Parametric Study of Braced Barrel Vault Structure to Cover Large Span

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Abstract - At the design stage of large span structures, the designer has to pay special consideration not only to the structural and architectural aspects of his structure, but he has also to aim towards simple fabrication and ease of erection. The recent trends put an increasing emphasis on the optimization of the structural material. Nowadays maximum exploitation of material combined with minimum use of energy becomes a focal point of interest. This explains the great interest in the design of structures with minimum unit weight per square area. At the same time attempts are made to simplify the fabrication with a saving in all kinds of energy during the construction. Braced barrel vaults undoubtedly belong to the most effective systems of this kind. Their main roof shape is characterized by the form of a barrel vault. Their basic form can, of course, be adapted in various ways to different purposes and requirements of the actual structure. Pertaining to cost effective engineering design of these structure, It is utmost important to study the effect of various parameters of designing on cost and performance of the structure. In this study, the effort will be made to study the influence on the pattern, relative depth to spacing ratio, supporting arrangement, bracing pattern etc. on the cost and performance of structure subjected to Indian loading condition.

Key Words: Large span structures, Braced barrel vaults, pattern, depth to spacing ratio, supporting arrangement, bracing pattern.

1. INTRODUCTION

Now a days a growing interest in space frame structures has been witnessed worldwide. The main objective of architects and engineers is to search for new structural forms to accommodate large unobstructed areas braced barrel vaults frequently provide the right answer and also satisfy the requirement for lightness, economy, and speedy construction with the development of new building techniques and construction materials. Barrel vault is a simple structural formation (space structure) made up of a network of longitudinal, transverse and bracing members with curvature in one direction. The configuration of the vault, or in other words the way in which the members are positioned and connected, has a major effect on the vault's structural performance, aesthetics and cost.. The interest in braced barrel vaults and the advantages offered by vault type of construction led to the introduction of different types of bracing system. Also vault can be analyzed with varying it's various parameter like different support conditions , Height to span ratio, No. of division of vault on each side from centre. With every variation of parameter it is expected that the performance of vault would change , leading sometime advantages improvement in vault's strength, Stress distribution, material requirement.

This paper present the result of parametric study for Braced barrel vault for study the effect parameter like different type of support condition, height , height to span ratio, bracing pattern, and no of division of arch is considered . Those configuration combinations are compared to found out the economical design option by comparing the uckling factor, steel requirement, and serviceability criteria. For designing and analysis of braced barrel vault STADD-PRO software is used.

2. PARAMETRIC STUDY

2.1 PRELIMINARY DESIGN DATA:

No	Design parameters	value
1	Height	3.75,6,9,13.5
2	Height / Span ratio	0.125,0.20
3	no. of divisions in arch direction on each side of rise (nl)	l1,l2,l3,l4
4	Support condition (SC)	S1,S2,S3
5	Bracing pattern	T1,T2,T3
6	Section	Circular Hollow section

2.2 DESIGN PARAMETER:

1) Span of braced barrel vault (SP): To study the braced barrel vault structure the transverse span is fixed as 30 m. while the longitudinal span is selected so as to give the ratio of longitudinal span to transverse span approximately equal to unity.

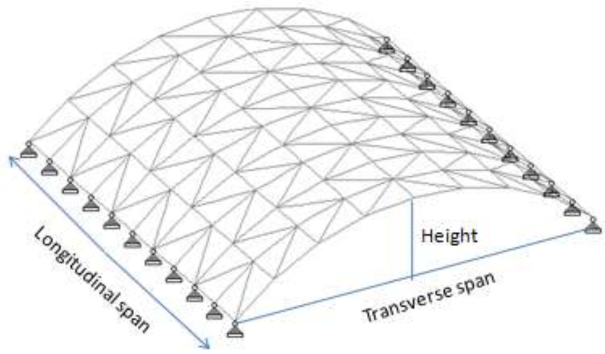

Fig -1: Vault component

2) Height to span ratio (H/S) : To study the effect of varying height on the performance of the barrel vault four different central height to transverse span ratio 0.125,0.2 is selected . the height to span ratio of braced vault is selected so that it gave practical solution.

