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Configurations of double-layer space trusses

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Abstract: Space truss structures may be fabricated in any of several common grid configurations. With different configurations, the truss performance varies considerably affecting both its competitiveness and suitability for specific applications. The work presented in this paper is an assessment of the most commonly adopted truss configurations and their effect on truss characteristics such as the stiffness/weight value, member stress distribution, number of joints and members, degree of redundancy and cost. The study is parametric and covers wide variations of truss aspect ratios, boundary conditions and span/depth ratios. The results of this study could be of significant value to the design of space truss structures.

Key words: Space trusses; design.

1. Introduction

Since the beginning of their commercial use half a century ago, space trusses have been increasingly popular, especially in large open areas with few or no intermediate supports. Over the years, they have become known for their pleasing appearance, light weight, easy fabrication and rapid erection. Hundreds of successful space truss applications now exist all over the world covering stadiums, public halls, exhibition centres, aeroplane hangers and many other buildings.

Space trusses may be built with many different configurations involving different arrangements of chord and diagonal members. The most commonly adopted configurations are listed in the following (refer to Fig. 1):

(1) Square-on-square configuration (SOS) in which both the top and bottom chords are composed of rectangular panels of the same size, Fig. 1a.

(2) Square-on-large-square configuration (SOLS) in which the bottom chord forms panels that are twice the size of the top chord panels in each direction, Fig. 1b.

(3) Square-on-diagonal configuration (SOD) in which the top chord members are parallel to the structure edges, while the bottom chord members run at 45°, Fig. 1c.

(4) Diagonal-on-square configuration (DOS) in which the top and bottom chords follow the description for the bottom and top chords of SOD configuration, respectively, Fig. 1d.

(5) The configuration shown in Fig. 1e which is constructed of two orthogonal series of plane trusses, each formed of two sets of chord (top and bottom) members interconnected by diagonal and vertical members in every panel.

(6) The configuration shown in Fig. 1f which involves identical top and bottom chords with rectangular panels connected together by diagonal members forming crosses, and running at 45° to the X- and Y-directions of the structure.

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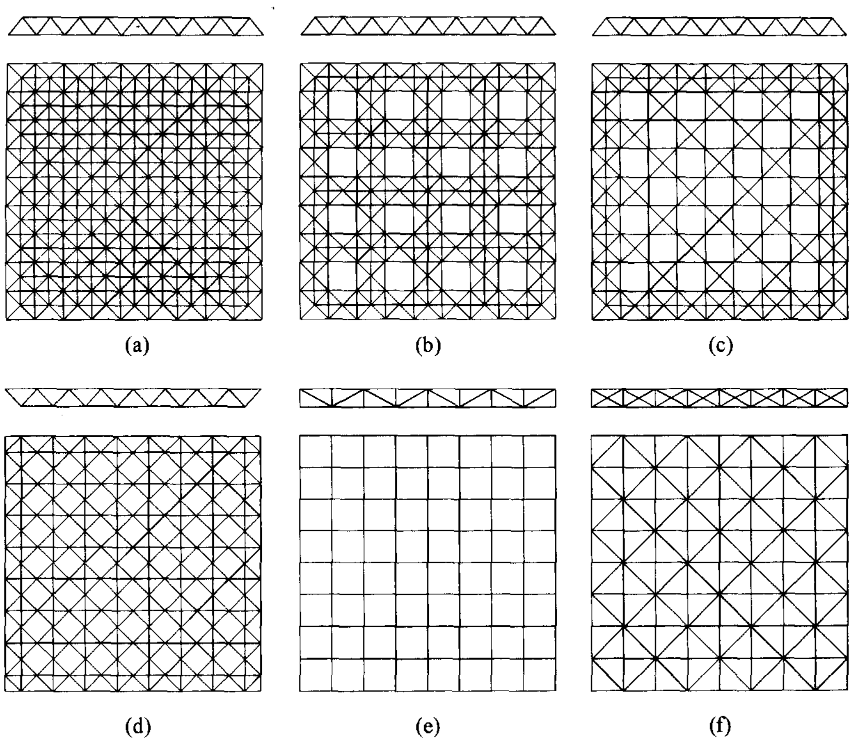


Fig. 1 Common configurations of space trusses

Different space truss configurations result in a considerable variation in the truss structural performance, constructional characteristics, competitiveness against alternative solutions, and hence the suitability for a specific application (Makowski 1981). For instance, altering the truss configuration leads to a change in its member stress distribution, stiffness, material consumption (and hence weight), degree of redundancy and sensitivity to local damage. Other non-structural factors that are affected by truss configuration include the structure's architectural appearance, flexibility with regard to support locations, number of joints and members, and ability to accommodate service ducts.

This paper presents the first results of a comprehensive study currently being carried out to assess the effects of adopting different space truss configurations. The discussion in this paper is focused on five parameters, namely; the truss stiffness, stiffness/weight value, member stress distribution, degree of statical redundancy and cost. Other factors are currently under consideration, and the results of that work will be presented in a future publication.

