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To cite this article: Bao Biyu 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **643** 012005

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# The design of bridge between structures based on the concept of "building on cable-stayed bridge"

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**Abstract.** Based on the concept of "building houses on cable-stayed bridges", a 4-storey bridge is set up in the first and second phase of the project, which makes the structural design interpret the architectural concept in a unique structural form. This paper focuses on the selection concept, structural layout, and the analysis of the rigidity, displacement, internal force and bearing capacity of the bridge structure. The experience can be used for reference in similar projects.

## 1. Project Profile

A project in Shandong province is composed of five major parts: an art gallery, a library, a mass art center, commercial and accessory buildings, underground garage and equipment rooms, where the library, art gallery and mass art center belong to the Phase I project, and the commercial and accessory buildings, underground garage and equipment room constitute the Phase II project. A four-layer bridge was built between Phase I and Phase II projects.

The design service life of this project is 50 years. With level II structural level and Category B and 7 degree of seismic fortification intensity, the project belongs to the seismic design of Category III, and the site construction is classified into Category III.

## 2. Design of the Connecting Bridge

### 2.1 Model selection and arrangement of structural system

The connecting bridge between Phase I and Phase II is similar to Dameisha Vanke Center Project of Shenzhen Dameisha Vanke headquarters. Located in Dameisha Holiday Resort in Yantian District, Shenzhen, the Dameisha Vanke Center Project was designed in cooperation with US Steven Holl Architecture. With structure known as the "floating skyline," the building scheme shows the major used space was elevated toward the sky 15 m away from the ground (the maximum superstructural span reaches 50 m, and the maximum overhang length is 20 m), and a continuous large space was formed at the bottom<sup>[1]</sup>.

The concept of "building on cable-stayed bridge", which is pioneering both in China and abroad, has been successfully applied to the Dameisha Vanke Center Project, and thus the architectural concept is interpreted by this structural design in unique structural forms. Based on the concept of "building on a cable-stayed bridge", the cable-stayed structure of ground-mounted reinforced concrete tube and steel frame is used in this project, where the ground-mounted tube supports the three-layer superstructure 12.9 m above the ground, the span is 50 m in the middle, and a continuous large space is formed at the bottom, with a small dead weight, low cable burden, strong compatible deformability



and reasonable stress-bearing feature, etc. In comparison with the steel frame plus mega steel support structure, this system has the following advantages:

(1) Passively bearing the external stress. The mega steel support structure cannot regulate the structural internal force. However, by adjusting the initial tensile force, the stay cable can actively control the staggered displacements of adjacent columns along the elevation, reduce the bending moment at the foot of the upper column, and improve the stress state.

(2) The design strength of the steel is much lower than that of stay cable, but their bearing capacities are the same. The section required by steel support is far larger than that required by stay cable, with greater influence on the internal space usage in the building.



Fig1 design of building of Wanke Center

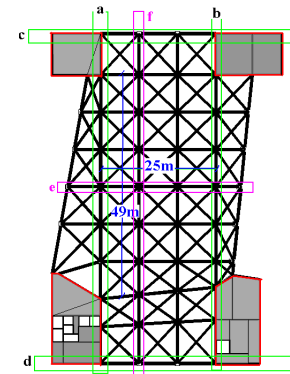


Fig2 Plan of bridge between structures

The red boxes in Figure 2 refer to the core tubes at the double-side corners of the building. The stay cable is placed at four positions: a, b, c and d. The bridge span and width are 49 m and 25 m, respectively, and the average overhang length at two sides is about 8 m. The gravity load of the superstructure is transferred to the vertical ground-mounted tube under the overall collaboration of the prestressed stay cable and steel floor structure; the horizontal load is transferred to the ground-mounted tube via the roofs of different floors. The cable is connected to ground-mounted vertical members through the cast steel joints, the transition zone for cable connection is embedded into the profile steel, and this zone bears the tensile force of the cable in the early phase, and participates in the work in the later phase.

The 3D overall structural model is shown in Figure 3.