3) No. of divisions in arch direction on each side of rise (ln): To study the effect of varying height on the performance of the barrel vault four different no. of divisions in arch direction on each side of rise is selected .the no of division on each side is designated as "n". the different no. of division used for study are 4,6,8,10.

Table -1: Types based on no. of division of arch of vault on each side of raise

l1	4
l2	6
l3	8
l4	10

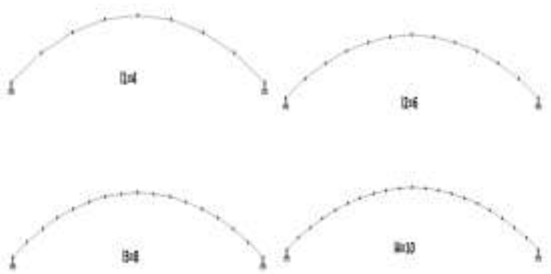

Fig -2: Configuration based on No. of division

4) Support condition (S): The braced barrel vault is designed and analyzed for three different type of support condition :

Table -2 : Support condition

S1	Both Longitudinal sides supported
S2	Both Transverse sides supported
S3	Both Transverse sides and longitudinal sides are supported

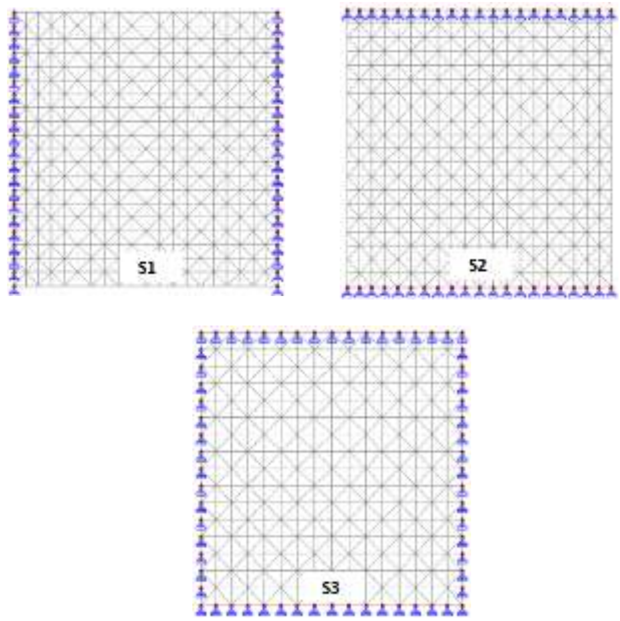

Fig -3: Support conditions

5) Bracing pattern (T): Bracing pattern play major role on the design, performance and execution of any braced barrel vault .In this study three different type of bracing pattern has been used to study and signify the effect of bracing pattern on the performance of braced barrel vaults.

Table -3: Bracing pattern

T1	Bracing pattern 1
T2	Bracing pattern 2
T3	Three way braced

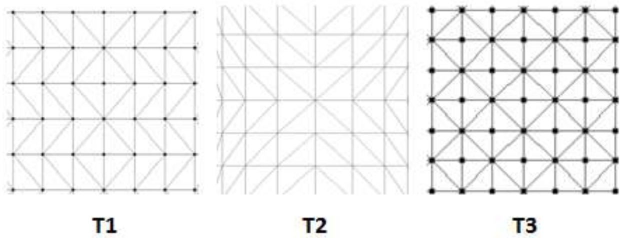

Fig -4: Bracing pattern

3. LOADING DETAILS :

The following loads are considered :
1) Dead load : The dead load includes self weight of the structure and the weight of the roof covering material and taken according to IS 875-1 (1987).

2) Live load : The live load depends upon rise/span ratio and it is calculated as per table-2 of IS 875 -2(1987).

3) Wind load : Wind load is considered according to the IS 875-3(2015).

Following are the primary load considered for combination :

1) Dead load (DL)
2) Live load(LL)
3) Wind load parallel to ridge $(WL+x)_1$ [WL_PA + Cpi]
4) Wind load parallel to ridge$(WL-x)_2$ [WL_PA – Cpi]
5) Wind load perpendicular to ridge $(WL+z)_1$ [WL_PER + Cpi]
6) Wind load perpendicular to ridge $(WL+z)_2$ [WL_PER – Cpi]

Here in the load cases two directions for wind loading is considered, one parallel to ridge line and second is perpendicular to the ridge line. The figure 5 here shows the identical direction for wind load consideration. +X direction shows the direction parallel to the ridge line. While +Z direction shows the direction perpendicular to the ridge line. And according to the sign used in consideration of the internal pressure (Cpi) co-efficient in wind load calculation, it will create Two load cases for each value of Cpi.

