Dynamic Analysis of Multi-Layered Grid Space Structures

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Abstract. In the present study, an attempt has been made to understand the structural behavior of a two-way lattice grid space structure. Two-way lattice grid space structures are analyzed for dynamic earthquake loads such as time-history analysis by STAAD. Pro V8i software, using structural steel hollow tubular sections for a span of 30 m for 4.0 m height column and 3 storeys were considered for a total height of 12 m. Further the dynamic analysis such as displacements and modal analysis to find natural frequency and time period, were carried out for the eight different configurations and three different grid sizes of space truss structure.

1. Introduction
Space structures refers to a structure made of assemblage of linear members interconnected to each other in space. The self-weight of these roofs is less than conventional type of roofs. It is the new structural form which accommodate large unobstructed areas such as sports arenas, canopies, stadiums, exhibition pavilions, reservoir covers, airplane hangars, transportation terminals, workshops, warehouses, etc.

1.1 Structural loads considered
The structural loads considering in structures is discussed in this section. Loads basically divide into vertical loads and horizontal loads. Low and medium rise building designs generally affected by vertical loads like dead and live loads. High rise building design affected by both vertical and horizontal (wind and seismic) loads.

1.2 Time history analysis
This is one of the method of dynamic analysis, this method overcomes the disadvantages of response spectrum analysis. This method requires greater efforts for computations for calculate response of building at smaller intervals. In this method base of the structure is exposed to selected earthquake motion. For the full period of the earthquake, immediate stress throughout the structure is evaluated at smaller intervals. From the output records we can obtain maximum stress in any member. This method is not generally used in seismic analysis because of its lengthy computer running time.
1.3 Modelling of the structure in STAAD.Pro
The analysis is carried out using STAAD.Pro V8i software. In this work the total roof to be covered is 33 m × 33 m is considered. The double layer of grids is provided by connecting the two layers by inclined members. The dimension of bottom layer is 30 m × 30 m. The interior supports were given are 8 numbers in which 4 columns are provided at the edges and another 4 are provided at corners. The spacing provides between the columns is 12 m. Three stories of each 4 m height are considered for the analysis. At each story levels the lateral beams are connected on all the sides of the structure.

Table 1. Structure details

| Components                  | Details          |
|-----------------------------|------------------|
| Plan dimension              | 33 m × 33 m      |
| Number of grid layers       | 2                |
| Grid spacing                | 2 m, 3 m and 4 m|
| Grid depth                  | 2 m              |
| Story height                | 4 m              |
| No. of story                | 3 story          |
| Total height                | 14 m             |
| Column spacing              | 12 m             |
| Foundation depth            | 1.5 m            |

Figure 1. Isometric view of structure

1.4 Properties of the model.
The structural steel tubes were used for the members. Section PIP2445H is used for the columns and the beams which are connected laterally. Section PIP1524H is used for members of grid roof. The sectional properties of the members are discussed in table 2.

Table 2. Section properties from IS 1161- 1998.

| Sections | PIP1524H | PIP2445H |
|----------|----------|----------|
| Class    | Heavy    | Heavy    |
| Thickness (mm) | 5.4    | 5.9      |
| Weight (kg/m)   | 19.6    | 37.4     |
| Area of cross section (mm²) | 25.0  | 44.2     |
| Moment of Inertia (mm⁴)  | 674.5   | 3149     |
2. Dynamic Analysis of Structure
To study the dynamic characteristics of the structure like horizontal and vertical displacement for the model which has got the optimum depth is chosen which is 2.0 m. The time-history analysis is done for Bhuj earthquake data and Equivalent static method for zone 2 and zone 5. The seismic analysis is also done for 8 different space structure configurations and for module sizes of 2m, 3m and 4m which are given in the table below.

