

The analysis on characteristic of pre-stressed reticulated mega-structure with grid sub-structure

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Abstract. The author brings a new structure named pre-stressed mega grid structure which can be applied to super large span architectural structure through combining the advantages of mega grid structure and beam string structure. This new structure has many advantages, such as, light weight, strong rigidity and large span. This article has secondly developed ANSYS software with APDL language for modeling establishment and solving integration, and also edited related programs. Referring to the contractive analysis of dynamic characteristics, static characteristics of pre-stressed mega grid structure and mega grid structure; and by adopting time history method to analyze the seismic response of pre-stressed mega grid structure. One may get the conclusions of strengths in deflection characteristics and mechanical characteristics of pre-stressed mega grid structure. Through analyzing the dynamic characteristics, static characteristics and seismic response of pre-stressed mega grid structure which is across 280m by the method of changing original pre-stress, loss ratio of main structure and the number of grids. It may get conclusions of range of evaluation of all above parameters.

1. Introduction

With the development of social economic development and the new requirements of structural span, the long span of mega grid structure has become main research direction of many researchers and exporters. Especially the appearance of haze weather in recent years, the architecture in whole sealing structure which spans across 300m, 500m and 1000m is the mainstream development trend of future city. Although research of long-span spatial structure in China has reached a significant development, it still has its' weakness as lacking research classification and engineering projects in 200m span across structure.

The author brings a new structure named pre-stressed mega grid structure combining the advantages of mega grid structure and beam string structure (see Figure 1). This new structure is that the horizontal truss of mega grid structure is designed as rigid beam-column, and the pre-stress steel cables are added between the junctions of horizontal truss and longitudinal truss of contiguous grids. The anchor strut is the connection between steel cables and truss arches. The truss will be adopted as anchor strut because of large span of steel cable and great pre-stress power. The paper gets the conclusion of the reasonableness for the new structure through contractive analysis of pre-stressed mega grid structure and mega grid structure by usage of software ANSYS, also gets a series of important conclusions which could provide significant reference for related research.



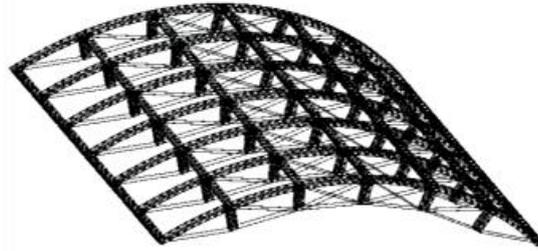


FIGURE 1 Pre-stress mega grid structure without sub-structure

2. Model establishment and secondary development of ansys

2.1. Model Establishment

(1) Set following assumptions in computer for convenience to calculation:

- (2) Space hinged node, and neglect the impact of node rigidity,
- (3) The member is in elastic state, and the whole structure is in small strain condition,
- (4) The effect of loading is only in the node without considering the plastic deformation,

The member of main structure and sub-structure, and the anchor strut will be simulated using the link 8 element, the cable will be simulated using the link 10 element.

Furthermore, in the characteristics analysis of pre-stressed mega grid structure and mega grid structure, the span is 280m, the number of horizontal grid of main structure is 6, and the number of longitudinal truss is 7, the number of horizontal grid of sub-structure is 6, the number of longitudinal grid of sub-structure is 7, the size of small grid of longitudinal truss is 3.5m, the height of the truss is 3.5m, and the span ratio of main structure is 1/5. The type of sub-structure is flat-panel grid structure. The height of flat-panel grid is 1.5m, the grid size of main structure and sub-structure is the same, the height of anchor strut is 10.5m, the steel density of structure is 7800kg/m^3 , the elasticity modulus is $E=2.1\times 10^8\text{ kN/m}^2$. The dead loading is 1.0 kN/m^2 . The living loading is 0.5 kN/m^2 . The transverse section of the main structure after the full stress optimization will be showed in table 1.