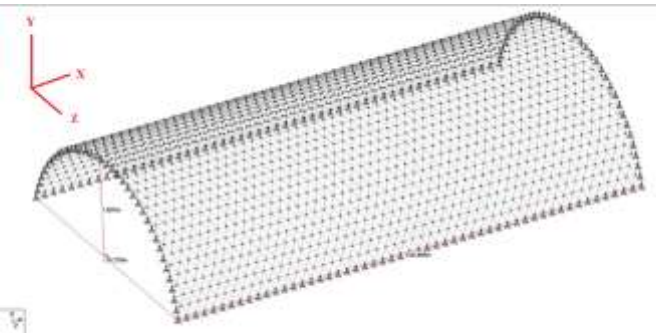

Fig -5: Direction for wind load cases

Following are the load combination used in the analysis of raced barrel vault :

1) 1.5(DL+LL)
2) 1.2DL+1.2LL+0.6WL_PA+CPI
3) 1.2DL+1.2LL+0.6WL_PA-CPI
4) 1.2DL+1.2LL+0.6WL_PER+CPI
5) 1.2DL+1.2LL+0.6WL_PER-CPI
6) 1.2(DL+LL)
7) 1.2(DL+LL+WL_PA+CPI)
8) 1.2(DL+LL+WL_PA-CPI)
9) 1.2(DL+LL+WL_PER+CPI)
10) 1.2(DL+LL+WL_PER-CPI)
11) 1.5(DL+WL_PA+CPI)
12) 1.5(DL+WL_PA-CPI)
13) 1.5(DL+WL_PER+CPI)
14) 1.5(DL+WL_PER-CPI)
15) 0.9DL+1.5WL_PA+CPI
16) 0.9DL+1.5WL_PA-CPI
17) 0.9DL+1.5WL_PER+CPI
18) 0.9DL+1.5WL_PER-CPI
19) DL+LL
20) DL+0.8LL+0.8WL_PA+CPI
21) DL+0.8LL+0.8WL_PA-CPI
22) DL+0.8LL+0.8WL_PER+CPI
23) DL+0.8LL+0.8WL_PER-CPI
24) DL+WL_PA+CPI
25) DL+WL_PA-CPI
26) DL+WL_PER+CPI
27) DL+WL_PER-CPI

4. RESULTS:

Here results are shown in form of graphs. The results are compared by forming the group of same bracing pattern and same H/S ratio and varying support condition.

The results are displayed in form of chart of Steel consumption(kg/m^2), vertical deflection(mm), and buckling factor.

Bracing type	H/s	Support condition
T1	0.125	S1,S2,S3

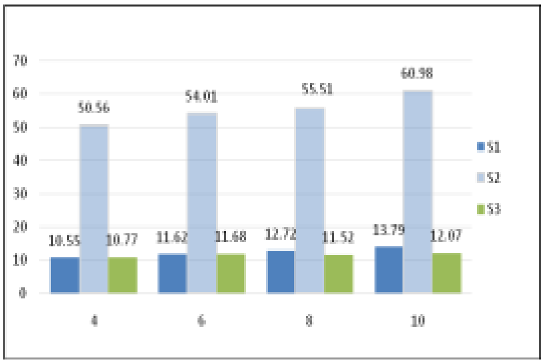

Fig -6: Steel Consumption

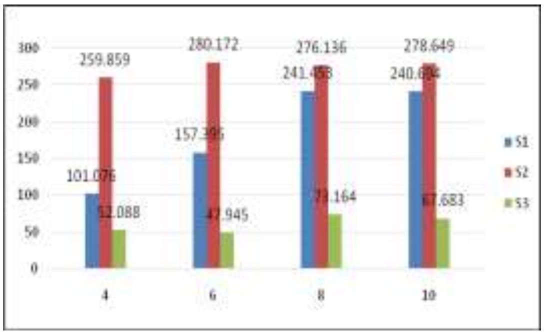

Fig -7: Maximum Vertical Deflection(mm)

