Ninth Canadian Conference on
Earthquake Engineering
Ottawa, Ontario, Canada
26-29 June 2007

EFFECT OF STRUCTURAL PARAMETERS ON SEISMIC RESPONSE IN THE ZHENGZHOU INTERNATIONAL CONFERENCE EXHIBITION CENTER

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ABSTRACT

The work of this paper proposes a design basis for stay pre-tension cable-arch structures for holding dynamic performances. In this paper, a rectangular unit of steel roof in the Zhenghou International Conference Exhibition Center is introduced to research the effects of different structural parameters on seismic performances with ANSYS software. Response spectrum method is applied to calculate dynamic displacements, and support reactions, ratio of the maximum dynamic forces over static forces and ratio of the maximum dynamic displacement over static displacement. Moreover, a comparative analysis is conducted to summarize the rules. The results indicate that the influence of the boundary condition can change mechanical performance under seismic response. Therefore, careful selection of these conditions is necessary. However, pre-tension on seismic properties may be ignored.

Introduction

Stay pre-tension cable-arch structures are a new hybrid system that has been successfully introduced into the steel roof of the Zhenghou International Conference Exhibition Center. Stay systems become structural primary load- bearing members, the lifting-points of which are turned into elastic supports of mid-span cable-arch members so as to increase span of roof and make the best of structural materials (Zhang 2002). Thus, the whole roof is provided with reasonable action, economical construction and beautiful sculpture in order to meet the demands of different architectural shape. This new structural system can have good mechanical performance benefiting from stay structure, pre-tension structure and cable-arch structure. Further research on its structural mechanism can offer a basis of application for stay pre-tension cable-arch structures.

Based on previous studies, structural parameters including boundary conditions and pre-tension are selected to discuss their influences on structural seismic performances by adopting a response spectrum method, according to basic analytical theory and the actual structural design criterion of China with ANSYS software. At the same time, some significant conclusions are drawn out to guide the design of this type structure.

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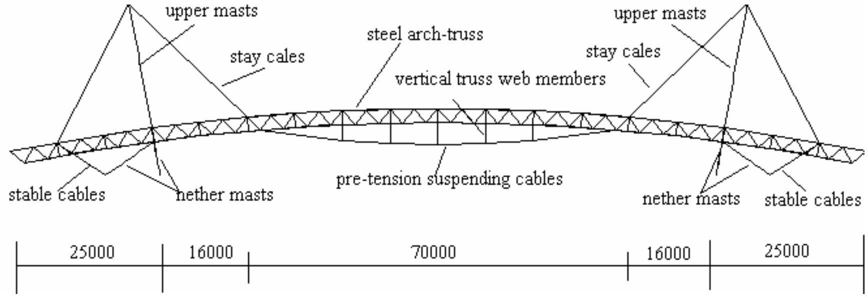
Finite Element Model

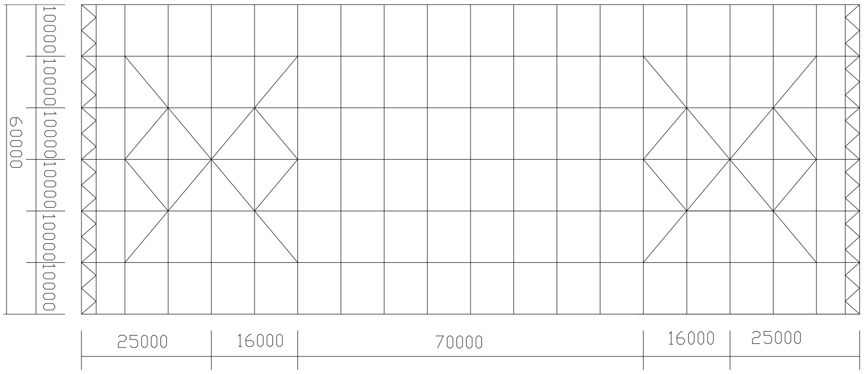
The steel roof in the Zhenghou International Conference Exhibition Center consists of upper masts, nether masts, stay cables, a steel arch-truss, pre-tension suspending cables, stable cables, vertical truss web members and supporting systems. The projective area amounts to almost 51,860 Sq.m. and steel content reaches 127 kg per stere. According to the order of lifting and installing, the whole roof is divided into four identical rectangular units and one fan-shaped unit. Geometric compositive connection of rectangular unit accords with one of fan-shaped unit. Considering the large roof area associated with 11,238 members, a rectangular unit is taken as an analytical model within the precision of engineering calculation to simplify analysis and increase maneuverability.