The study presented in this paper is parametric with a wide variation of many important parameters including the truss aspect ratio, boundary conditions, span/depth ratio, and essentially, the truss configuration. The work carried out earlier by West (1967) is of special importance to the present study, and its findings have been of much value in designing the present work and arriving at its final conclusions.

2. Parameters considered

The present parametric study involves 144 space trusses designed to cover four main parameters, namely:

(1) Space truss configuration: SOS, SOLS, SOD and DOS, sketched in Fig. 1a to 1d, respectively,
(2) Aspect ratio: 1:1, $1\frac{1}{2}$:1 and 2:1,
(3) Boundary conditions: with corner and edge supports, in addition to two intermediate cases (see Fig. 2), and
(4) Short-span/depth ratio: 16, 20 and 24.

The space trusses have three overall plan sizes of 50m × 50m, 50m × 75m and 50m × 100m. In each case, three truss depths of 2.083m, 2.50m and 3.125m are considered.

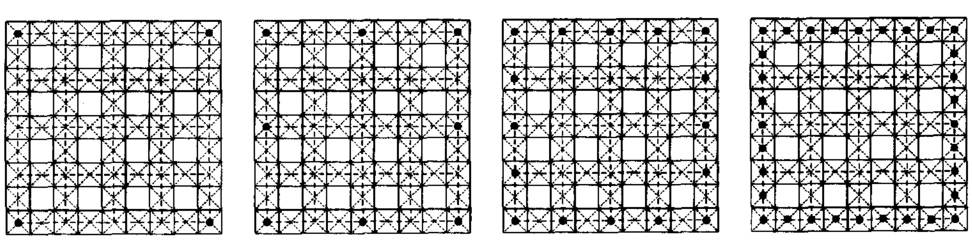
The space trusses have been designed to simulate the conditions of large-span roof structures with a total factored load of 5.0 kN/m^2 (1.4 × 0.7 kN/m^2 dead load+1.6 × 2.5 kN/m^2 live load), applied as concentrated loads on the top chord joints. Simple linear analyses, based on the finite element method and using ABAQUS package, have been conducted to determine the internal forces in all truss members, and according to these forces, truss members have been sized assuming steel grade S355N throughout. Six different member sizes are chosen for every truss, the heaviest of which are at truss edges in the corner-supported cases, and in truss central regions in other cases with different boundary conditions. The diagonal members that are directly in contact with support joints are also heavy.

The trusses included in this study have been analysed twice; once with the same cross sectional area for all members, and another after completing the design process described above. The first set of analyses, although refer to an impractical situation, have been carried out to assist parts of the discussion in this paper, as will be shown later.

The next five sections of the paper present the results obtained from analysing the space trusses considered. The analyses discussed there have been carried out in order to assess the effect of space truss configuration on truss stiffness, stiffness/weight value, member stress distribution, degree of statical redundancy and cost.

3. Stiffness

Using the stiffness of space trusses as a measure of their structural efficiency is valid provided that a number of points are taken into consideration. Firstly, all trusses involved should be designed to have the same strength. Secondly, it ought to be acknowledged that with different configurations, the number of space truss joints and overall weight vary. And as these two factors have a direct bearing on truss cost, they should be included in other efficiency measures such as stiffness/weight value, stiffness/number-of-joints value and



(a) Corner-supported truss (b) Intermediate case 1 (c) Intermediate case 2 (d) Edge-supported truss

Fig. 2 Different boundary conditions considered stiffness/cost value.

The purpose of this section is to address two vital questions: how the stiffness of a particular truss compares with that of other similar trusses with the same strength but with different configurations and/or boundary conditions? and how sensitive each truss is (particularly in terms of stiffness variation) to having more supports? Later in this paper, the questions about how space trusses with the same weight, or the same number of joints, differ in performance are addressed.

Table 1 presents the analytically obtained stiffness values for the 144 space trusses studied herein. (The stiffness values presented refer to the uniformly distributed load required to produce a unit central deflection.) The results of this table show clearly that space truss stiffness varies considerably with different truss configurations, aspect ratios, boundary conditions and span/depth ratios. It is clear that SOS space trusses enjoy the highest flexural stiffness, followed in a descending order by SOD, SOLS and DOS trusses. The closest results occur in the corner-supported cases with a span/depth ratio of 16. For all other cases, the higher stiffness of SOS trusses becomes more evident. The results also depict a clear similarity in performance between SOS and SOLS trusses, and between SOD and DOS trusses, mainly because each group adopts a similar arrangement of chord members. However, there is a clear superiority of SOS and SOD trusses over equivalent SOLS and DOS trusses in all cases considered.