Table 3. Studied Grid Space Structure Cases

| S.no. | Configuration                     | Modulus sizes | Type of analysis     | Total Cases |
|-------|-----------------------------------|---------------|----------------------|-------------|
| 1     | Two-way double layered grids      | 2 m           | Time-history method   | 24          |
| 2     | Three-way double layered grids    |               |                      |             |
| 3     | Four-way double layered grids     | 3 m           |                      |             |
| 4     | Three-way on Periphery            |               |                      |             |
| 5     | Four-way on Periphery             |               |                      |             |
| 6     | Two-way three-layered grids       | 4 m           |                      |             |
| 7     | Three-way three-layered grids     |               |                      |             |
| 8     | Four-way three-layered grids      |               |                      |             |
2.1. Time-History function
In the time history analysis, an earthquake motion is applied directly to the base of the structure. For the full duration of the earthquake, instantaneous stress throughout the structure are evaluated at small intervals. From the output records we can obtain maximum stress in any member. In this study, Bhuj earthquake data is selected for analysis. The graph below shows acceleration vs time graph of Bhuj earthquake data.
Figure 9. Acceleration v/s Time graph of Bhuj earthquake data

Table 4. Time History Definitions: Type I

| Type                 | Acceleration | Data source       |
|----------------------|--------------|-------------------|
|                      |              | File Bhuj.txt     |

Table 5. Time History Parameters

| Damping | 0.05 |
|---------|------|
| Time step | -    |
| Arrival Time ( sec ) | 1,2,3 |

3. Results and discussion

3.1 Results of dynamic analysis of grid space structure

Table 6. Maximum horizontal displacements (mm) for 2 m, 3 m and 4 m grid size

| Sl.no | Configuration                      | 2.0 m | 3.0 m | 4.0 m |
|-------|------------------------------------|-------|-------|-------|
| 1     | Two-way double layered grids       | 52.08 | 52.65 | 50.56 |
| 2     | Three-way double layered grids     | 62.85 | 46.36 | 46.55 |
| 3     | Four-way double layered grids      | 63.44 | 62.64 | 47.49 |
| 4     | Three-way on Periphery             | 55.42 | 49.41 | 48.49 |
| 5     | Four-way on Periphery              | 60.09 | 46.29 | 49.36 |
| 6     | Two-way three-layered grids        | 63.23 | 55.92 | 52.15 |
| 7     | Three-way three-layered grids      | 64.37 | 64.42 | 61.99 |
| 8     | Four-way three-layered grids       | 82.82 | 63.81 | 63.77 |

Table 7. Maximum vertical deflection (mm) for 2 m, 3 m and 4 m grid size

| Sl.no | Configuration                      | 2.0 m | 3.0 m | 4.0 m |
|-------|------------------------------------|-------|-------|-------|
| 1     | Two-way double layered grids       | 11.99 | 10.57 | 9.33  |
|   | Grid Configuration                      | Maximum Displacement (mm) | Minimum Displacement (mm) | Average Displacement (mm) |
|---|----------------------------------------|---------------------------|---------------------------|--------------------------|
| 2 | Three-way double layered grids         | 11.45                     | 8.22                      | 7.79                     |
| 3 | Four-way double layered grids          | 13.68                     | 8.89                      | 8.97                     |
| 4 | Three-way on Periphery                 | 11.84                     | 9.56                      | 8.35                     |
| 5 | Four-way on Periphery                  | 11.59                     | 8.68                      | 7.45                     |
| 6 | Two-way three-layered grids            | 8.82                      | 5.67                      | 5.84                     |
| 7 | Three-way three-layered grids          | 9.23                      | 5.48                      | 5.79                     |
| 8 | Four-way three-layered grids           | 10.85                     | 6.45                      | 7.15                     |

**Figure 10.** Variation of maximum displacement of 2 m grid size space structure

**Figure 11.** Variation of maximum displacement of 3 m grid size space structure
3.2 Modal Analysis Results

The modal analysis is carried out for different configurations of grid space structures for grid spacing of 2 m, 3 m and 4 m. The results of analysis are tabulated in the table 8. A maximum of 6 number of modes is considered. A maximum time period of 2.317 seconds is obtained for Four way three layered grids for 2 m grid size. A maximum frequency of 6.705 Hz is obtained for Four way double layered grids for 4 m grid spacing.