TABLE 1 Transverse section specifications

Location of Members	Models of Members(mm)
Top Chord And Lower Chord Of Main Structure	$\Phi 219*14$
Diagonal Struts Of Main Structure	$\Phi 180*12$
Top Chord And Lower Chord Of Sub Structure	$140*10$
Diagonal Struts Of Sub Structure	$114*10$
Anchor Strut	$102*10$

2.2. Secondary Development

Author has secondary developed the APDL parameters design language of ANSYS to set the related program for the convenience to calculation, and the program and design language is shown in figure 2, the program can make an integration for structural modeling and calculation.

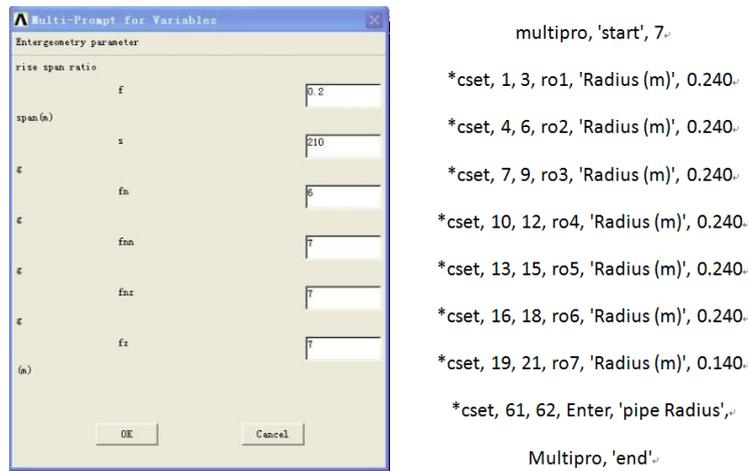


FIGURE 2 Program order and UI

3. Static characteristics analysis

3.1. Static Characteristics Analysis of Pre-stressed Mega Grid Structure and Mega Grid Structure

It may get a conclusion that maximum displacement has occurred in the middle of span in two structures, of which node displacement of top chord of mega grid structure is 0.14294m, node of lower chord of mega grid structure is 0.13352m, node of top chord of pre-stressed mega grid structure is 0.0864m, node of lower chord of mega grid structure is 0.079807m (see Figure 3). Through contractive analysis of node displacement of same location of main structure and stress of member under the normal working condition, it proves that for pre-stressed mega grid structure, portrait displacement has been decreased for the reason of which loading of main structure and pre-stress has been balanced.

Otherwise, for pre-stressed mega grid structure, the member stress of horizontal truss of main structure is larger than the member stress of longitudinal truss of main structure. This shows that main bearing member in pre-stressed mega grid structure is horizontal truss arch. The compression member is top chord member of main structure, the members in middle of structure is tension member, the stress will become smaller from both ends to middle part; compression member is lower chord member of main structure in pre-stressed mega grid structure, internal force of lower chord member will become smaller from both ends to middle part.

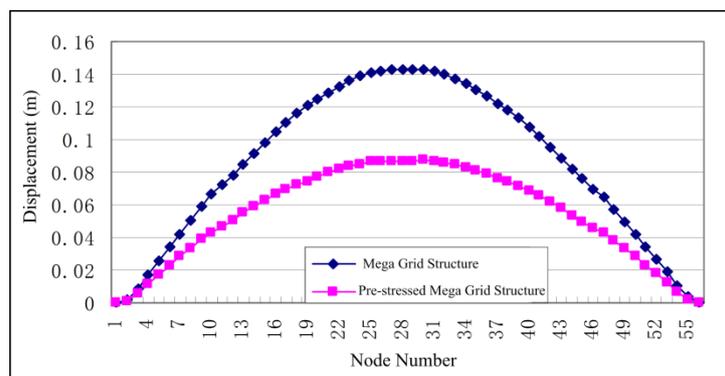


FIGURE 3 Comparison chart displacement of top chord node of two structures

3.2. Parameter Analysis of Static Characteristic of Pre-Stressed Mega Grid Structure

Through analyzing the impacts of node displacement of same location in pre-stressed mega grid structure which crossed 280m and stress of member by the method of changing original pre-stress, loss ratio of main structure, the differences of number of grids, it may get a conclusions as below:

(1) It has decreasing trend in displacement of node in same location with enlarging pre-stress; this proves that pre-stress and external loading is one pair of opposite acting force.

