along bay spacing consumption of steel quantity decreases as the bay spacing increases. The minimum consumption of steel from table 8 is 22.25kg/m^2 when θ = 6^0.5 and bay spacing is 7.5m.

Table 8a				S = 30m
MOMENT INTERACTION RATIO				
θ\B	5.5m	6.5m	7.5m	8.5m
2^0.86	0.913-0.981	0.908-0.952	0.910-0.987	0.931-0.964
6^0.5	0.952-0.993	0.886-0.982	0.896-0.969	0.932-0.985
10^0	0.905-0.970	0.887-0.959	0.946-0.973	0.946-0.958

Table 9				S = 40m
STEEL CONSUMPTION(kg/m^2)				
θ\B	5.5m	6.5m	7.5m	8.5m
2^0.86	37.42	34.22	36.83	25.42
6^0.5	33.58	27.50	26.16	25.51
10^0	32.97	27.83	26.34	24.84

It may be seen from the table 9 that for a frame span 40m as the angle (θ) and bay spacing increases consumption of steel does not have a definite pattern. The minimum consumption of steel from table 9 is 24.84kg/m^2 when
θ = 10^0 and bay spacing is 8.5m.

Table 9a				S = 40m
MOMENT INTERACTION RATIO				
θ\B	5.5m	6.5m	7.5m	8.5m
2^0.86	0.947-0.987	0.914-0.994	0.964-0.986	0.927-0.984
6^0.5	0.887-0.964	0.899-0.985	0.886-0.989	0.886-0.946
10^0	0.843-0.973	0.939-0.984	0.888-0.997	0.900-0.991

Table - 10			θ = 2^0.86
MAX VALUE OF BASE REACTION AT EXTREME COLUMN(kN)			
B\S	25m	30m	40m

5.5m	153.66	186.78	260.74
6.5m	178.09	215.68	298.70
7.5m	202.51	244.58	336.67
8.5m	227.04	273.48	374.63

In table 10, it may be noted that a maximum value of base reaction at an extreme column occurs for an angle10^0 and bay spacing of 8.5m and 40m span. The base reaction seems to increase with span and bay spacing.

Table - 11			θ = 2^0.86
MAXIMUM VALUE OF MOMENT AT BEAM COLUMN JUNCTION(kNm)			
B\S	25m	30m	40m
5.5m	527.12	880.71	1650.73
6.5m	679.42	943.24	1721.6
7.5m	729.79	1061.98	2190.58
8.5m	852.4	1325.23	2300.54

In the table- 11, that max moments are tabulated for various bay spacing's (B) and spans (S). It can be similarly observed that as the bay spacing and span increase moments also increase. The increase seems to have a definite pattern. The largest moment is 2300.54kNm when bay spacing is 8.5m and span is 40m.

Table - 12			θ = 2^0.86
MAXIMUM VALUE OF MOMENT AT RIDGE OF RAFTER(kNm)			
B\S	25m	30m	40m
5.5m	37.74	109.16	128.33
6.5m	52.16	21.26	212.55
7.5m	36.98	48.75	266.65
8.5m	35.645	167.8	384.49

In the table – 12 the maximum value of moments are tabulated for various bay spacing's (B) and spans (S). It can be similarly observed that as thespan increases the moments also increase, while along bay spacing moment does not seem to have a definite pattern. The largest moment is 384.49kNm when a bay spacing is 8.5m and span is 40m.

Table - 13			θ = 2^0.86
MAXIMUM VALUE OF HORIZONTAL DISPLACEMENT AT BEAM COLUMN JUNCTION (mm)			
B\S	25m	30m	40m
5.5m	19.19	7.454	11.221
6.5m	16.222	8.951	10.189
7.5m	17.466	8.325	9.418
8.5m	16.415	7.386	7.798

In the table - 13 maximum values of horizontal displacement at beam column junction are tabulated for various bay spacing's (B) and span (S).It can be similarly observed that as the bay spacing increases the displacement decreases while as the span increases the displacements decreases and then increases. The largest displacement is 19.19mm when bay spacing is 5.5m and span is 25m.

Table - 14			θ = 2^0.86
MAXIMUM VALUE OF HORIZONTAL DISPLACEMENT AT RIDGE OF RAFTER(mm)			
θ\B	25m	30m	40m
5.5m	18.985	7.854	9.841
6.5m	18.227	8.951	7.445
7.5m	17.466	8.325	6.749
8.5m	16.415	7.386	5.954

In the table - 14 maximum values of horizontal displacement at ridge of rafter are tabulated for various bay spacing (B) and span(S). It can be similarly observed that as bay spacing increases the displacement also decreases, while as span increases it does not have definite pattern. The largest displacement is 18.985mm for a bay spacing of 5.5m and span of 25m.