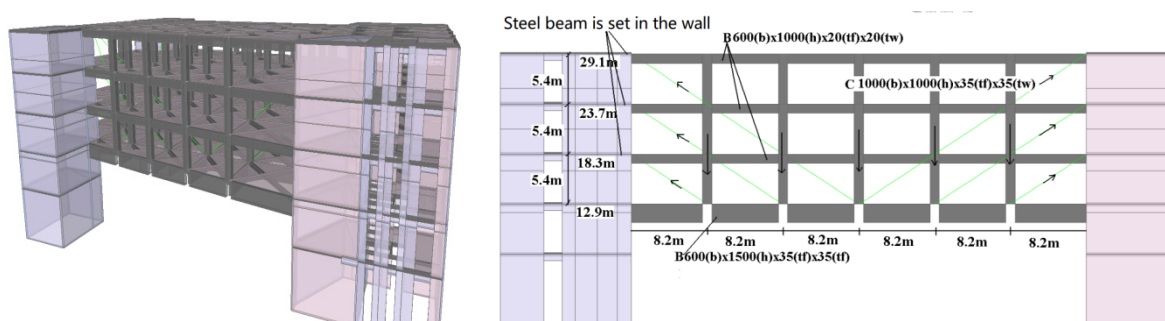


Fig3 Three dimensional model of overall structure

In order to strengthen the collaboration capability between the tubes and guarantee the effective transfer of tensile force of the stay cable, horizontal counterbracing is added within the floor plane, which can strengthen the stiffness and bearing capacity inside the roof plane. Meanwhile, the horizontal counterbracing also serves as a spandrel girder, which horizontally supports the hinge joints at two ends. Post-casting blocks are placed on tube edges, they are folded before the decoration after the completion of major structure to eliminate the concrete tensile stress during the tensioning process

of the cable, and adapt to the structural deformation in the construction loading process. At the same time, post-casting blocks are arranged in the local region of cable tensioning and anchoring nodes of the tube, and their casting will be implemented after the cable tensioning. The arrangement plan of floor slabs is presented in Figure 4.

## 2.2 Control criteria for the structural design

### (1) Tensile stress control for the stay cable

In order to ensure the initial tensile stiffness of the cable so it can provide enough strength reserves for bearing the later applied load, the tensile stress is determined through a test as 0.08-0.18  $f_{yk}$ , where  $f_{yk}$  refers to the breaking strength of the cable.

### (2) Control of the design cable stress ( $\leq 0.5 f_{yk}$ ) under the most unfavorable combination

### (3) Displacement of the key point

① While the stay cable is tensioned by applying the initial tensile force, the midspan arch-up deformation of the first-layer steel beam is controlled as  $< L/1000$ . With the construction of concrete superstructure, the gravity load is continuously increased, the overall structure gradually experiences downward bending deformation, and after all dead loads such as decoration and curtain wall are applied, the midspan down-warping deformation of the first-layer steel beam is controlled as  $< L/1000$ .

② Following the application of all dead loads like decoration and curtain wall, the horizontal displacement at the top of the tube is controlled as  $< 5\text{mm}$ .

(4) Finished cables are used in consideration of their importance and the reliability of tensile and anchoring tests. All finished cables pass the tensile test during the fabrication process, some cables are embedded with fiber optical sensors for structural health monitoring, and a mechanical property test is also carried out for a small number of large cables.