Furthermore, the stiffness values presented in Table 1 have been analysed to extract the average improvements in stiffness associated with more supports, lower aspect ratios and lower span/depth ratios (see Table 2). The results of this analysis indicate that DOS trusses benefit from having more supports and lower aspect ratios, much more than trusses with other

Table 1 Stiffness of space trusses designed

Truss details*	Stiffness (kN/mm)				Truss details*	Stiffness (kN/mm)			
	Corner+	Inter 1+	Inter 2+	Edge+		Corner+	Inter 1+	Inter 2+	Edge+
SOS, 1:1, 16	6.9	18.5	24.1	30.3	SOD, 1:1, 16	5.7	16.4	21.1	23.8
SOS, 1½1, 16	3.5	14.6	20.4	27.8	SOD, 1½1, 16	2.3	13.0	17.2	20.4
SOS, 2:1, 16	1.7	13.9	21.6	34.1	SOD, 2:1, 16	1.0	10.8	13.8	23.4
SOS, 1:1, 20	5.6	15.7	20.2	26.6	SOD, 1:1, 20	4.5	14.3	16.9	21.1
SOS, 1½1, 20	2.8	12.4	16.8	24.4	SOD, 1½1, 20	1.6	10.4	12.7	18.3
SOS, 2:1, 20	1.4	11.7	18.3	30.0	SOD, 2:1, 20	0.7	9.2	11.7	20.7
SOS, 1:1, 24	4.7	13.5	17.2	23.4	SOD, 1:1, 24	3.7	12.4	15.8	18.7
SOS, 1½1, 24	2.3	10.6	14.5	21.4	SOD, 1½1, 24	1.2	9.7	11.7	16.1
SOS, 2:1, 24	1.2	10.0	15.7	26.5	SOD, 2:1, 24	0.5	7.8	10.0	18.3
SOLS, 1:1, 16	5.0	14.1	17.4	22.5	DOS, 1:1, 16	3.4	12.8	20.8	22.1
SOLS, 1½1, 16	2.6	9.7	13.0	20.8	DOS, 1½1, 16	0.9	8.1	14.4	16.8
SOLS, 2:1, 16	1.3	10.7	16.4	25.7	DOS, 2:1, 16	0.4	7.3	12.1	15.7
SOLS, 1:1, 20	4.0	11.6	16.1	20.0	DOS, 1:1, 20	2.9	10.8	15.2	20.7
SOLS, 1½1, 20	2.0	9.1	12.9	18.4	DOS, 1½1, 20	0.7	7.6	10.9	15.6
SOLS, 2:1, 20	1.0	8.7	13.6	22.9	DOS, 2:1, 20	0.3	6.1	9.8	14.1
SOLS, 1:1, 24	3.3	9.8	12.0	17.6	DOS, 1:1, 24	2.5	9.2	13.8	18.9
SOLS, 1½1, 24	1.7	6.8	9.9	16.3	DOS, 1½1, 24	0.6	7.3	10.3	13.9
SOLS, 2:1, 24	0.8	7.3	11.4	20.3	DOS, 2:1, 24	0.2	5.3	8.5	12.6

*Note: Truss details are given in the following order: configuration, aspect ratio and short-span/depth ratio.
+Refer to Fig. 2 for a description of the boundary conditions considered

Table 2 Average improvements in space truss stiffness

Parameters considered	Average improvements in stiffness			
	SOS	SOLS	SOD	DOS
Cases with edge supports / Cases with corner supports	1050%	1120%	1410%	2660%
1:1 aspect ratio / 1½:1 aspect ratio	107%	115%	144%	211%
1:1 aspect ratio / 2:1 aspect ratio	267%	267%	431%	701%
Span/depth=16 / Span/depth=20	19%	16%	23%	20%
Span/depth=16 / Span/depth=24	39%	41%	44%	38%

configurations. However, no notable difference could be seen between the response of space trusses with different configurations to changes in the span/depth ratio.

4. Stiffness/weight value

The stiffness/weight values of space trusses are a good measure of their structural efficiency with higher values being indicative of a better use of material. Table 3 presents the stiffness/

