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Space truss design using STAAD.Pro Software

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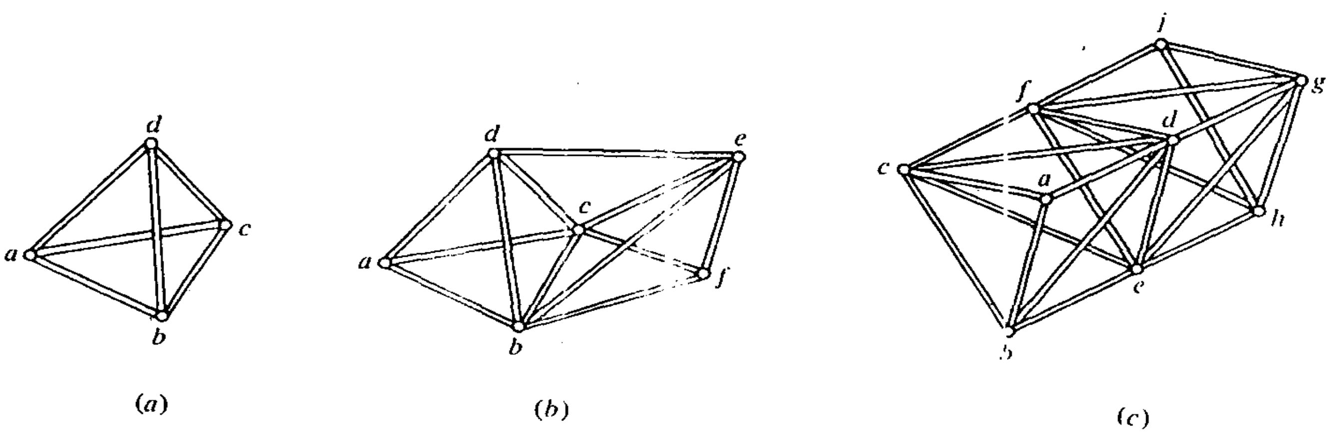
Abstract - *The search for new structural forms to accommodate large unobstructed areas has always been the main objective of architects and engineers. With the advent of new building techniques and construction materials, space frames frequently provide the right answer and satisfy the requirements for lightness, economy, and speedy construction. In the past few decades, the proliferation of the space frame was mainly due to its great structural potential and visual beauty. New and imaginative applications of space frames are being demonstrated in the total range of building types, such as sports arenas, exhibition pavilions, assembly halls, transportation terminals, airplane hangars, workshops, and warehouses. They have been used not only on long-span roofs, but also on mid- and short-span enclosures as roofs, floors, exterior walls and canopies. Here design and analysis of a space truss using STAAD.Pro software has been done as an example.*

1. INTRODUCTION

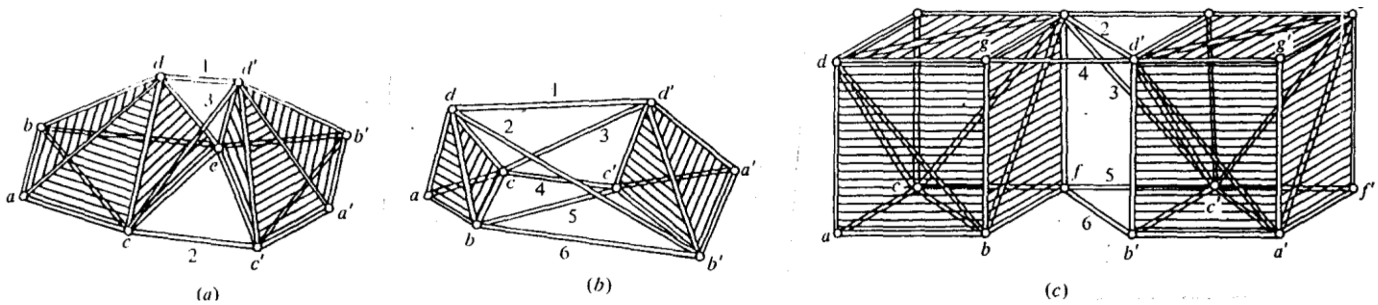
A space frame is a structure system assembled of linear elements so arranged that forces are transferred in a three-dimensional manner. In some cases, the constituent element may be two-dimensional. Macroscopically a space frame often takes the form of a flat or curved surface. Occasionally the term space truss appears in the technical literature. According to the structural analysis approach, a space frame is analyzed by assuming rigid joints that cause internal torsions and moments in the members, whereas a space truss is assumed as hinged joints and therefore has no internal member moments. The choice between space frame and space truss action is mainly determined by the joint-connection detailing and the member geometry is no different for both. However, in engineering practice, there is no absolutely rigid or hinged joints. For example, a double layer flat surface space frame is usually analyzed as hinged connections, while a single layer curved surface space frame may be analyzed either as hinged or rigid connections. The term *space frame* will be used to refer to both space frames and space trusses. Space truss is commonly used in three dimensional structural element. The forces are subjected axially in space truss elements, which are assumed pin connected where all the loads act only at joints. Due to application of forces, deformation happens in the axial direction and space trusses cannot sustain the shear and moment