Figure 12. Variation of maximum displacement of 4 m grid size space structure

Figure 13. Variation of maximum deflection of 2 m, 3m and 4m grid size space structure
Table 8. Frequency and Time period for 2 m, 3 m and 4 m grid size space structures

1. Two-way double layered grids

| Mode No. | Frequency (Hz) 4 m | 2 m | 3 m | Time Period (Seconds) 4 m | 2 m | 3 m |
|----------|-------------------|-----|-----|---------------------------|-----|-----|
| 1        | 0.706             | 0.633 | 0.713 | 1.417                     | 1.579 | 1.403 |
| 2        | 0.706             | 0.633 | 0.713 | 1.417                     | 1.579 | 1.403 |
| 3        | 0.795             | 0.751 | 0.872 | 1.259                     | 1.331 | 1.147 |
| 4        | 5.373             | 5.215 | 5.484 | 0.186                     | 0.192 | 0.182 |
| 5        | 5.39              | 5.339 | 5.511 | 0.186                     | 0.187 | 0.181 |
| 6        | 5.39              | 5.339 | 5.511 | 0.186                     | 0.187 | 0.181 |

2. Three-way double layered grids

| Mode No. | Frequency (Hz) 4 m | 2 m | 3 m | Time Period (Seconds) 4 m | 2 m | 3 m |
|----------|-------------------|-----|-----|---------------------------|-----|-----|
| 1        | 0.657             | 0.579 | 0.658 | 1.522                     | 1.728 | 1.52 |
| 2        | 0.665             | 0.583 | 0.666 | 1.503                     | 1.715 | 1.501 |
| 3        | 0.748             | 0.693 | 0.814 | 1.337                     | 1.444 | 1.229 |
| 4        | 5.409             | 5.224 | 5.531 | 0.185                     | 0.191 | 0.181 |
| 5        | 5.435             | 5.341 | 5.551 | 0.184                     | 0.187 | 0.18 |
| 6        | 5.478             | 5.351 | 5.604 | 0.183                     | 0.187 | 0.178 |

3. Four-way double layered grids

| Mode No. | Frequency (Hz) 4 m | 2 m | 3 m | Time Period (Seconds) 4 m | 2 m | 3 m |
|----------|-------------------|-----|-----|---------------------------|-----|-----|
| 1        | 0.654             | 0.516 | 0.583 | 1.528                     | 1.938 | 1.715 |
| 2        | 0.654             | 0.516 | 0.583 | 1.528                     | 1.938 | 1.715 |
| 3        | 0.742             | 0.618 | 0.72  | 1.348                     | 1.619 | 1.389 |
| 4        | 6.674             | 5.23  | 5.613 | 0.15                      | 0.191 | 0.178 |
| 5        | 6.705             | 5.349 | 5.613 | 0.149                     | 0.187 | 0.178 |
| 6        | 6.705             | 5.349 | 5.615 | 0.149                     | 0.187 | 0.178 |

4. Three-way on Periphery

| Mode No. | Frequency (Hz) 4 m | 2 m | 3 m | Time Period (Seconds) 4 m | 2 m | 3 m |
|----------|-------------------|-----|-----|---------------------------|-----|-----|
| 1        | 0.685             | 0.618 | 0.693 | 1.461                     | 1.617 | 1.443 |
| 2        | 0.69              | 0.618 | 0.699 | 1.449                     | 1.617 | 1.431 |
| Mode No. | 4 m | 2 m | 3 m | 4 m | 2 m | 3 m |
|---------|-----|-----|-----|-----|-----|-----|
| 1       | 0.646 | 0.596 | 0.662 | 1.549 | 1.679 | 1.51 |
| 2       | 0.646 | 0.596 | 0.662 | 1.549 | 1.679 | 1.51 |
| 3       | 0.699 | 0.682 | 0.779 | 1.430 | 1.467 | 1.284 |
| 4       | 5.435 | 5.216 | 5.553 | 0.184 | 0.192 | 0.18 |
| 5       | 5.441 | 5.333 | 5.573 | 0.184 | 0.188 | 0.179 |
| 6       | 5.441 | 5.333 | 5.573 | 0.184 | 0.188 | 0.179 |