(2) Displacement of same location has been enlarged with the increasing of loss ratio, and it proves that horizontal main truss is the main compression member in the structure, then loss ratio should be design as $1/5 \sim 1/6$.

(3) With the decreasing of number of grids in main structure, i.e. enlarged the size of one grid, both member stress and displacements of top and lower node in pre-stressed mega grid structure will be increased. Then number of grids should not be design too few, and the size of it should be set as $35\text{m} \sim 45\text{m}$.

4. ANALYSIS OF DYNAMIC CHARACTERISTICS

4.1. Contractive Analysis of Dynamic Characteristics in Pre-Stressed Mega Grid Structure and Mega Grid Structure

It may get a conclusion of that the frequency of the first 6-stage of pre-stressed mega grid structure is bigger than the frequency of the first 6-stage of mega grid structure through the free vibration characteristics contractive analysis with the iterative methods of above two structures (figure 4), basic frequency of pre-stressed mega grid structure and mega grid structure which is 0.9487Hz and 0.62665Hz. There are fewer differences in frequency between 7th~16th stage of two structures, generally speaking, the frequency of pre-stressed mega grid structure is larger than the other one, and the frequency in 17th stage starts increasing in pre-stressed mega grid structure. The reason of all above appearance is the rigidity of structure has been strengthened after adding pre-stress steel cable, then the span of pre-stressed mega grid structure has increased as well, so seismic performance of structure with pre-stress is better than the structure which is not with pre-stress.

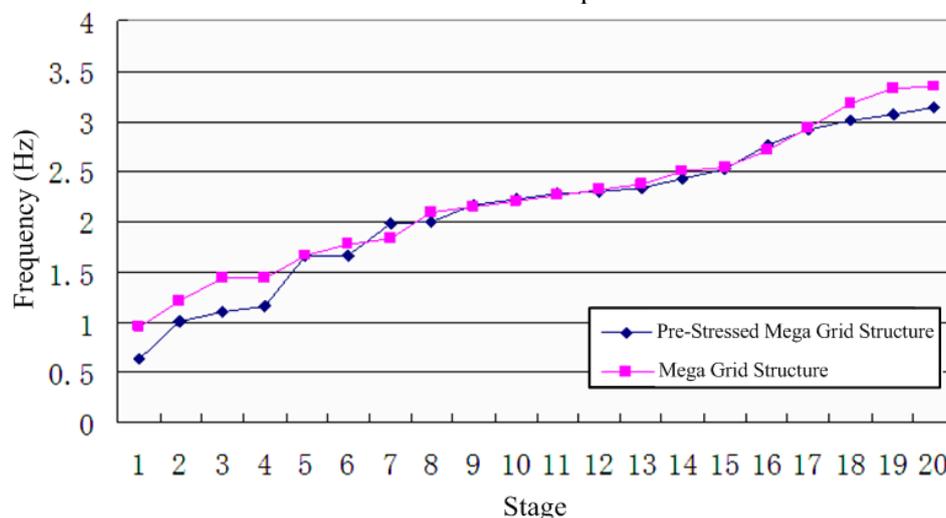


FIGURE 4 Comparison chart of free vibration frequency in two structures

Moreover, model 1 and 8 show that they vibrated in transverse horizontal direction. Model 2 and 5 shows that they vibrated in transverse horizontal direction with up and down vibration. Model 3, 6, 7, 9 and 10 shows that they vibrate in up and down direction. Model 4 shows that it vibrated anti-symmetric up and down direction. Model 11 shows that it vibrated in vertical direction, and it has a portrait symmetry vibration in horizontal direction with four half waves, and they will keep in same step of each arches, but only the vibration range of middle part is slightly larger than both ends. Model

12 shows that it vibrated in portrait direction, and it has a portrait symmetry vibration in portrait direction with two half waves, and they will keep in same step of each arches. The less component of longitudinal displacement in two models of those two structures proves that rigidity in vertical direction is the most maximum rigidity after adding in sub structures of flat framework.