Table - 15			$\theta = 2^0.86$
MAXIMUM VALUE OF VERTICAL DEFLECTION AT RIDGE OF RAFTER(mm)			
θ\B	25m	30m	40m
5.5m	43.392	47.395	122.916
6.5m	39.126	50.239	124.36
7.5m	41.287	44.753	99.961
8.5m	39.256	46.083	127.509

From the table - 15 it may be observed that maximum value of vertical deflection at ridge of rafter for various bay spacing's (B) and span(S). It can be similarly observed that as the span increases the deflection increases, while along bay spacing deflection does not have definite pattern. The largest deflection is 127.509mm when a bay spacing 8.5m and 40m span.

Table - 16			$\theta = 2^0.86$
STEEL CONSUMPTION(kg/m^2)			
B\S	25m	30m	40m
5.5m	23.20	38.61	37.42
6.5m	22.05	35.25	34.22
7.5m	20.62	33.26	36.83
8.5m	19.32	28.03	25.42

It may be seen from the table 16 that as the bay spacing increases the consumption of steel decreases for 25, 30m and for 40m it decreases and then increases slightly but severally a decreases, while as the span increases the consumption of steel does not seem to have a definite pattern. A minimum value 19.32kg/m^2 is obtained for 8.5m bay spacing and 25m span.

Table – 16a			$\theta = 2^0.86$
MOMENT INTERACTION RATIO			
B\S	25m	30m	40m
5.5m	0.911-0.954	0.913-0.981	0.947-0.987
6.5m	0.904-0.916	0.908-0.952	0.914-0.994
7.5m	0.885-0.951	0.910-0.987	0.964-0.986
8.5m	0.934-0.979	0.931-0.964	0.927-0.984

Table 16a, 17a, and 18a gives the moment interaction factor which are kept close to unity but always less then unity.

Table - 17			$\theta = 6^0.5$
STEEL CONSUMPTION(kg/m^2)			
B\S	25m	30m	40m
5.5m	23.74	29.29	33.58
6.5m	23.12	25.90	27.50
7.5m	21.11	22.25	26.16
8.5m	19.81	24.19	25.51

It may be seen from the table 17 that as the bay spacing increases the consumption of steel decreases, while as the span increases the consumption of steel increases. A minimum value 19.81kg/m2 is obtained for 8.5m bay spacing and 25m span.

Table – 17a			$\theta = 6^{0}.5$
MOMENT INTERACTION RATIO			
B\S	25m	30m	40m
5.5m	0.948-0.978	0.952-0.993	0.887-0.964
6.5m	0.917-0.997	0.886-0.982	0.899-0.985
7.5m	0.904-0.949	0.896-0.969	0.886-0.989
8.5m	0.922-0.965	0.932-0.985	0.886-0.946

It may be seen from the table 18 that as the bay spacing increases the consumption of steel decreases, while as the span increases the consumption of steel increases. A minimum value 19.74kg/m^2 is obtained for 8.5m bay spacing and 25m span.

Table - 18			$\theta = 10^{0}$
STEEL CONSUMPTION(kg/m^2)			
B\S	25m	30m	40m
5.5m	24.87	27.49	37.97
6.5m	24.77	26.26	27.83
7.5m	21.09	24.94	26.34
8.5m	19.74	22.94	24.84

Table – 18a			$\theta = 10^{0}$
MOMENT INTERACTION RATIO			
B\S	25m	30m	40m
5.5m	0.897-0.967	0.905-0.970	0.843-0.973
6.5m	0.859-0.945	0.887-0.959	0.939-0.984
7.5m	0.929-0.964	0.946-0.973	0.888-0.997
8.5m	0.912-0.991	0.946-0.958	0.900-0.991

Table - 19				$\theta = 2^{0}.86$
MAX VALUE OF BASE REACTION AT EXTREME COLUMN(kN)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	145.065	170.51	189.51	220.082
30m	186.456	339.15	248.25	274.68
40m	381.307	425.13	518.93	568.813

Table - 20				$\theta = 2^{0}.86$
MAXIMUM VALUE OF MOMENT AT BEAM COLUMN JUNCTION(kNm)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	527.12	679.42	729.79	852.4
30m	880.71	943.24	1061.9	1325.23
40m	1650.73	1721.6	2190.58	1299.83

Table – 21				$\theta = 2^{0}.86$
MAXIMUM VALUE OF MOMENT AT RIDGE OF RAFTER(kNm)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	37.74	52.16	36.98	35.645
30m	109.16	30.0	48.75	167.8
40m	128.33	212.55	266.65	384.49

Table – 22				$\theta = 2^{0}.86$
MAXIMUM VALUE OF HORIZONTAL DISPLACEMENT AT BEAM COLUMN JUNCTION(mm)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	19.19	16.227	17.466	16.415
30m	7.454	8.951	8.325	7.386
40m	11.221	10.189	7.798	9.935

Table – 23				$\theta = 2^{0}.86$
MAXIMUM VALUE OF HORIZONTAL DISPLACEMENT AT RIDGE OF RAFTER(mm)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	19.19	16.227	17.466	16.415
30m	7.854	8.951	8.325	7.386
40m	9.841	7.445	5.233	6.749

Table – 24				$\theta = 2^{0}.86$
MAXIMUM VALUE OF VERTICAL DEFLECTION AT RIDGE OF RAFTER(mm)				
S\B	5.5m	6.5m	7.5m	8.5
25m	51.914	39.126	41.287	39.256
30m	99.893	50.239	44.753	46.083
40m	281.45	124.36	99.961	127.509