Table 3 Stiffness/weight values for space trusses designed

Truss details	Weight kN	Stiffness/Weight (1/m)				Truss details	Weight kN	Stiffness/Weight (1/m)			
		Corner+	Inter 1+	Inter 2+	Edge+			Corner+	Inter 1+	Inter 2+	Edge+
SOS, 1:1, 16	507	13.6	36.4	47.5	59.9	SOD, 1:1, 16	416	13.7	39.6	50.7	57.2
SOS, 1½ 1: 16	739	4.8	19.8	27.7	37.6	SOD, 1½ 1:1, 16	597	3.9	21.8	28.9	34.2
SOS, 2:1, 16	971	1.8	14.4	22.2	35.1	SOD, 2:1, 16	779	1.2	13.8	17.7	30.0
SOS, 1:1, 20	657	8.6	23.9	30.7	40.5	SOD, 1:1, 20	525	8.6	27.1	32.2	40.2
SOS, 1½ 1:1, 20	964	2.9	12.8	17.4	25.3	SOD, 1½ :1, 20	762	2.2	13.7	16.6	24.0
SOS, 2:1, 20	1271	1.1	9.2	14.4	23.6	SOD, 2:1, 20	998	0.7	9.2	11.7	20.7
SOS, 1:1, 24	807	5.8	16.7	21.3	28.9	SOD, 1:1, 24	635	5.8	19.5	24.9	29.5
SOS, 1½ 1:1, 24	1190	2.0	8.9	12.2	18.0	SOD, 1½ 1:1, 24	926	1.3	10.5	12.6	17.3
SOS, 2:1, 24	1573	0.7	6.4	10.0	16.8	SOD, 2:1, 24	1218	0.4	6.4	8.2	15.0
SOLS, 1:1, 16	421	11.8	33.5	41.3	53.5	DOS, 1:1, 16	310	11.0	41.3	66.9	71.2
SOLS, 1½ 1, 16	611	4.2	15.8	21.3	34.0	DOS, 1½ 1, 16	440	2.0	18.5	32.8	38.1
SOLS, 2:1, 16	800	1.6	13.4	20.5	32.2	DOS, 2:1, 16	570	0.6	12.7	21.3	27.6
SOLS, 1:1, 20	541	7.5	21.5	29.7	36.9	DOS, 1:1, 20	382	7.7	28.3	39.9	54.1
SOLS, 1½ 1, 20	790	2.6	11.5	16.3	23.3	DOS, 1½ 1, 20	548	1.3	13.9	19.8	28.4
SOLS, 2:1, 20	1040	1.0	8.4	13.1	22.0	DOS, 2:1, 20	715	0.4	8.6	13.7	19.8
SOLS, 1:1, 24	661	5.1	14.8	18.1	26.7	DOS, 1:1, 24	455	5.5	20.2	30.4	41.6
SOLS, 1½ 1, 24	971	1.7	7.0	10.2	16.8	DOS, 1½ 1:1, 24	588	1.0	12.4	17.5	23.7
SOLS, 2:1, 24	1280	0.6	5.7	8.9	15.9	DOS, 2:1, 24	860	0.2	6.1	9.8	14.6

+Refer to Fig. 2 for a description of the boundary conditions considered weight values for all cases studied. From the table, it can be seen that no single configuration is best in all situations. However, it is clear that while DOS trusses have the highest average stiffness/weight value ($21.2m^{-1}$), their performance shows the highest sensitivity to truss details (such as aspect ratio and boundary conditions), and their use should therefore be considered carefully in the light of this characteristic. On the other hand, SOS and SOLS trusses (with average stiffness/weight values of $18.9m^{-1}$ and $16.9m^{-1}$, respectively) demonstrate the least sensitivity to truss details. Finally, SOD trusses with an average value of $18.6m^{-1}$ are found to have a degree of sensitivity to truss details between the above two cases.

It is interesting to see that the relative efficiency of DOS and SOD trusses (in terms of stiffness/weight values) is best in structures with a 1:1 aspect ratio. In rectangular areas with aspect ratios 1½:1 and 2:1, SOS and SOLS trusses become more efficient. The results of Table 3 also show that DOS and SOD trusses benefit most from having more supports. However, the finding that the stiffness/weight values of edge-supported SOS trusses outperform those of equivalent SOD trusses (by an average of 7.3%) should not be considered a contradiction to the above statement as half the supports in the latter case are not directly connected to the main bottom members, and hence have only a little contribution to truss stiffness.

The results presented in Table 3 also show that comparing the stiffness/weight values of SOS and SOLS trusses yields consistent results, with SOLS trusses being less efficient by 7-16% in most cases. This finding is attributed to the fact that both configurations are based on similar orthogonal arrangements of chord members. The removal of a regular set of diagonal members, and the bottom members attached to them, in SOLS trusses helps reduce the overall weight, but the effect of removing these members on truss stiffness leads to an overall adverse effect on truss stiffness/weight efficiency.

5. Member stress distribution

Stress distribution in space truss members is another good measure of truss efficiency. Since in practical applications, the number of variations in member size is quite limited, it would be better to employ a truss configuration that produces a more uniform distribution of member stresses in order to improve the efficiency of using material as this in turn can result in reduced cost and weight.

The results presented in Table 4 are of statistical analyses carried out on space trusses with

Table 4 Standard deviation of member stresses in the space trusses designed

Truss details	Supports at	Bottom Members		Top Members		Diagonal Members	
		1 Size	2 Sizes	1 Size	2 Sizes	1 Size	2 Sizes
SOS, 1:1, 16	Corner	0.837	0.374	0.836	0.589	0.404	0.325
SOS, 1:1, 16	Edge	0.268	0.291	0.375	0.357	0.170	0.170
SOLS, 1:1, 16	Corner	1.365	0.701	0.968	0.490	0.444	0.383
SOLS, 1:1, 16	Edge	0.471	0.557	0.424	0.372	0.188	0.188
SOD, 1:1, 16	Corner	1.198	0.655	0.960	0.515	0.476	0.411
SOD, 1:1, 16	Edge	0.355	0.412	0.433	0.391	0.210	0.210
DOS, 1:1, 16	Corner	1.504	0.569	1.656	1.685	1.083	0.712
DOS, 1:1, 16	Edge	0.446	0.528	0.476	0.500	0.441	0.441

the four configurations considered. Focus in this study is limited to square trusses with span/depth ratio of 16. However, the results obtained depict a clear enough trend to justify general conclusions.