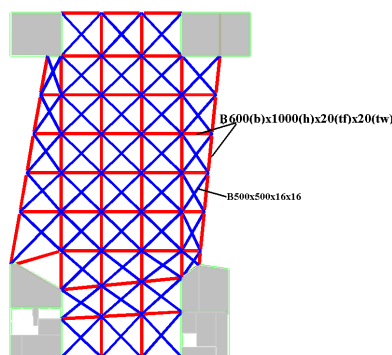


Fig4 Plan of floor

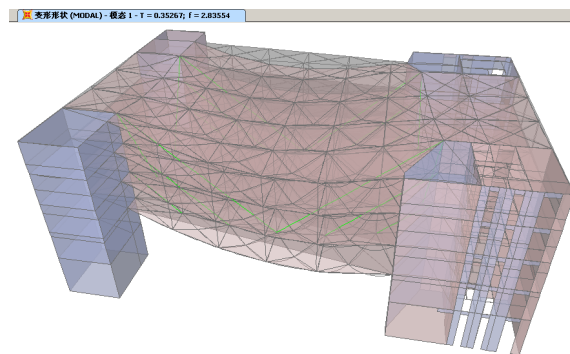


Fig5 Results of vertical dominant frequency

(5) Different from the ordinary cable-stayed bridge, “building on cable-stayed bridge” is featured by a small number of cables, great force bearing and large load in the later phase, without the help of any anchor ropes. To meet the minimum pre-tension stress of the cable while not to cause excessive upper arch deformation to the first-layer steel beam, and to ensure that the cable tensioning and subsequent gravity load addition layer by layer will not generate excessive sideways deformation to the vertical members, wall columns, the dead weight of partial upper roof structure is tactfully used as the counterweight, and meanwhile, the horizontal stiffness and bearing capacity of the roof, which is prerequisite for the upper part, are utilized to balance the horizontal components of tensile force of the stay cables, a critical concept that help realize the “building on cable-stayed bridge” in this project.

## 2.3 Main calculation results

### (1) Analysis of vertical stiffness and comfort level

From the above figure, the vertical dominant frequency of the structure is 2.8 Hz, and the analysis of man walking and jumping comfort level is supplemented. This analysis mainly aims at midspan

regions of steel structures and regions with large pedestrian flow on different floors, where single-person jumping and walking excitation time histories are respectively applied. The overall structural damping ratio is taken as 0.01. According to the calculation results, the maximum excitation effect occurs in vertical dominant frequency regions. By reference to Design Guide for Reducing Floor Slab Vibration released by US ATC1999, the maximum allowed vertical vibration acceleration is 0.075 m/s<sup>2</sup> for the comfort levels of residence, office and hotel, and that for the comfort levels of commerce, catering, dance hall and aisle is 0.22 m/s<sup>2</sup>. The maximum acceleration of the vibration generated by single-person jumping and walking is much smaller than the limiting value; meanwhile, the number of people jumping at the same time and at the same point can reach 484, this most unfavorable circumstance seldom happen, so the comfort level meets the related requirements.

### (2) Displacement analysis

Displacement analysis is carried out by taking typical roof trusses a, e and f as examples under the standard gravity load.