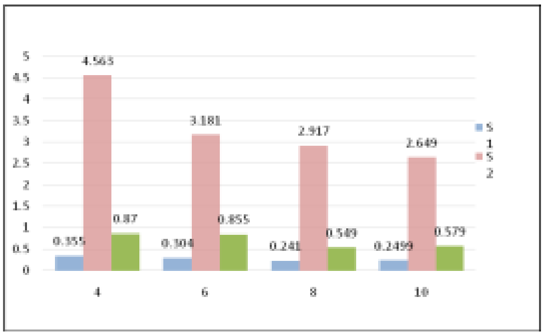

Fig -8 : Buckling Factor

Bracing type	H/s	Support condition
T2	0.125	S1,S2,S3

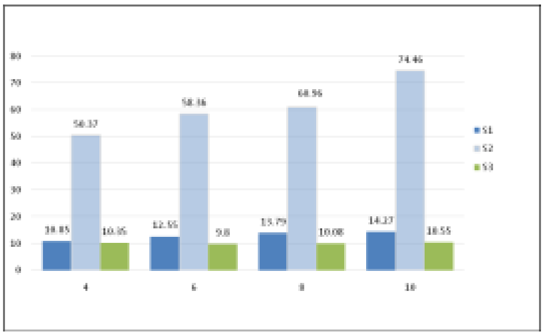

Fig -9: Steel Consumption

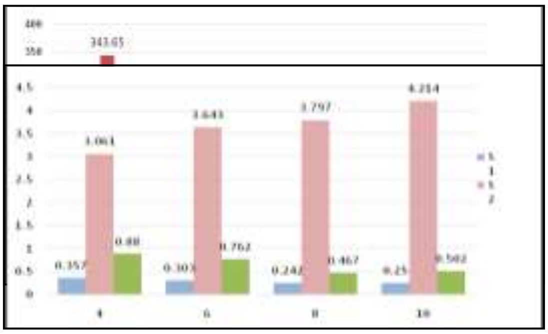

Fig -10: Maximum Vertical Deflection(mm)

Fig -11 : Buckling Factor

Bracing type	H/s	Support condition
T3	0.125	S1,S2,S3

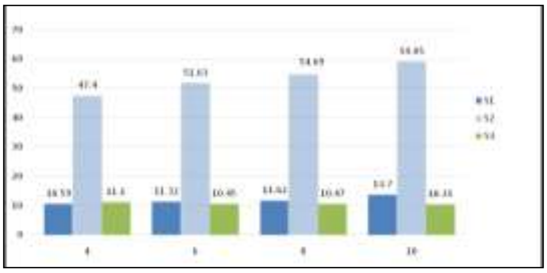

Fig -12: Steel Consumption

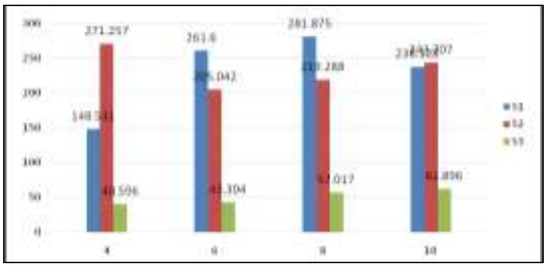

Fig -13: Maximum Vertical Deflection(mm)