The results shown correspond to two stages in truss analysis: (1) with all members having the same cross section, and (2) after design is carried out and six different member sizes are used (two in each of the top and bottom chord and two for diagonal members). It is clear that when the edge members in every group ($\approx$ 5-10%) are sized separately, the internal forces in the remaining members (which form the bulk of the truss) have a much lower standard deviation, especially in the corner-supported cases. This finding is thought to be reasonable as with more member sizes allowed, the variation of member forces in each sub-group is likely to decrease, leading to a more efficient use of material. However, there is a practical limit to the number of sizes designers can employ in a truss.

In general, the results show that SOS trusses have the least standard deviation values, followed in an ascending order by SOLS, SOD and DOS trusses. It could be seen that while SOLS and SOD trusses vary in performance within narrow limits, and are only slightly behind SOS trusses, DOS trusses are clearly much less efficient.

Notice also that due to the many more load paths available in edge-supported trusses, the standard deviation values in these cases are much smaller compared with cases with corner supports. Average reductions of 69%, 59% and 58% are extracted from the data of Table 4 for bottom, top and diagonal members, respectively when all truss members are sized equally. When, on the other hand, truss members are given six different sizes, the corresponding average reductions are 22%, 39% and 46%.

6. Degree of statical redundancy

The degree of statical redundancy is an important characteristic of any structural system including space trusses. It defines the maximum number of truss members that can be

Table 5 Degrees of statical redundancy for space trusses with different configurations

	SOS trusses (Fig. la)	SOLS trusses (Fig. Ib)	SOD trusses (Fig. Ic)	DOS trusses (Fig. Id)
Number of bottom members	$2B_xB_y+B_x+B_y$	$B_xB_y+B_x+B_y$	$B_xB_y+2B_x+2B_y$	$\frac{1}{2}B_xB_y+\frac{1}{2}B_x+\frac{1}{2}B_y$
Number of top members	$2B_xB_y+3B_x+3B_y+4$	$2B_xB_y+3B_x+3B_y+4$	$2B_xB_y+3B_x+3B_y+4$	$B_xB_y+3B_x+3B_y+4$
Number of diagonal members	$4B_xB_y+4B_x+4B_y+4$	$3B_xB_y+4B_x+4B_y+4$	$2B_xB_y+6B_x+6B_y$	$B_xB_y+2B_x+2B_y+4$
Total number of members	$\mathbf{8B_xB_y+8B_x+8B_y+8}$	$\mathbf{6B_xB_y+8B_x+8B_y+8}$	$\mathbf{5B_xB_y+11B_x+11B_y+4}$	$\mathbf{2\frac{1}{2}B_xB_y+5\frac{1}{2}B_x+5\frac{1}{2}B_y+8}$
Total number of joints	$\mathbf{2B_xB_y+3B_x+3B_y+5}$	$\mathbf{1\frac{3}{4}B_xB_y+3B_x+3B_y+5}$	$\mathbf{1\frac{1}{2}B_xB_y+3\frac{1}{2}B_x+3\frac{1}{2}B_y+4}$	$\mathbf{\frac{3}{4}B_xB_y+2B_x+2B_y+5}$
Redundancies with corner supports	$\mathbf{2B_xB_y-B_x-B_y+5}$	$\mathbf{\frac{3}{4}B_xB_y-B_x-B_y+5}$	$\mathbf{\frac{1}{2}B_xB_y+\frac{1}{2}B_x+\frac{1}{2}B_y+4}$	$\mathbf{\frac{1}{4}B_xB_y-\frac{1}{2}B_x-\frac{1}{2}B_y+5}$
Redundancies with supports in mtermediate case 1	$2B_xB_y-B_x-B_y+17$	$\frac{3}{4}B_xB_y-B_x-B_y+17$	$\frac{1}{2}B_xB_y+\frac{1}{2}B_x+\frac{1}{2}B_y+16$	$\frac{1}{4}B_xB_y-\frac{1}{2}B_x-\frac{1}{2}B_y+17$
Redundancies with supports in case 2	$2B_xB_y-B_x-B_y+41$	$\frac{3}{4}B_xB_y-B_x-B_y+41$	$\frac{1}{2}B_xB_y+\frac{1}{2}B_x+\frac{1}{2}B_y+40$	$\frac{1}{4}B_xB_y-\frac{1}{2}B_x-\frac{1}{2}B_y+41$
Redundancies with edge supports	$\mathbf{2B_xB_y+5B_x+5B_y-7}$	$\mathbf{\frac{3}{4}B_xB_y+5B_x+5B_y-7}$	$\mathbf{\frac{1}{2}B_xB_y+6\frac{1}{2}B_x+6\frac{1}{2}B_y-8}$	$\mathbf{\frac{3}{4}B_xB_y+2\frac{1}{2}B_x+2\frac{1}{2}B_y-7}$

removed before the structure forms a mechanism. Earlier work by Schmidt *et al.* (1976) found that space truss statical redundancy makes trusses more susceptible to the effects of member lack of fit. Against this drawback is the fact that with higher degrees of redundancy, the degree by which individual members are critical to truss integrity reduces, leading to more tolerance to individual member losses, and local damage in general (see, El-Sheikh 1995, 1997a). From the work presented in these references, it seems that in overall the advantages of higher degrees of redundancy outweigh their drawbacks.