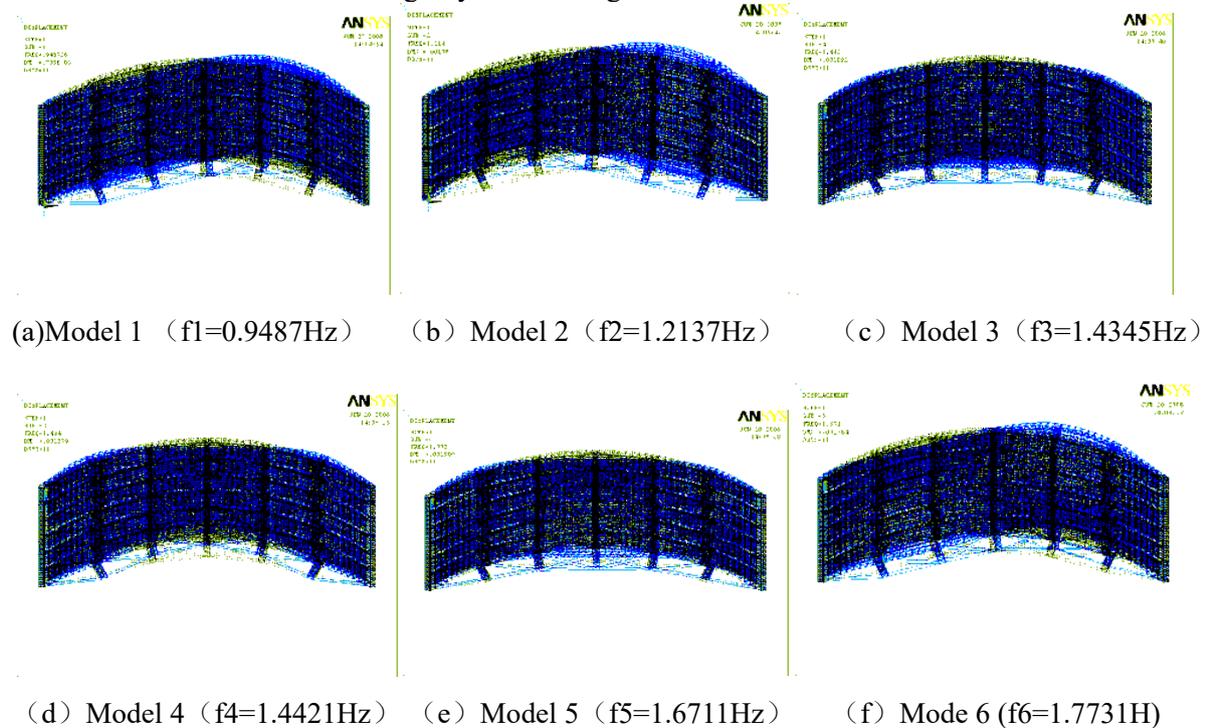


FIGURE 5 Vibration chart of pre-stressed mega grid structure

4.2. Parameter Analysis of Dynamic Characteristic of Pre-Stressed Mega Grid Structure

Through analyzing the impact to the parameters of dynamic characteristics of pre-stressed mega grid structure which is across 280m by the method of changing original pre-stress, loss ratio of main structure and the number of grids, it may get following conclusions:

(1) Assumed pre-stress as S, then pre-stress will be $S_1=0.8S$; $S_2=S$; $S_3=1.2S$; $S_4=1.4S$, through analyzing above four pre-stress models of calculation, one can conclude (figure 6): By increasing the pre-stress, free vibration of each stage in its structure will be increased as well, this is the reason that the strengthening through whole rigidity of structure became, the larger of original pre-stress of steel cable would be made.