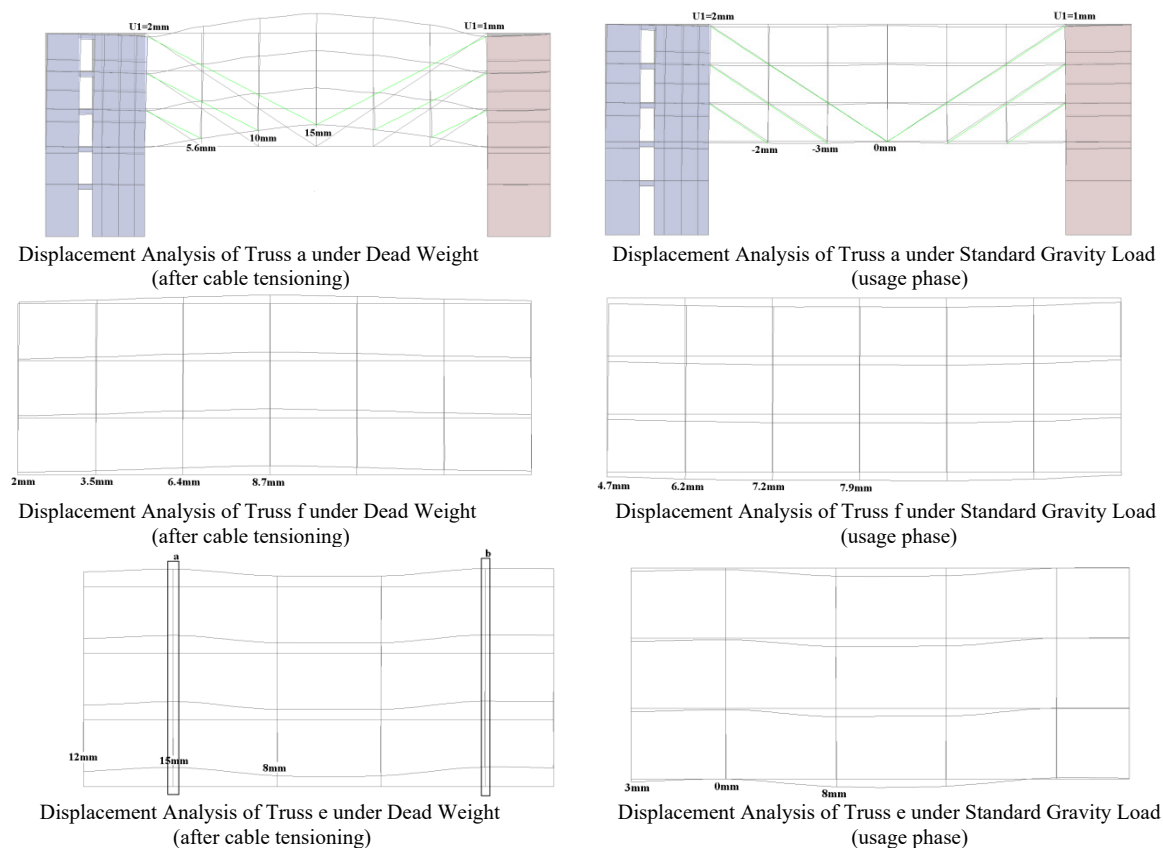


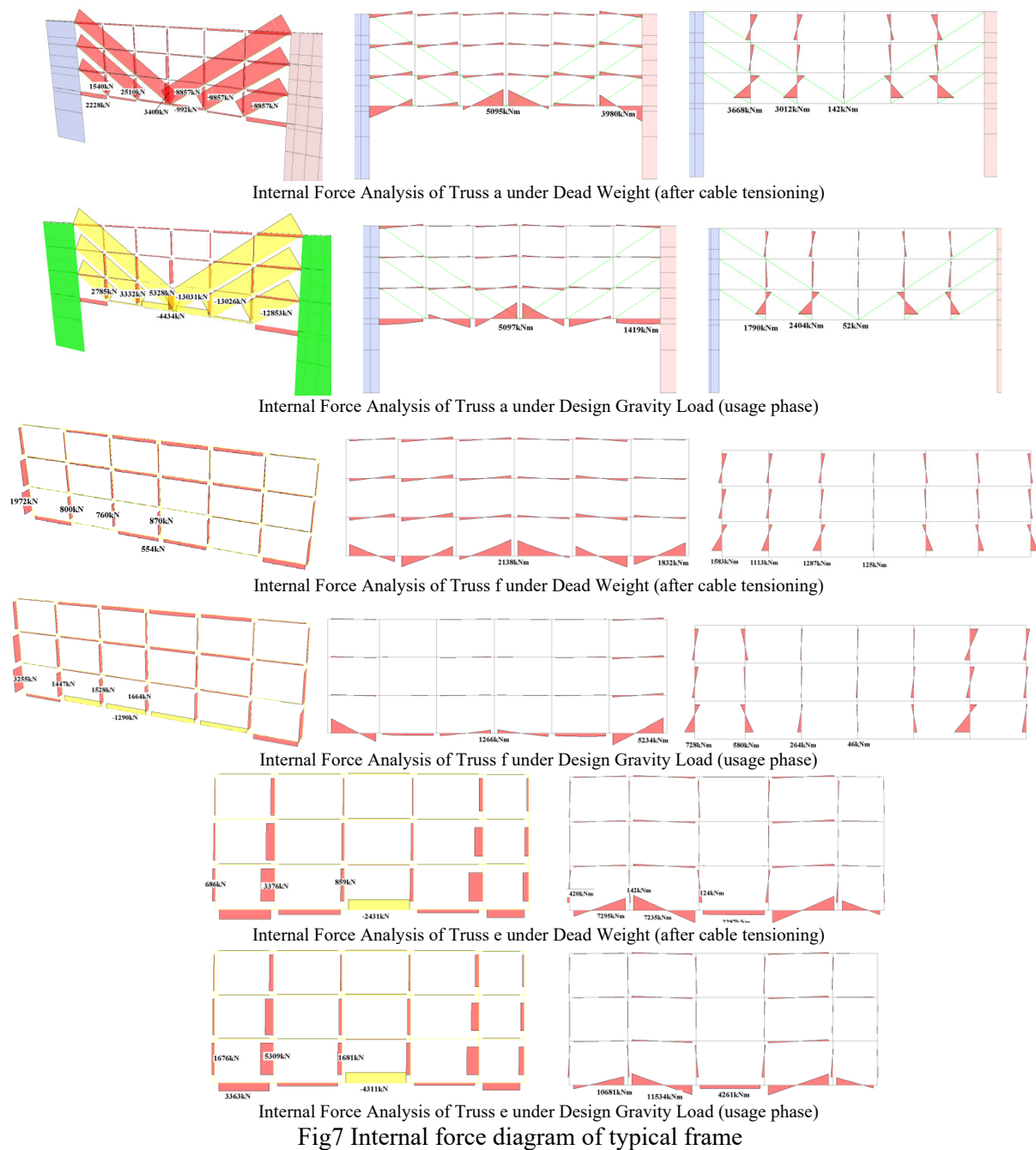
Fig6 Displacement diagram of typical frame