1.1 Types of space trusses

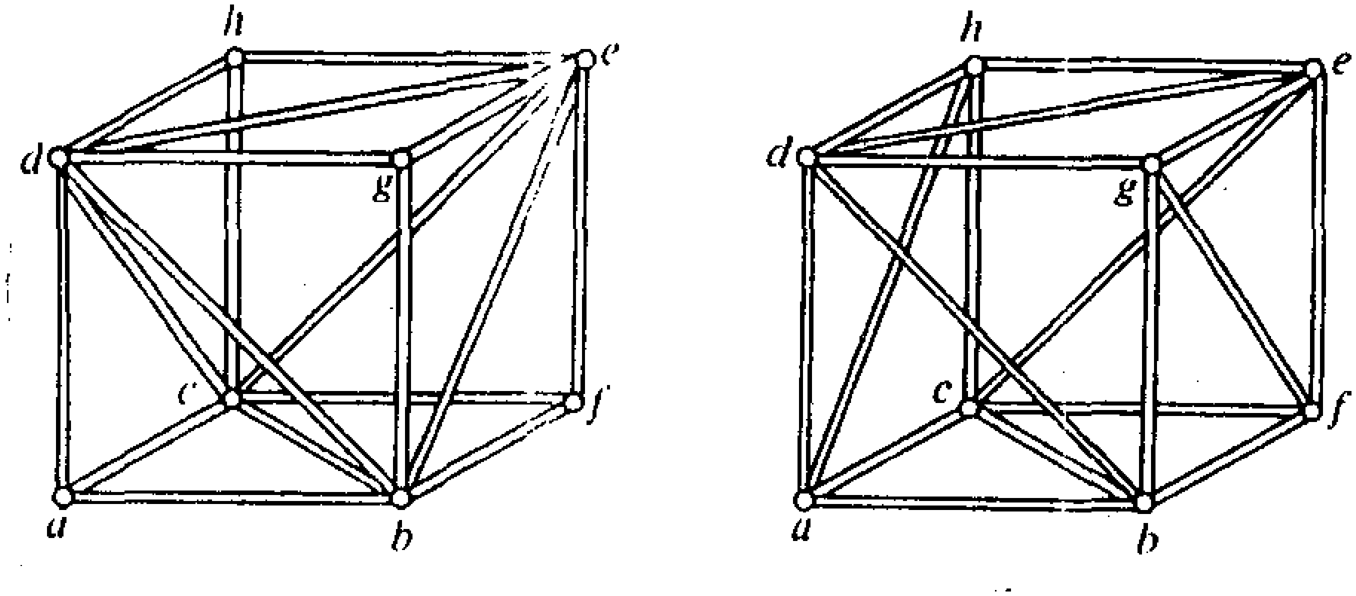
The commonly used space truss elements can be broadly classified into three types viz. Simple, Compound and Complex. Simple space is made from tetrahedron. This can be enlarged by adding members. Compound space truss is made by joining simple space truss elements. Complex space truss doesn't belong to the above categories.



Simple space truss



Compound space truss



Complex space truss

1.2 Determinacy and Stability aspects of space truss

For internal determinacy, if m = number of members; j = number of joints; r = number of supports;

If $m=3j+r$ then the truss is stable and internally determinate
If $m<3j+r$ then it is unstable and
If $m>3j+r$ the truss is internally indeterminate
Internal stability can sometimes be checked by careful inspection of the member arrangement.
External redundancy can be determined in terms of r

Externally

$r < 6$ Unstable Truss
$r = 6$ Determinate if Truss is Stable
$r > 6$ Indeterminate Truss

The assumptions for the design are

1.The members are joined together by smooth pins (no friction – cannot resist moment)
2.All loadings and reactions are applied centrally at the joints
3.The centroid for each members are straight and concurrent at a joint. Therefore, each truss member acts as an axial force member:

If the force tends to elongate> Tensile (T)
If the force tends to shorten >Compressive (C)

2. DESIGN OF A SPACE TRUSS USING STAAD.Pro

STAAD or Structural analysis and Design software application is a widely used software for the purpose of analysis and design of civil engineering structures. It supports over 90 international steel, concrete timber and Aluminum design codes. It can make use of various forms of analysis to more recent analysis like p-delta analysis, geometric nonlinear analysis. It can also make use of various forms of dynamic analysis methods from time history analysis to response spectrum analysis.