The degree of statical redundancy in space trusses can be calculated using the following formula:

$$s = m - 3j + c$$

where s is the degree of statical redundancy of a space truss with m members, j joints and c restrained degrees of freedom. This equation assumes that truss joints have only three degrees of freedom (u, v, w) each, and consequently truss members are unable to transmit bending or torsional moments. This simplification is normally adopted in space truss design and justified by the finding that considering the bending and torsional stiffness of members yields insignificant differences in truss overall behaviour (El-Sheikh 1997b).

Applying the above equation to calculate the number of statical redundancies in space trusses with different configurations yields the following general equations presented in Table 5. In these equations, B_x and B_y are the number of bays (panels) of the bottom chord in the X- and Y-direction, respectively.

Applying these equations in all 144 cases studied results in the distribution of joint numbers, member numbers and numbers of redundancies in the corner- and edge-supported

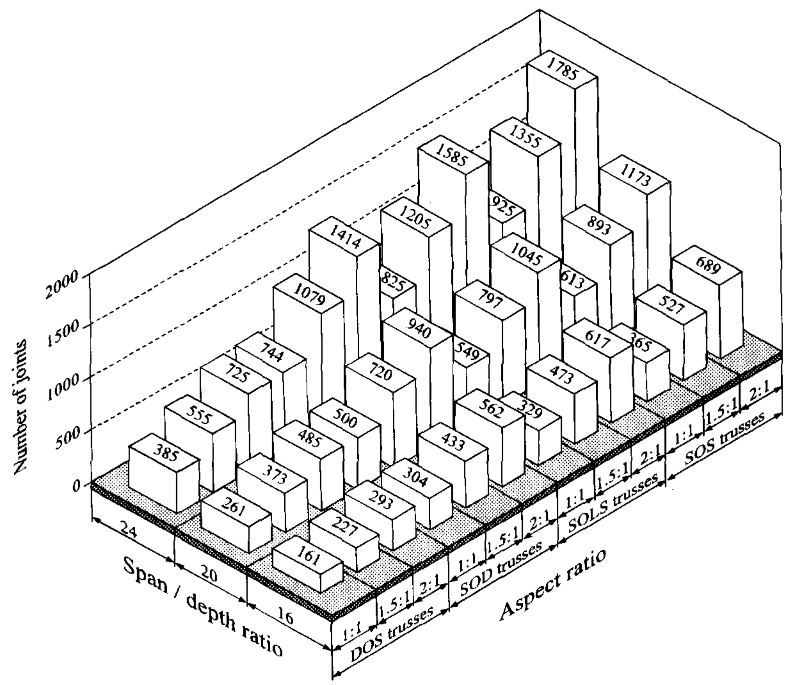


Fig. 3 Number of joints in space trusses with different configurations

cases, shown in Figs. 3 to 6, respectively. These results reveal that SOS trusses have, by far, the largest number of joints, more than SOLS, SOD and DOS trusses by average values of 12%, 24% and 140%. Considering that the cost of joints forms a large percentage of the cost of the total structure (more than 50% according to Iffland 1982 and others), the relative efficiency of SOS and DOS trusses may be viewed in a manner different from that depicted earlier in this paper. For instance, as DOS trusses typically have much less stiffness than SOS trusses with the same strength, the relatively smaller number of joints of DOS trusses may allow a significant increase in their member sizes such that their stiffness is enhanced without damaging their cost competitiveness. Same argument may also be applicable to SOLS and SOD trusses.

However, in order to arrive at concrete conclusions on the relative competitiveness of trusses with different configurations, an accurate estimation of the percentage of the total cost attributed to truss joints needs to be made.

As for the member numbers, Fig. 4 shows that SOS trusses again have the maximum numbers in all cases, more than SOLS, SOD and DOS trusses by average values of 29%, 44% and 187%, respectively. Having more members in a space truss has its *pros* and *cons*. With more members, the degree of statical redundancy grows with an overall positive effect on truss performance. However, using more members results in more costly fabrication and more assembly time, although individual members become lighter and easier to handle. Overall, it is rather difficult to rule that having more members is better or worse for the truss overall performance.