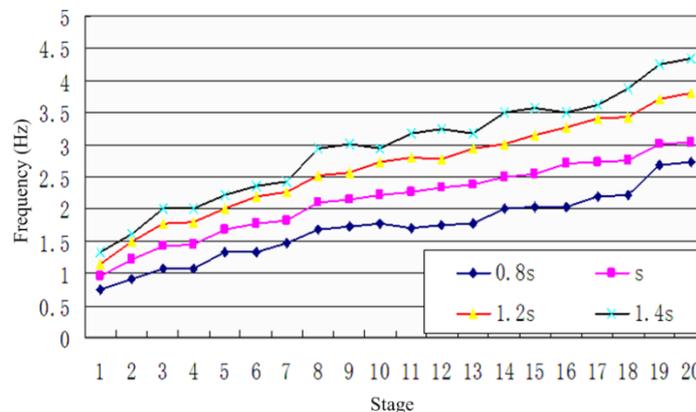


FIGURE 6 Frequency comparison for different pre-stress models

(2) Trough analyzed above calculation of four pre-stress models which loss ratio of main structure is $1/3$ 、 $1/4$ 、 $1/5$ 、 $1/6$ respectively, it can be concluded as (figure 7): with the increase of loss ratio of main structure, frequency of free vibration of each stage in its structure will be decreased, and this is the result of decreasing in rigidity which led by increasing of the height of arch in main structure. Then ratio of main structure should not be designed too large.

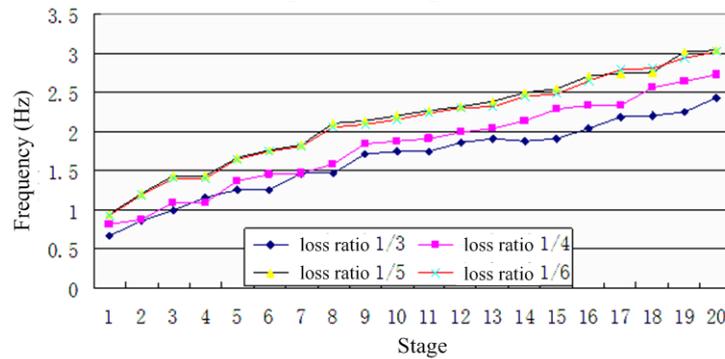


FIGURE 7 Frequency comparison for different ratio model

(3) Trough analyzing above calculation of four grids which grid number is 4, 5, 6 and 7 respectively (table 7): with the increase of numbers of grid in main structure, frequency of free vibration of each stage in its structure will be increased, basic frequency of 7 grid number and 4 grid number pre-stressed mega grid structure are 0.8348Hz and 1.0436Hz. This is because the numbers of grid has been decreased, then each size of unit grid will become smaller, then the whole rigidity has been decreased.

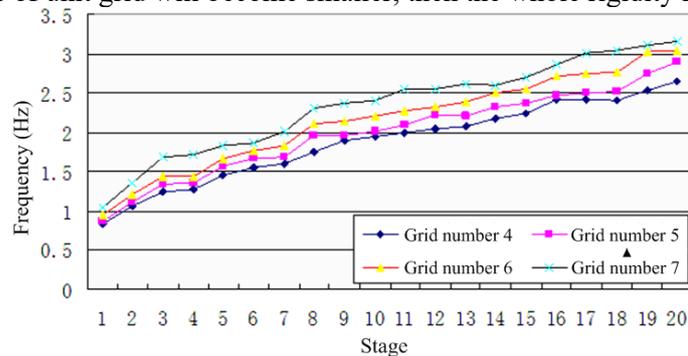


FIGURE 8 Frequency comparison for different grid number

5. Analysis of multi-dimensional seismic response

5.1. Analysis of Multi-Dimensional Seismic Response of Pre-Stressed Mega Grid Structure

Through analyzing the response of pre-stressed mega grid structure which is across 280m in Tianjin earthquake by the method of time history (figure 9 and 10): displacement of each node of main truss in pre-stressed mega grid structure, especially the displacement of top chord is mainly in portrait direction (Z direction), but displacement peak of top chord node is slightly larger than the number of lower chord node. Maximum number of top chord node in mid-span is 0.162m, while maximum displacement number in horizontal and vertical direction is -0.093m and 0.062m.