For the analysis of a structure in STAAD.Pro one has to illustrate the structure in it first. Consequently the entire loads are to be applied. Different loads applicable to the structure are predefined in the software. The loads are separately provided. Different load combinations if any, should be provided. The software gives the Bending moment diagram, Shear force diagram and the deflection profile of the structure.

Here, an example of analysis of a space trussed roof using the software is illustrated.

SPACE TRUSSED ROOF:
Shape: Curved (Arch)
Span: 21.5 m
Length: 52 m
Rise of the arch shape: 3.5m

One can draw the shape directly into the software or may be imported after drawing in CAD software. Next step is to apply loads. It has been found that there are 3 kinds of loads acting in the truss viz.

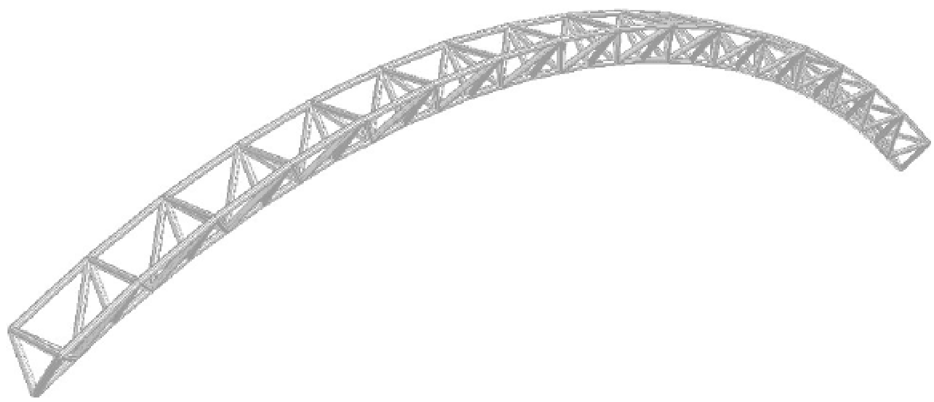
1. Dead load due to the weight of the roofing material and the self-weight of the truss itself
2. Live load in case of labor entrance to top of roofing for the construction or maintenance whose value is to be provided as per the design code
3. Wind load

2.1 LOAD CALCULATIONS

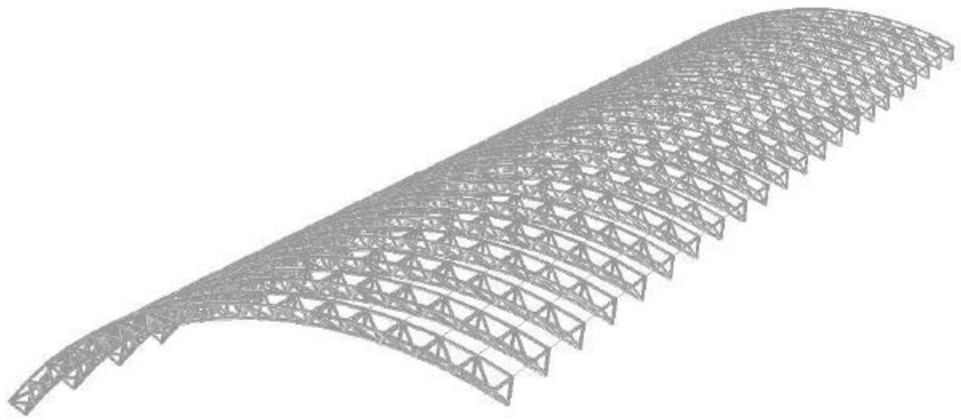
1. Dead load as per the code provision of roofing material = 0.762 kN
2. Live load= 0.106 kN
3. Wind load calculations