The results presented finally include the distribution of statical redundancy degrees (in percentage values of total numbers of degrees of freedom). Figs. 5 and 6 show this distribution in the corner- and edge-supported cases, respectively. The figures illustrate that

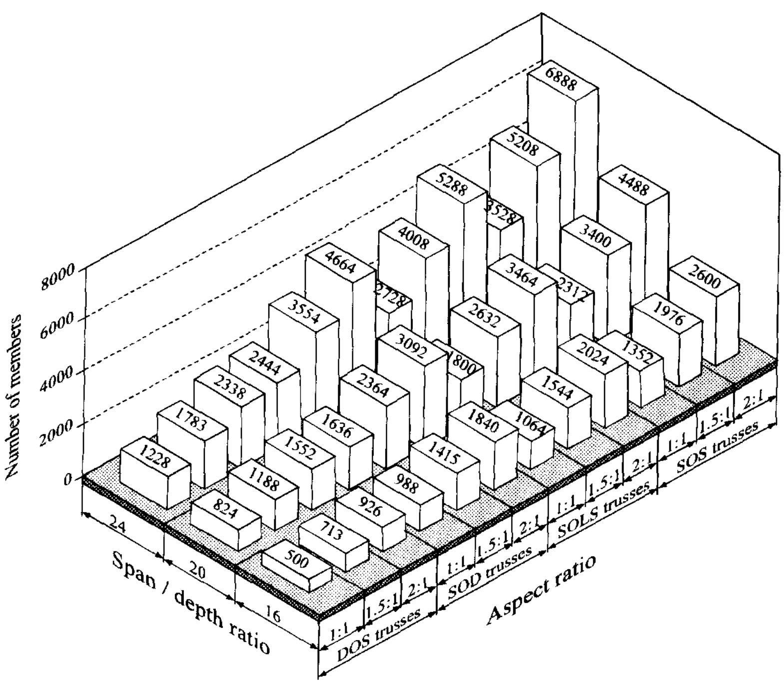


Fig. 4 Number of members in space trusses with different configurations

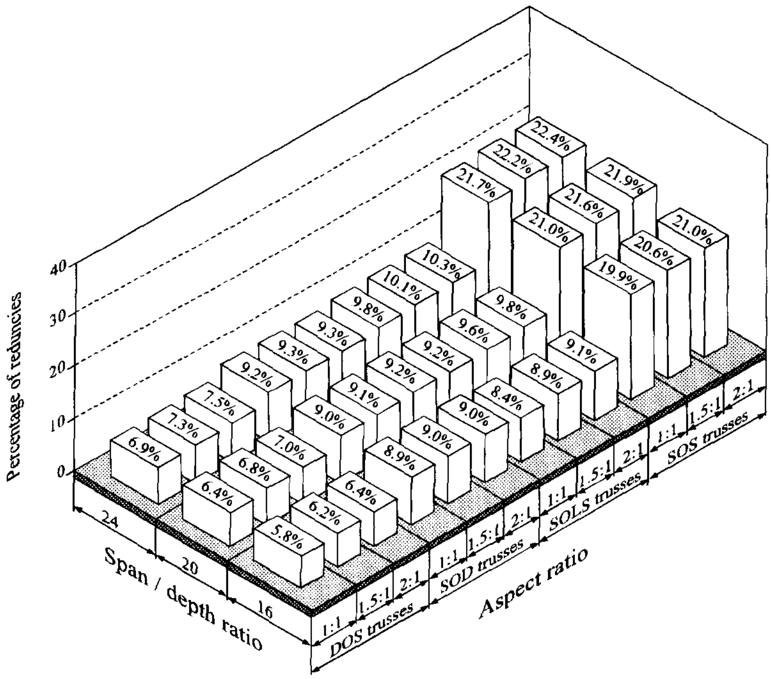


Fig. 5 Degrees of statical redundancy of corner-supported space trusses

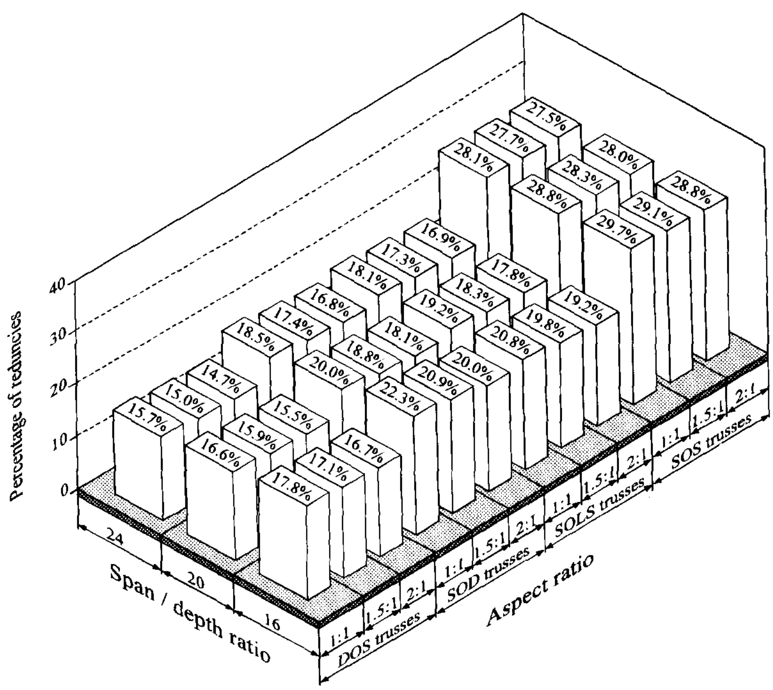
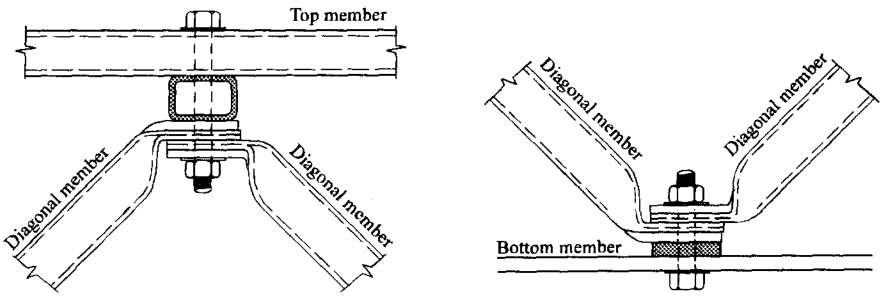