The longitudinal length of the rectangular steel roof unit is 60 meters and its span is 102 meters. The length of the cantilever part at every side of the roof is 25 meters, which is hung by two suspended systems consisting of one upper mast and six stay cables. The cables on each mast connect side-span and mid-span cable-arch components. The span of the midspan roof is composed of pre-tension cables and the steel arch-truss is 70 meters. Single pre-tension suspending cable is joined with lower chords through five vertical truss web members so that the structural system can obtain more stiffness to maintain better integral stability subjected to part distributed load.

On a foundation of finite segment method, a three-dimensional structural discrete model is presented to perform the finite element analysis. Several basic assumptions are recommended as follows :(1) Material satisfies Hook's principle; (2)The pre-tension suspending cables possess ideal flexibility, namely they are only subjected to tensile force, otherwise, the cables are out of work. (3)The connections between steel arch-truss members, as well as between vertical truss web members and lower chords, are assumed as rigid. These members are simulated by spatial beam element beam4, and all kinds of cables are simulated by spatial truss element LINK10. Simulating the introduction of pre-tension is dealt with defining initial strain of LINK10. As a result, the finite element model is established as expressed in Fig.1.



(a) Section drawing



(b) Architectural ichnography of a rectangular unit

Figure 1. Spatial stay pre-tension cable-arch structure.

Response Spectrum Method

Based on Chinese code for seismic design of buildings (GB500011-2001), the seismic fortification intensity of this work is defined as seven degree and site belongs to second type. The maximum earthquake effect coefficient ($\alpha_{\max}$) is equal to 0.08, the characteristic period (T_g) is 0.35 second, and the damping ratio (ξ) is 0.02. With the help of above parameters, the structural spectrum curve is obtained.

The equation of motion under earthquake action is described as follows (Ray 1995):

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=-[M]\{\ddot{u}_g\} \tag{1}$$

Note:

$\{u\}, \{\dot{u}\}, \{\ddot{u}\}$ -- respectively defined as displacement, velocity and acceleration vector.

$\{\ddot{u}_g\}$ -- Acceleration vector of ground motion.

$[M]$ --Mass matrix

$[C]$ --Damping matrix, besides

$[K]$ -- Stiffness matrix.

From seismic spectrum theory, structural inertial force is counted as follows:

$$\{P\}_j=\alpha_j\eta_j[G]\{\phi\}_j \tag{2}$$

Note:

α_j -- Earthquake effect coefficient corresponds to the j th mode;

η_j -- Participation factor corresponds to the j th mode;

$\{\phi\}_j$ -- Structural mode vector;

$[G]$ -- Structural gravity matrix.

On the foundation of the above mode analysis response spectrum theory, the internal forces subjected to earthquake action are counted by solving equations (1) and (2) with ANSYS software considering the former fifty-mode contribution and adopting the square root of sum of squares mode combination method, so as to explore the effects of structural parameters on dynamic performance under earthquake.

Boundary Conditions Influences

Boundary supports are taken as an important part of stay pre-tension cable-arch structures, which can define characteristics of the structure (Buchholdt 1985). Accordingly, simulating correctly the boundary supports with numerical methods becomes crucial to probe into the performance of structural systems.

In this engineering project, there are mutual restrictions between nether masts and stable cables because the steel roof is connected with the substructure by nether masts, secondary supporting and stable cables. In the authors' view, boundary supports are supposed as pinned joints in order to transfer only horizontal forces and vertical forces between nether masts and stable cables, ensuring free rotation in phase among members of the roof so as not to produce forced displacements. This constraint assumption accords with actual engineering, which prevents masts from initiating unitary overturning or side-instability circling around their axes. As a result, it is valid for a steel roof to avoid torsion. By contrast, in some reports (KISHO KUROKAWA 2003), rigid points are introduced into this project. In this paper, the natural vibration characteristics of these two conditions are compared to explore the effects of boundary on dynamic performance.