Basic Wind Speed in the region = 39 m/s
Design wind speed = 39.39 m/s
Design wind pressure = 930 N/m^2
Wind pressure coefficients
Internal coefficients, Cpi = ± 0.2
External coefficients for ached roof
At θ = 0°
Cpe1 = -0.861
Cpe2 = +0.22
At θ = 90°
Near gable end = -0.5
Near middle half = -0.1

Wind force at X-direction ($-Cp_i$) = 1.776 kN
Wind force at X-direction ($+Cp_i$) = 1.106 kN
Wind force at Z-direction ($-Cp_i$) = 1.506 kN
Wind force at Z-direction ($+Cp_i$) = 0.837 kN



Rendered view of space truss



Rendered view of roof

STAAD.Pro Input data:

Structure Type	SPACE FRAME

Number of Nodes	67	Highest Node	1409
Number of Elements	179	Highest Beam	3761

Number of Basic Load Cases	7
Number of Combination Load Cases	10

Section Properties

Prop	Section	Area (mm^2)	I_{yy} (mm^4)	I_{zz} (mm^4)	J (mm^4)	Material
1	PIPS40	1.92E+3	2.84E+6	2.84E+6	5.68E+6	STEEL
2	PIPS80	5.06E+3	28.3E+6	28.3E+6	56.7E+6	STEEL
3	PIPS35	1.62E+3	1.88E+6	1.88E+6	3.76E+6	STEEL
4	PIPS30	1.34E+3	1.19E+6	1.19E+6	2.37E+6	STEEL
5	PIPS20	645.160	261E+3	261E+3	522E+3	STEEL
6	PIPS25	1.03E+3	604E+3	604E+3	1.2E+6	STEEL
7	PIPX20	896.772	344E+3	344E+3	688E+3	STEEL
8	PIPX15	645.160	155E+3	155E+3	310E+3	STEEL
9	PIPS15	483.870	122E+3	122E+3	244E+3	STEEL
10	PIPS12	399.999	76.6E+3	76.6E+3	153E+3	STEEL
11	PIPX10	387.096	42E+3	42E+3	84E+3	STEEL
12	PIPS10	296.774	34.5E+3	34.5E+3	69.2E+3	STEEL
13	PIPX7	264.516	17.9E+3	17.9E+3	35.7E+3	STEEL
14	PIPS60	3.37E+3	11E+6	11E+6	22E+6	STEEL

DESIGN RESULTS:
STAAD Output Summary

```
P R O B L E M   S T A T I S T I C S
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NUMBER OF JOINTS         67  NUMBER OF MEMBERS     179
NUMBER OF PLATES          0  NUMBER OF SOLIDS        0
NUMBER OF SURFACES        0  NUMBER OF SUPPORTS      2
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ALL UNITS ARE - KN   METE (UNLESS OTHERWISE Noted)

MEMBER     TABLE        RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX            MY             MZ       LOCATION
=======================================================================

  3722 ST   PIPS30                     (AISC SECTIONS)
                          PASS     IS-7.1.2           0.620        12
                        6.52 T       0.00             2.59        1.45
  3723 ST   PIPX20                     (AISC SECTIONS)
                          PASS     IS-7.1.1(A)        0.894        16
                       17.63 C       0.00             1.39        0.00
  3724 ST   PIPS25                     (AISC SECTIONS)
                          PASS     IS-7.1.1(A)        0.774        16
                        0.34 C       0.00             2.03        0.00
  3725 ST   PIPS25                     (AISC SECTIONS)
                          PASS     7.1.2 BEND C       0.758        12
                        3.36 T       0.00             1.99        0.00
  3726 ST   PIPS15                     (AISC SECTIONS)
                          PASS     7.1.2 BEND C       0.765        12
                        1.15 T       0.00             0.59        0.00
  3727 ST   PIPS15                     (AISC SECTIONS)
                          PASS     IS-7.1.1(A)        0.820        16
                        1.44 C       0.00             0.62        0.96
  3729 ST   PIPX20                     (AISC SECTIONS)
                          PASS     IS-7.1.1(B)        0.794        14
                       64.40 C       0.00             0.58        0.00
  3730 ST   PIPX20                     (AISC SECTIONS)
                          PASS     7.1.2 BEND C       0.962        12
                        1.51 T       0.00             1.66        1.38
  3731 ST   PIPS25                     (AISC SECTIONS)
                          PASS     IS-7.1.1(A)        0.704        16
                        6.86 C       0.00             1.65        1.38
```

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STEEL TAKE-OFF
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   PROFILE                  LENGTH(METE)       WEIGHT(KN  )