Fig. 6 Degrees of statical redundancy of edge-supported space trusses

the degree of statical redundancy varies only within narrow limits with changes in the span/depth ratio and aspect ratio.



(a) Top Joint (b) Bottom Joint

Fig. 7 Jointing system of Catrus space trusses

Overall, it is apparent that SOS trusses enjoy the highest degrees of statical redundancy, more than SOLS, SOD and DOS trusses by average values of 126%, 135% and 219%, in the corner-supported cases, and 53%, 48% and 77% in the edge-supported cases. It is also clear that trusses with DOS and SOD configurations benefit more than SOS and SOLS trusses from having more supports. The average degrees of improvement in truss redundancy between cases with edge and corner supports are 33% (SOS), 96% (SOLS), 111% (SOD) and 140% (DOS). This finding indicates that while SOS and SOLS trusses may be more suitable in applications with corner supports, the balance may turn in favour of SOD and DOS trusses in edge-supported applications.

6. Cost

Commercial space truss systems can generally be divided into two main groups:

- Systems with short chord members joined together by node connectors, and
- Systems with continuous chord members that do not need nodes for their assembly.

Most available space truss systems belong to the first group; typical examples include Mero, Nodus, Triodetic and Power Strut systems. The node connectors needed in this group are usually sophisticated and expensive, and typically account for a large percentage of the structure's cost. This characteristic must be born in mind when choosing a configuration for a certain truss, and usually a compromise has to be struck between truss cost and performance as both are directly affected by the configuration used. At the extreme ends SOS trusses stand with the maximum number of nodes and the best behaviour, against DOS trusses with the least number of nodes and the highest sensitivity to support locations, aspect ratios and span/depth ratios.

In order to resolve the above described conflict between cost and performance, space truss systems belonging to the second group have recently been designed, e.g. Harley and Catrus systems. These systems do not rely on special node connectors for assembly. Instead, the chord members simply cross each other and get connected together, and with the diagonals, by bolting or welding, see for example Fig. 7. In this space truss group, the joints do not represent a major cost item, and therefore having more joints would not necessarily jeopardise the structure cost competitiveness. In this case, using the SOS configuration ought to be more favourable with the only valid efficiency measures being the stiffness/weight and strength/weight values.

7. Conclusions

Several parameters need to be considered before adopting a certain space truss configuration. It has been shown that space trusses with the same strength and different configurations possess widely variant characteristics such as stiffness/weight values, sensitivity to boundary conditions, number of joints and members, degree of redundancy and distribution of member stresses. The question of cost is also prominent. In some cases it is closely related to the number of joints if the space truss relies on node connectors for assembly. Otherwise, if the truss uses continuous chord members and no node connectors are employed, the cost becomes directly related to the weight, and perhaps the number of members. Additionally, the following conclusions have been drawn from the results presented in this paper:

1. For space trusses designed to have the same strength, SOS trusses usually have the highest flexural stiffness followed by SOD, SOLS and DOS trusses.
2. In average, DOS space trusses enjoy the highest stiffness/weight values followed by SOS, SOD and finally SOLS trusses.
3. In general, SOD and DOS configurations appear to be most suitable for edge-supported structures with 1:1 aspect ratio. At the other end, SOS and SOLS trusses excel in applications with larger aspect ratios and with corner supports.
4. Although DOS space trusses possess clear advantages for having the least number of joints, and the highest stiffness/weight values, their use should be handled with care due to their high sensitivity to truss boundary conditions, aspect ratio and span/depth ratio.
5. Due to the similarity in chord member arrangement between SOS and SOLS trusses, they appear to behave in a similar manner. Same observation is applicable to SOD and DOS trusses.
6. Removing diagonal and bottom chord members from SOS trusses in order to arrive at the SOLS configuration has an overall adverse effect on truss stiffness/weight value.
7. Overall, SOS space trusses clearly demonstrate the best performance relative to trusses with other configurations. It only remains to be decided whether their use is economical. The detrimental factor is undoubtedly the cost of truss joints, and hence the space truss system to be employed.

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