Table - 25				$\theta = 2^{0}.86$
STEEL CONSUMPTION(kg/m^{2})				
S\B	5.5m	6.5m	7.5m	8.5m
25m	23.20	22.05	20.62	19.32
30m	38.61	35.25	33.26	28.03
40m	37.42	34.22	36.83	25.42

Similar observation can be noted in the remaining tables 19 to 25. It is self-explanatory finally It may be seen from the table 25 as span increases the consumption of steel increases and then decreases, while as the bay spacing increases the consumption of steel decreases. A minimum value 19.32kg/m^{2} is obtained for 8.5m bay spacing and 25m span.

Table - 25a				$\theta = 2^{0}.86$
MOMENT INTERACTION RATIO				
S\B	5.5m	6.5m	7.5m	8.5m
25m	0.911-0.954	0.904-0.916	0.885-0.951	0.934-0.979
30m	0.913-0.981	0.908-0.952	0.910-0.987	0.931-0.964
40m	0.947-0.987	0.914-0.944	0.964-0.986	0.927-0.984

Table 25a, 26a and 27a give the interaction ratio which should be always less than unity for a safe design. It is maintained at a value of about 0.9 and above for economy but keeping the same always less than unity.

Table - 26				$\theta = 6^{0}.5$
STEEL CONSUMPTION(kg/m^{2})				
S\B	5.5m	6.5m	7.5m	8.5m
25m	23.74	23.12	21.11	19.81
30m	29.29	25.90	22.25	24.19
40m	33.58	27.50	26.16	25.51

Table - 26a				$\theta = 6^0.5$
MOMENT INTERACTION RATIO				
S\B	5.5m	6.5m	7.5m	8.5m
25m	0.948-0.978	0.917-0.997	0.904-0.949	0.922-0.965
30m	0.952-0.993	0.886-0.982	0.896-0.969	0.932-0.985
40m	0.887-0.964	0.899-0.985	0.886-0.989	0.886-0.946

Table - 27				$\theta = 10^0$
STEEL CONSUMPTION(kg/m2)				
S\B	5.5m	6.5m	7.5m	8.5m
25m	24.87	24.77	21.09	19.74
30m	27.49	26.26	24.94	22.94
40m	32.97	27.83	26.34	24.84

Table - 27a				$\theta = 10^0$
MOMENT INTERACTION RATIO				
S\B	5.5m	6.5m	7.5m	8.5m
25m	0.897-0.967	0.859-0.945	0.929-0.964	0.912-0.991
30m	0.905-0.970	0.887-0.959	0.946-0.973	0.946-0.958
40m	0.843-0.973	0.939-0.984	0.888-0.997	0.900-0.991

It may be seen from the tables 26 and table 27 as the span increases the consumption of steel increases, while as bay spacing increases the consumption of steel decreases.Similar observation is seeninboth the tables. From table 26 minimum value is 19.81kg/m^2 obtained for 25m span and 8.5m bay spacing. From table 27 a minimum value is 19.74kg/m^2 obtained for 25m span and 8.5m bay spacing.

VI. CONCLUSION

In the present work an attempt is made to optimize the quantity of steel in PEB one storey gable industrial shed. The three parameters which influence the reactions, moments and displacements are the angle of inclination θ, the bay spacing (B) and the span (S).
When span of 25m, bay spacing and roof angles are varied steel consumption is shown in table 7. Minimum steel consumption obtained in this combination is given below,

MINIMUM STEEL CONSUMPTION

Table - 28		Absolute minimum steel consumption		
	Bay spacing (B)	Span (S)	Ridge angle (θ)	Steel consumption(kg/m^2)
1.	8.5m	25m	$2^0.86$	19.32
2.	8.5m	25m	$6^0.5$	19.81
3.	8.5m	25m	10^0	19.74

In table 28 the various minima are tabulated for different combination of Q, B and S. The absolute minimum steel combination can be seen to be 19.32 kg/m^2 for a combination of the parameter of $\theta = 2^0.86$, B = 8.5m and S =25m.

When span of 30m, bay spacing and roof angles are varied steel consumption is shown in table 8. Minimum steel consumption obtained in this combination is given below,
For S = 30m, $\theta = 6^0.5$ and B = 7.5 steel consumption obtained is 22.25 kg/m^2.

When span of 40m, bay spacing and roof angles are varied steel consumption is shown in table 9. Minimum steel consumption obtained in this combination is given below,
For S = 40m, $\theta = 10^0$ and B = 8.5 steel consumption obtained is 24.84kg/m^2.

Therefore it may be concluded that for an industrial building consisting of ridge frames located the zone III and with other data assumed having the above combination can be the optimum, minimum steel consumption is 19.32kg/m^2 obtained for, bay spacing (B) = 8.5m, span(S) =25m and angle (θ) =2^0.86. However, it will be different for different data input like location zone for earthquake and wind, grade of steel, type of soil, frame with special with cranes and multi-spans.

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