181. 3620 TO 3628 3630 TO 3639 3641 TO 3650 3652 TO 3661 3663 TO 3672 3674 TO 3683 -
182. 3685 TO 3694 3696 TO 3705 3707 TO 3716 3718 TO 3727 3729 TO 3738 -
183. 3740 TO 3749 3751 TO 3760
ST  PIPS80                       3.37              1.312
ST  PIPS40                       3.82              0.562
ST  PIPS35                       4.01              0.499
ST  PIPS30                      41.50              4.278
ST  PIPS20                      10.77              0.534
ST  PIPS25                      36.44              2.872
ST  PIPX20                      28.82              1.985
ST  PIPX15                      15.13              0.750
ST  PIPS15                       9.60              0.357
ST  PIPS12                      11.30              0.347
ST  PIPX10                       4.57              0.136
ST  PIPS10                       6.25              0.143
ST  PIPX7                        0.96              0.020
ST  PIPS60                       1.92              0.497
                                     ----------------
                                 TOTAL =          14.291
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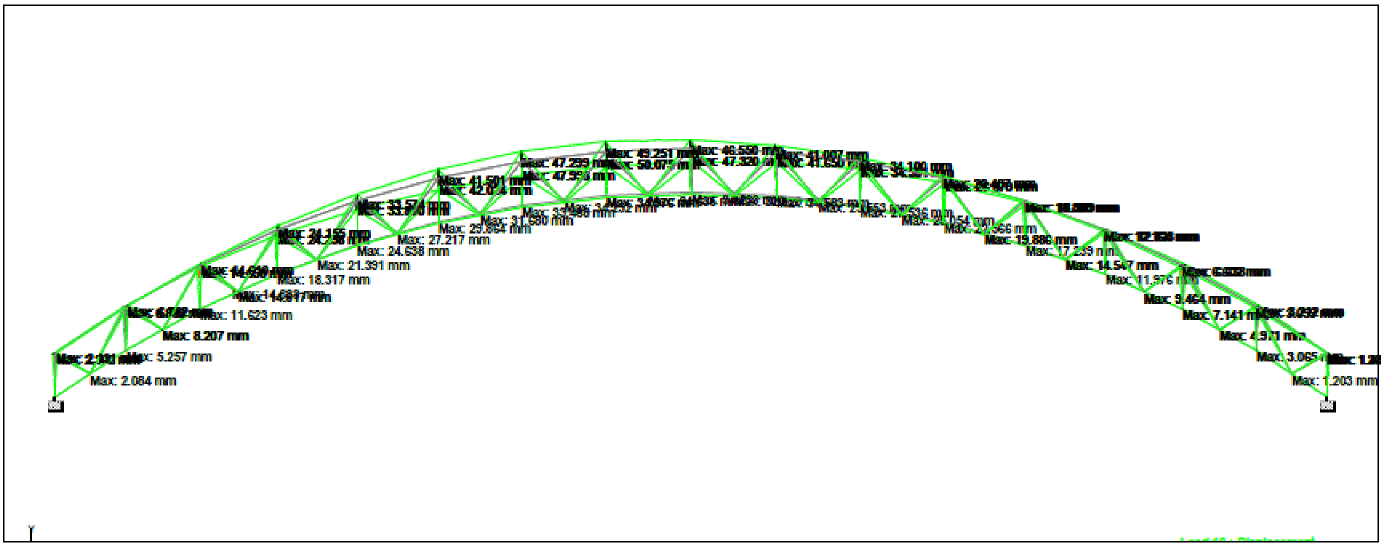

Whole Structure Displacements 0.0508mm:1mm 16 COMBINATION LOAD CASE 16 (Input data was modified after picture taken)

3. CONCLUSIONS

Space truss has many advantages over the other types on account of its light weight, mass production, stiffness and versatility. Moreover it is very much preferable in case of long spans when compared to others. On account of the simplicity and aesthetic aspects the arch shape is preferable. Analysis of civil engineering structures become much easier with the advent of the STAAD Pro. Software. STAAD outputs the Bending moment diagram shear force diagram and deflection profile of the structure. STAAD not only check whether the structure is safe or not for the given loads but also advises suitable dimensions in order to make the structure safe for the given loading conditions.

4. REFERENCES

[1] Bureau of Indian Standards, IS 875 (Part 1, 2, 3, 5): 1987 – Code of Practice for Design Load (Other than Earthquake) for Buildings and Structures

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