Conclusion: While the stay cable is tensioned by the applied initial tensile force, the midspan arch-up deformation of the first-layer steel beam is  $L/3000 < L/1000$ . With the construction of the concrete superstructure, the gravity load is continuously increased, and the overall structure gradually experiences downward bending deformation. After all constant loads like decoration and curtain wall are applied, the midspan down-warpage deformation of the first-layer steel beam is much smaller than  $L/1000$ , and meanwhile, the horizontal displacement at the top of tube is smaller than 5 mm, thus satisfying the design requirements.

### (3) Stress analysis

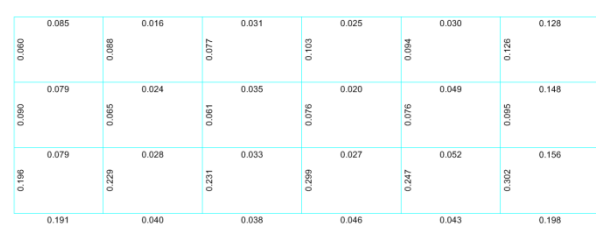
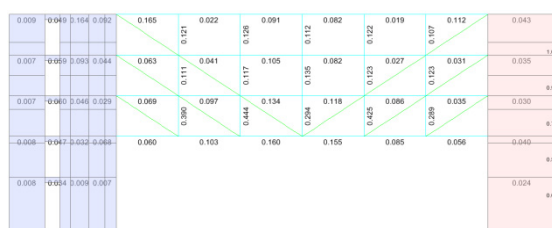
The internal force analysis is conducted by taking typical trusses a, e and f under the design gravity load as examples.

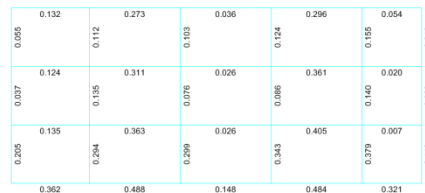




#### (4) Stress ratio analysis

The stress ratio analysis is implemented by taking typical trusses a, e and f as examples.





Stress Ratio of Truss e under Design Gravity Load  
Fig8 Stress ratio diagram of typical frame

Conclusion: The bearing capacities of the structural members satisfy the related requirements.

### 3. Conclusions

(1) While satisfying the building requirements, the design of the connecting bridge aggravates the challenge and difficulty of the structural design. The key to the design lies in the perfect building-structure combination and good structural working performance.

(2) With a ground-mounted reinforced concrete tube-stay cable-steel frame structure, the bridge between structures integrates the merits of small dead weight, low cable burden, strong compatible deformability, reasonable stress bearing, etc.

### References

- [1] Fu Xueyi, GaoYing, Xiao Congzhen, Tian Chunyu, Chen Xianchuan, Yang Xiangbing, Tang Haijun, Wu Bing. Structural design of building of Wanke Center floating 10~15m high on the ground[J]. building structure, 2009, 39(05):91-96
- [2] Ceb-Fip Model Code 1990: Design Code[S]. 1990
- [3] USA Applied Technology Council. Design Guide for reducing floor vibration[S]. 1999.(in USA)
- [4] Ministry of Housing and Ruban-rural Development of the People's Republic of China. JGJ 92-2016 Technical specification for concrete structures prestressed with unbonded tendons [S]. Beijing: China Architecture and Building Press, 2016. (in Chinese)
- [5] Ministry of Housing and Ruban-rural Development of the People's Republic of China. GB50010-2010(2015) Code for design of concrete structures [S]. Beijing, 2015. (in Chinese)