The dynamic displacements and support reactions are reckoned under pinned joints and rigid joints. The calculated results are listed in Table 1 as follows:

Table 1. Results under pinned joints and rigid joints.

Boundary Condition	Maximum of vertical Displacement (mm)	Reactions at X direction (kN)	Reactions at Y direction (kN)	Reactions at Z direction (kN)	Moments at X direction (kN.m)	Moments at Y direction (kN.m)	Torsions at X direction (kN.m)
Pinned joints	4.422	328.87	474.36	788.17	-	-	-
Rigid joints	4.298	280.92	439.32	767.02	65.86	84.978	9.364
Difference percent	2.89%	17.06%	7.97%	2.75%	-	-	-

The following points are drawn from Table 1:

(1) When the boundary condition varies from pinned joints to rigid joints, structural displacements and support reactions decrease, but the location of maximum cannot be changed.

(2) Although horizontal support reactions under rigid joints are diminished when subjected to X-direction earthquake action, moments in the Y-direction can be added, tending to increase the difficulty of joint design.

(3) The introduction of stable cables into boundary conditions can diminish structural reactions so as to settle the problem of larger support reactions belonging to space long-span buildings.

Pre-tension Influences

At the initial state, pre-tension is reasonably introduced to make stay cable-arch systems become a stable structural system and to compensate exterior load effects (Saitoh 1998). Consequently, the introduction of pre-tension is turned into an important task in structural design (Zhang and Zhang 2000). The effects on seismic performance are explored by changing the pre-tension values of suspending cables to provide a reference about determination of pre-tension, which makes for better holding structural performance of this new type of structure.

Specifically, boundary conditions are supposed as space pinned joints, and a value of pre-tension ranging from 0 kN to 1,500 kN is chosen considering the actual 750 kN of suspending cables.

Structural dynamic displacement, internal forces, and support reactions, as well as, the ratio of the maximum dynamic forces over static forces and ratio of the maximum dynamic displacement over static displacement, are calculated, subject to eighteen pre-tension values. At the same time, the displacement figure under earthquake action in the X- direction is described in Fig. 5 and the relations between pre-tension and above parameters is shown in Figs. 3 to 7.

The following points are drawn from Figs. 2 to 7:

(1) Subjected to eighteen pre-tension values, the variation is only up to 0.013 mm, even most of them are equal; the displacement figures and the place of maximum can hardly be changed. It can be concluded that pre-tension has no obvious change on structural dynamic displacement.

(2) There exist flowing horizontal lines in Fig. 3 and Fig. 5. In addition, the values and places of maximum support reactions and axial forces are not changed. In conclusion, pre-tension can have no effect on structural internal forces and distribution.

(3) Ratio of dynamic over static pressure increases along with pre-tension value adding, and the range of variation is smaller. By contrast, the ratio of dynamic over static tension greatly decreases along

with pre-tension value adding, namely, varying from 0.09652 without pre-tension to 0.013455 at 500 kN, and finally down to 0.07603 at 1,500 kN step by step. Furthermore, the ratio of dynamic over static pressure increasing along with pre-tension value adding can explain again that reasonable introduction of pre-tension may make structural stiffness and static tension augmented, as well as static vertical displacements diminished. However, pre-tension can hardly bring any change to dynamic performance.

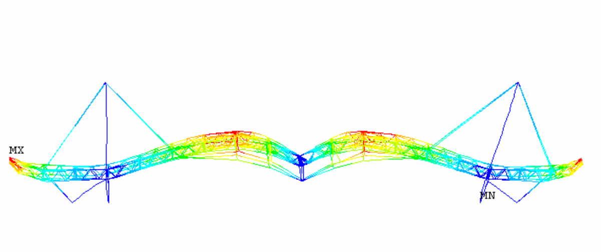


Figure 2. Displacement under earthquake in X direction.