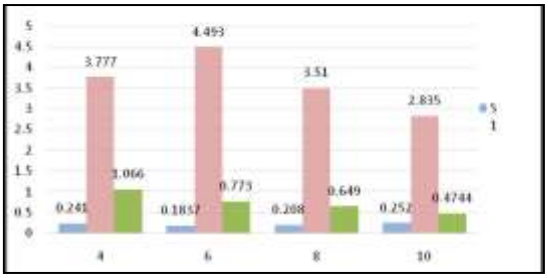

Fig -14 : Buckling Factor

Bracing type	H/s	Support condition
T1	0.2	S1,S2,S3

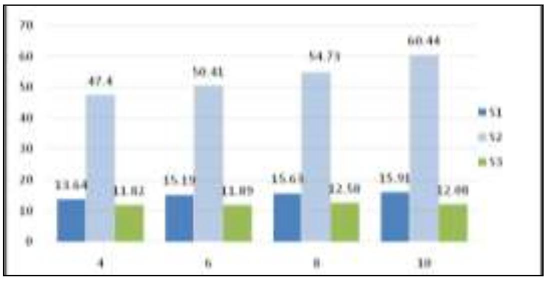

Fig -15: Steel Consumption

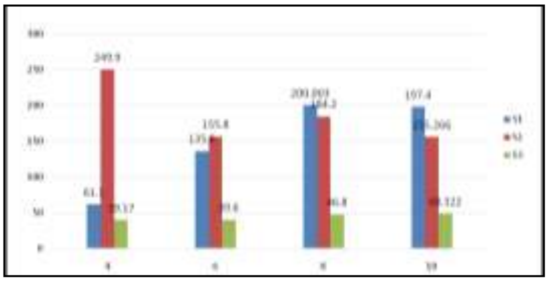

Fig -16: Maximum Vertical Deflection(mm)

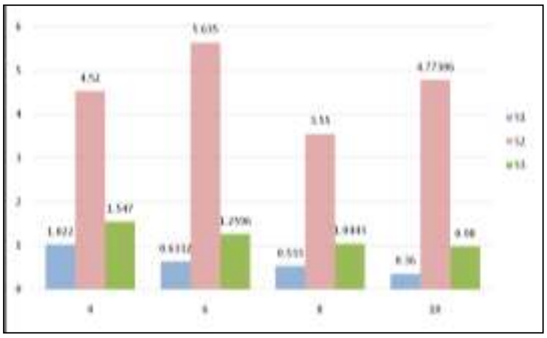

Fig -17 : Buckling Factor

Bracing type	H/s	Support condition
T2	0.2	S1,S2,S3

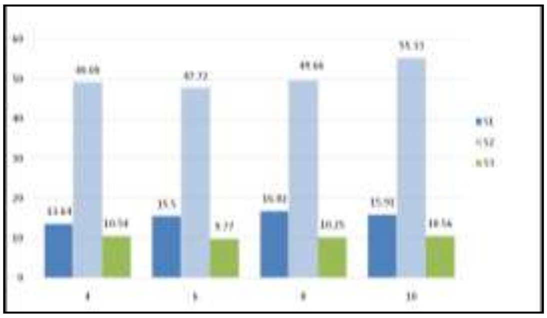

Fig -18: Steel Consumption

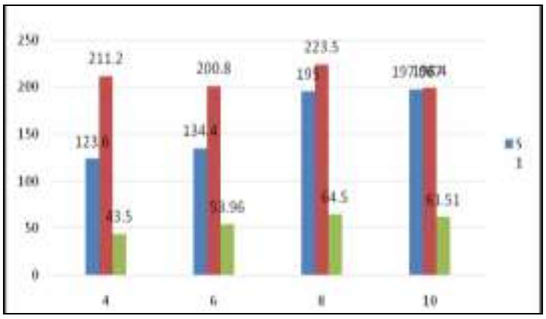

Fig -19: Maximum Vertical Deflection(mm)