6. Two-way three-layered grids

| Mode No. | 4 m | 2 m | 3 m | 4 m | 2 m | 3 m |
|---------|-----|-----|-----|-----|-----|-----|
| 1       | 0.634 | 0.519 | 0.616 | 1.578 | 1.925 | 1.622 |
| 2       | 0.634 | 0.519 | 0.616 | 1.578 | 1.925 | 1.622 |
| 3       | 0.741 | 0.625 | 0.774 | 1.350 | 1.599 | 1.291 |
| 4       | 5.382 | 5.217 | 5.493 | 0.186 | 0.192 | 0.182 |
| 5       | 5.382 | 5.322 | 5.494 | 0.186 | 0.188 | 0.182 |
| 6       | 5.383 | 5.322 | 5.494 | 0.186 | 0.188 | 0.182 |

7. Three-way three-layered grids

| Mode No. | 4 m | 2 m | 3 m | 4 m | 2 m | 3 m |
|---------|-----|-----|-----|-----|-----|-----|
| 1       | 0.583 | 0.475 | 0.565 | 1.715 | 2.105 | 1.77 |
| 2       | 0.59 | 0.479 | 0.572 | 1.694 | 2.089 | 1.748 |
| 3       | 0.688 | 0.577 | 0.717 | 1.453 | 1.734 | 1.394 |
| 4       | 5.399 | 5.225 | 5.514 | 0.185 | 0.191 | 0.181 |
| 5       | 5.443 | 5.326 | 5.558 | 0.184 | 0.188 | 0.18 |
| 6       | 5.467 | 5.337 | 5.586 | 0.183 | 0.187 | 0.179 |
8. Four-way three-layered grids

| Mode No. | Frequency (Hz) | Time Period (Seconds) |
|----------|----------------|-----------------------|
|          | 4 m    | 2 m    | 3 m    | 4 m    | 2 m    | 3 m    |
| 1        | 0.523  | 0.432  | 0.511  | 1.911  | 2.317  | 1.958  |
| 2        | 0.523  | 0.432  | 0.511  | 1.911  | 2.317  | 1.958  |
| 3        | 0.619  | 0.525  | 0.649  | 1.616  | 1.906  | 1.541  |
| 4        | 5.477  | 5.231  | 5.600  | 0.183  | 0.191  | 0.179  |
| 5        | 5.477  | 5.338  | 5.600  | 0.183  | 0.187  | 0.179  |
| 6        | 5.501  | 5.338  | 5.621  | 0.182  | 0.187  | 0.178  |

Figure 14. Frequency in Two Way Double layer grids for different grid spacing

Figure 15. Period in Two Way Double layer grids for different grid spacing
4. Conclusions
The analytical study on grid space structure is carried in this study. From the results and comparative study, following conclusions are drawn:

- From the modal analysis results, a maximum time period of 2.317 seconds is obtained for Four way three layered grids for 2 m grid size. A maximum frequency of 6.705 Hz is obtained for Four way double layered grids for 4 m grid spacing.
- The deflection is reduced by 46.3% for three-layered grids compared to double layered grids. Hence three-layered grids are suitable for long span space structures.
- From the dynamic analysis results of 2 m, 3 m and 4m grid spacing, the displacement values are less for 3 m compared to 2 m and 4 m. Hence 3 m grid spacing is optimum.
- From the dynamic analysis of grid space structures, the value of maximum horizontal displacement for zone 2 and zone 5 for 3.0 m grid size is 21.40 % greater for Two-way three-layered grids compared to Two-way double layered grids. Hence double layered grids are more suitable for earthquake regions.

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