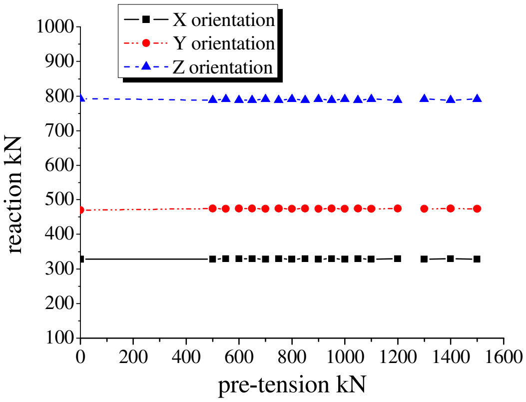


Figure 3. Pre-tension vs. Reactions.

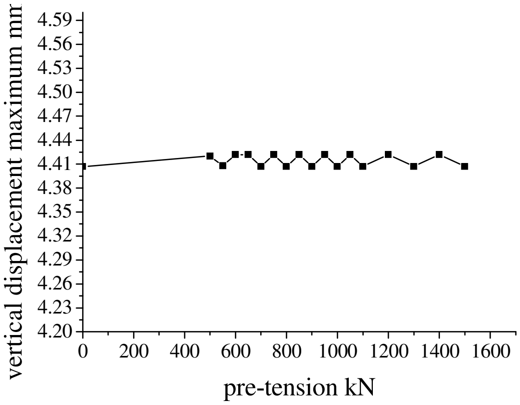


Figure 4. Pre-tension vs. Maximum of vertical Displacement.

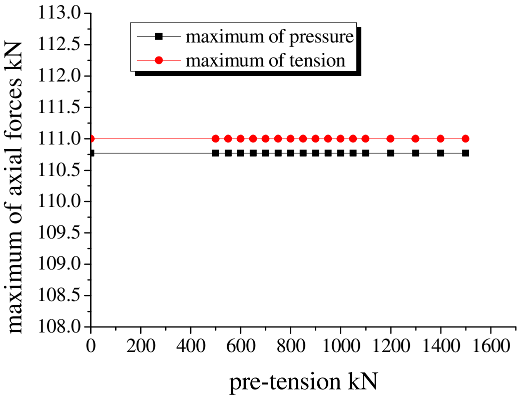


Figure 5. Pre-tension vs. Maximum of axial forces.

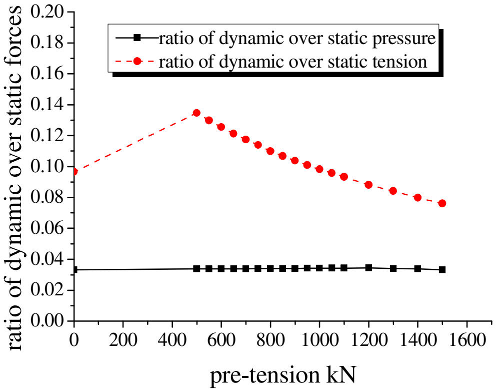


Figure 6. Pre-tension vs. Ratio of dynamic over static forces.

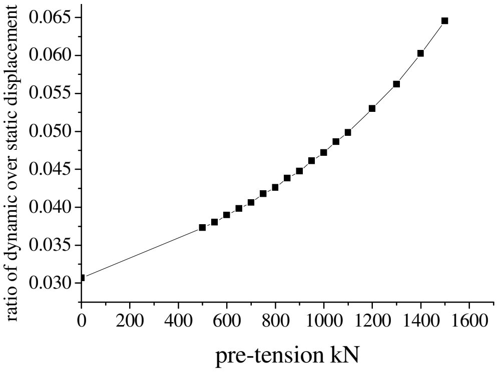


Figure 7. Pre-tension vs. Ratio of dynamic over static displacement.

Conclusions

Based on the above analysis, some conclusions are drawn from this paper, which can offer references for seismic design.

(1) The change of boundary condition has some effect on seismic performance. A suggestion is put forward that boundary conditions should be carefully chosen according to actual boundary characteristics;

(2) The reasonable introduction of pre-tension can increase structural stiffness and decrease static displacements, but has little effect on earthquake action. Thus, the influences brought by pre-tension can be ignored in design;

(3) Non-linear time history analysis should be still conducted when seismic characteristics of spatial stay pre-tension cable-arch structures are studied. The authors will continue the present research in the future.

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