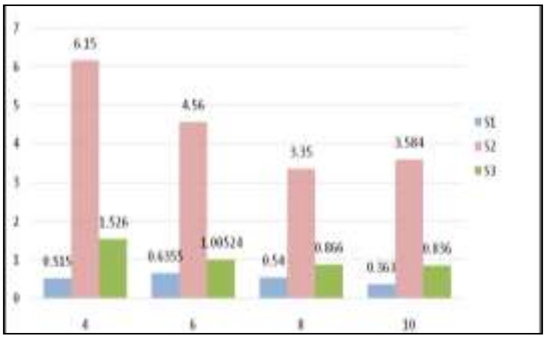

Fig -20 : Buckling Factor

Bracing type	H/s	Support condition
T2	0.2	S1,S2,S3

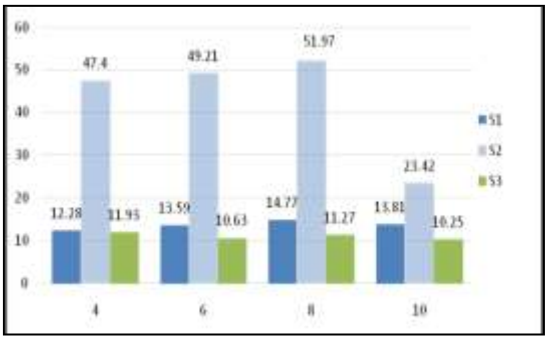

Fig -21: Steel Consumption

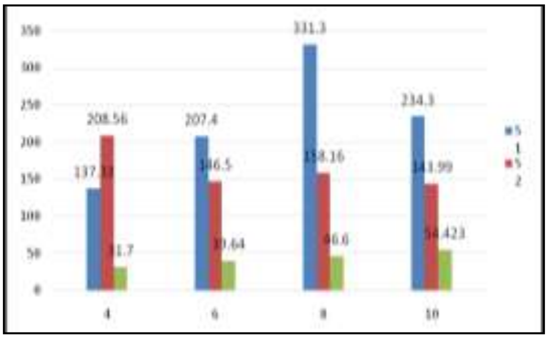

Fig -22: Maximum Vertical Deflection(mm)

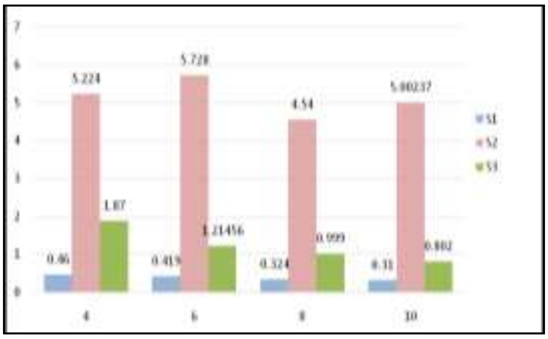

Fig -23: Buckling Factor

4. OBSERVATION:

1) h/s=0.125,TYPE-1 bracing arrangements :

(a) From Fig 6, For h/s 0.125, it is observed that steel consumption is highest in case of maximum number of divisions with support condition type-2. For other two conditions 1 & 3, there is almost same results obtained. But again, the maximum values for these two support conditions is also in case of maximum number of divisions(n=10).
(b) From Fig .7, For h/s 0.125, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 6 division of support-3 conditions type.In case of Support-2, the deflection is maximum even the requirement of bigger sizes members in strength analysis.
(c) From Fig 8, For h/s 0.125, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support condition the buckling factor are even less than1. Further, in case of support condition 1, the buckling factor are least for all divisions. Also , it is been observed for all the support conditions that the buckling factor value reduces as the number of divisions increases.

2) h/s=0.125,TYPE-2 bracing arrangements

(a) From Fig .9, For h/s 0.125, it is observed that steel consumption is highest in case of maximum number of divisions with support condition type-2. For other two conditions 1 & 3, the least value is in case of support-3 type cases. Also, it is been observed for all the support conditions that the steel consumption value increase as the number of divisions increases.
(b) From Fig.10, For h/s 0.125, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 6 division of support-3 conditions type. In case of Support-2, the deflection is more compared to support -1 condition for divisions upto-8, but for divisions 10, the deflection in case of Support-1 is highest.
(c)From Fig.11, For h/s 0.125, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support condition the buckling factor are even less than1. Further, in case of support condition 1, the buckling factor are least for all divisions. Also, it is been observed for all the support conditions that the buckling factor value reduces as the number of divisions increases in case of support 1 & 3, but in case of support-2 type, the buckling factor value increases as the number of divisions increases.