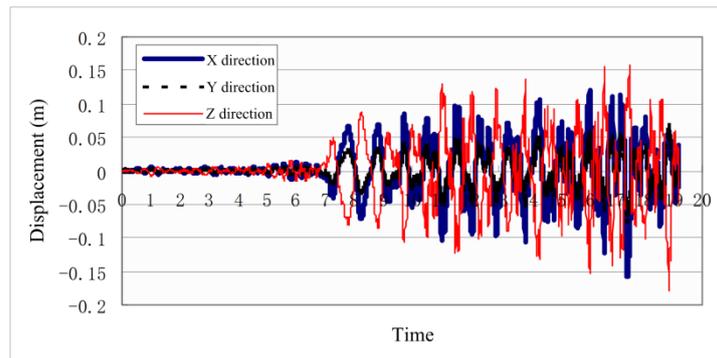


FIGURE 9 Time history curve of lower chord node of mid-span in x、y、z direction

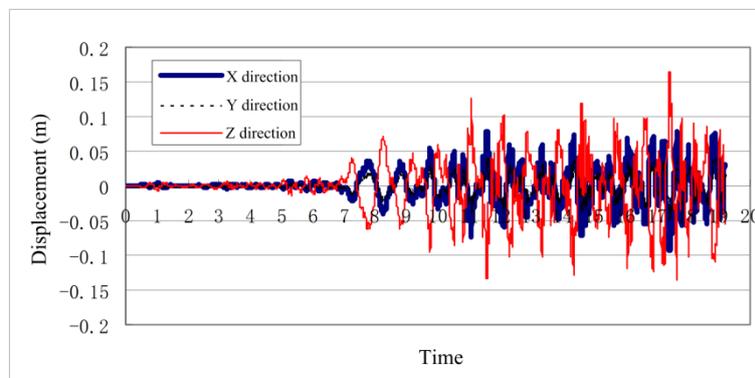


FIGURE 10 Time history curve of top chord node of mid-span in x、y、z direction

Moreover, both displacement responses in horizontal transverse (X direction) and longitudinal horizontal (Y direction) are shorter than portrait direction (Z direction), this is the reason of sub-structure settlement in main structure, the appearance of sub-structure greatly increased the rigidity of structure in vertical (Y direction) and portrait direction (Z direction).

5.2. Analysis for Parameters of Seismic Response

Through analyzing the impact to the parameters of seismic response of pre-stressed mega grid structure which across 280m by the method of changing original pre-stress, loss ratio of main structure and the number of grids, it may get following conclusions:

(1) With the increase of pre-stress, both responses in displacement of top and lower chord of the structures has been decreased, which proves that adding pre-stress will strengthen rigidity.

(2) With the decreasing of loss ratio of main structure, both responses in displacement of top and lower chord of the structures have been decreased. The response of maximum displacement in structure has been raised to -0.23m when loss ratio is 1/3, while the response of maximum displacement in structure has been raised to -0.062m when loss ratio is 1/6. This proves that loss ratio has a great significant influence on structural displacement. Also proves that rigidity of structure will be decreased after increased loss ratio of main structure, and the height of arch in main structure has been raised.

(3) With the increase of number of grid in main structure, both responses of displacement in top and lower chord of the structures will be decreased. This is the reason of decreasing of number of grids in main structure which leads to the size will become larger in each grid, i.e, the longer of each member being made, the whole rigidity in structure will be decreased.

6 Conclusions

In this article, we can get following conclusions through above analysis:

(1) A new long span structure has been brought based on the advantages of pre-stressed mega gird structure and mega gird structure.

(2) Under the conditions of same span and loading effects, the statically characteristics in node displacement and member stress of pre-stressed mega gird structure are better than those characteristics in mega gird structure.

(3) The free vibration characteristics of pre-stressed mega gird structure is better than that mega gird structure, i.e. the whole rigidity of pre-stressed mega gird structure is better than that mega gird structure.

(4) The best design parameters will be determined after contractively analyzed the structure characteristics by changing loss ratio, pre-stress and number of grids, which can provide significances in actual design.

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