3) h/s=0.125,TYPE-3 bracing arrangements :

(a) From Fig.12, For h/s 0.125, it is observed that steel consumption is highest in case of maximum number of divisions with support condition type-2. For other two conditions 1 & 3, the least value is in case of support-3 type cases with maximum divisions. Further for support-1 &2 type cases, the steel consumption value increases as the number of divisions increases, whereas in case of support-3 type models, it decreases with the increase in the number of divisions.
(b) From Fig .13, For h/s 0.125, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 4 division of support-3 conditions type. In case of Support-2, the deflection is least in case of 6 divisions and in case of Support-1,the deflection is least in case of 4 divisions. Also, alike other two case of type-1 & type-2, with type-3 bracings pattern, the support-2 condition is having lesser deflection than even the
support-1 condition.
(c) From Fig.14, For h/s 0.125, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support condition the buckling factor are even less than 1 except support-3 with 4 no's division case. Further, in case of support condition 1, the buckling factor are least for all divisions. Also, it is been observed that the buckling factor value reduces as the number of divisions increases in case of support-3. The maximum buckling factor for support-2 is in case of 6 number of divisions, for support-1 is in case of 10 number of divisions and for support-3 is in case of 4 number of divisions.

4) h/s=0.20,TYPE-1 bracing arrangements

(a) From Fig.15, For h/s=0.20, it is observed that steel consumption is highest in case of maximum number of divisions with support condition type-2. For other two conditions 1 & 3, the least value is in case of support-3 type cases with 4 nos. of divisions. Also, it is been observed for all the support conditions that the steel consumption value increases as the number of divisions increases.
(b) From Fig.16, For h/s=0.20, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 4 division of support-3 conditions type. In case of Support-2, the deflection is least in case of 6 divisions and in case of

Support-1,the deflection is least in case of 4 divisions. Also, the support-2 condition is having lesser deflection than the support-1 condition in case of 8 and 10 number of divisions.
(c) From Fig.17, For h/s=0.20, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support condition the buckling factor are even less than1. Further, in case of support condition 1, the buckling factor are least for all divisions. Also , it is been observed for all the support conditions that the buckling factor value reduces as the number of divisions increases. But it can also be seen that in case of support-1 condition, the buckling factor are even less than 1 except 4 nos division case. Further, in case of support condition 1, the buckling factor are least for all divisions. Also, it is been observed that the buckling factor value reduces as the number of divisions increases in case of support-3. The maximum buckling factor for support-2 is in case of 6 number of divisions, for support-1 is in case of 4 number of divisions and for support-3 is in case of 4 number of divisions.

5) h/s=0.20,TYPE-2 bracing arrangements

(a) From Fig.18, For h/s=0.20, it is observed that steel consumption is highest in case of maximum number of divisions with support condition type-2. For other two conditions 1 & 3, the least value is in case of support-3 type cases with 6 nos. of divisions.
(b) From Fig .19, For h/s 0.2, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 4 division of support-3 conditions type. Further as the no of division increase the difference of their max. vertical deflection decrease and reach almost equal at 10 no of division.
(c) From Fig 20, For h/s 0.2, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support condition the buckling factor are even less than1.Also , it is been observed for all the support conditions that the buckling factor value reduces as the number of divisions increases.

6) h/s=0.20,TYPE-3 bracing arrangements

(a) From Fig.21, For h/s=0.20, it is observed that steel consumption is highest in case of 8 number of divisions with support condition type-2. For other two conditions 1 & 3, the least value is in case of support-3 type cases with 10 nos. of divisions. There is drastic reduction in steel consumption for support type-3 when no. of division changes from 6 to 10.
(b) From Fig .22, For h/s 0.2, The deflection is less in case of support-3 with respect to support condition 1 & 2.Further, the least deflection is obtained in case of 4 division of support-3 conditions type.max. vertical deflection show increasing trend for support type-3 while shows decrease trend for support type-2 with increase in no. of division.
(c) From Fig 23, For h/s 0.2, It is obvious to have the highest buckling factor in case of larger c.s members in case of Support type-2. But it can also be seen that in case of other two support. it is been observed for all the support conditions that the buckling factor value reduces as the number of divisions increases.

5. CONCLUSONS:

As per the observations made for the conclusions can be made as following :

1) Support condition type-3 is most economical solution for both h/s ratio whatsoever the bracing pattern. Also, support condition type-2 proved to be costlier one.
2) As h/s ratio increase there is general trend that Max. vertical deflection tend to decrease and buckling factor increase.
3) The buckling factor is maximum in case of support-2 type structure , hence support condition-2 is batter for strength criteria.
4) Deflection is found to be maximum in all case for support-2,even though the larger c/s is provided.
5) The optimum solution in terms of steel consumption is depend upon the different number of division, support condition and bracing pattern.

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