Analysis on Prestress Application for Cable Net Supported Curtain Wall

Li Ming
Civil Engineering College
Shenyang Jianzhu University
Shenyang, China
Jangho Group Co., Ltd.
Beijing, China
e-mail: dingxianxing@126.com

Wang Liguo
Civil Engineering College
Shenyang Jianzhu University
Shenyang, China
e-mail: 625042821@qq.com

Wang Yuanqing
Civil Engineering College
Tsinghua University
Beijing, China
e-mail: wang-yq@mail.tsinghua.edu.cn

Tao Wei
Jangho Group Co., Ltd.
Beijing, China
e-mail: taowei@jangho.com

Wang Bin
Jangho Group Co., Ltd.
Beijing, China
e-mail: wangbin06@jangho.com

Shan Renliang
Civil Engineering and Mechanics
China University of Mining&Technology
Beijing, China
e-mail: srl@cumtb.edu.cn

Abstract—Plane cable net supported glass curtain wall (PCNSGCW) has become the development trend of large scale curtain wall due to its beautiful appearance and good limpidity. In China, a large amount of research has been done on it and it develops fast in recent years. But there are still many problems need to be studied. In order to provide technology support reference for the construction of PCNSGCW, the process of how the prestress is applied on the cable net is simulated and analyzed based on a real building. By comparing different prestress application program, the following conclusions can be gotten: the number of prestress application can be reduced near to 50% by adjusting the prestress load of each step; the distance of moving prestress application equipments can be greatly reduced by adjusting the sequence of prestress application. So it is an effective method to make the construction easy by adjusting the prestress load of each step and the sequence of prestress application for buildings that uneven prestress leads to small inhomogeneous deformation of the main structure.

Key words- Plane cable net; Curtain wall; Construction; simulation; Prestress

Ⅰ.INTRODUCTION

Glass curtain wall is composed of support structure system, glass panels and sealing materials etc. There are three major forms of support structure system, including exposed frame, concealed frame and point-supported style. The former two styles are assembled in prefabricated units and applied in civil engineering early, but they are limited in some buildings because the continuity of transparent glass is broken by the four sides supported opaque frames. The support structure of the third curtain wall is independent to from the glass panels, in which the glass panel is directly connected with the support structure via a stainless steel claw and the glass panels are connected only by waterproof glue. Therefore, it is much favored by architects for its beautiful appearance, flexible layout and good permeability. The support system of it can be classified in rigid and flexible one, and the flexible support system can be classified in cable net and cable truss one, and the cable net support system can be classified in plane and curved one, and the plane cable net support system includes single layer plane and double layer one. Among them, single plane cable net supported glass curtain wall (PCNGCW) stands out for its better permeability in the group curtain wall forms. It has become the representative of the development direction of large-scale glass curtain wall.In recent years, the development of research on cable net curtain wall is very rapidly in China. A large amount of results are achieved in the static calculation method, the wind and seismic performance, damage analysis [1-10]. But the theory still lags behind the engineering need. Utill now, the complete plane cable net curtain wall design calculation theory system has not been formed, and there are still many problems need to research. In the following, the porcess and menthod of prestress application for Cable Net supported curtain wall will be analyzed based on a real building, which will provide reference for the construction of such curtain wall.

Ⅱ. ENGINEERING SITUATION

3D axonometric diagram of an exhibition Center' s roof structure and cable curtain wall structure is shown in Fig .1. Cable curtain wall structure is divided into 3 region: MQ1a region including the cables between axis 1A-18~1A-K; MQ2a region including the cables between axis 1A-K~1A-AE; MQ3a region including the cables between axis1A-AE~1A-16. The resiogns are shown in Fig .2. The number of cables in the three resgion is 20, 36 and 27 seperately. The cables being dived into three regions is because there are not so many tension equipments for all the cables being tensioned at the same time. The tension can only be applied for the first MQ1a region, then for the MQ2a region, then for the MQ3a region. Because in the process of tensioning, inhomogeneous deformation will cause the damage of the main structure. So, in the process of tensioning, the prestress of the cables of each region can't be completely applied by one step. That is, in the actual construction, first all cables are hung on the main structure, and then the part of prestress are applied for the cables in the following sequence: MQ1a region, MQ2a region, MQ3a region.After that, another part of prestress are applied for the cables in the same sequence. The process are repeated untill all the cables are tentioned to the designed prestress. The smaller of the applied prestress of each step is the smaller the inhomogeneous deformation of the main structure is. But the times of tension will be increased, which will make the construction difficult. Therefore, in the following, the magnitude of the prestress applied at each step will be analyzed wiht the condition that no large inhomogeneous deformation is produced in the main structure.

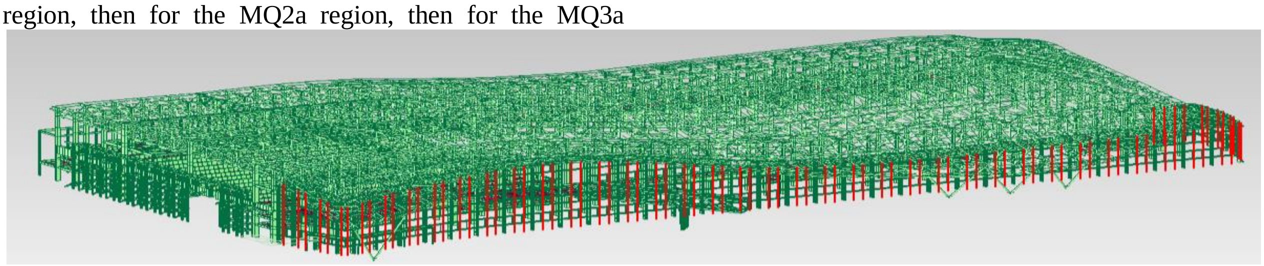
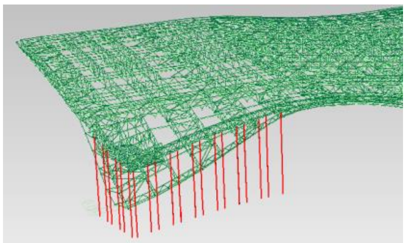
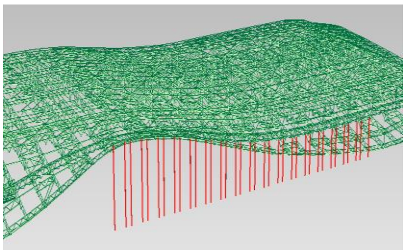


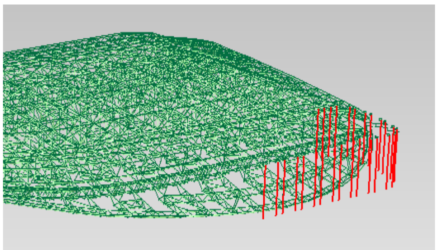
Figure 1. 3D axonometric diagram of a exhibition Center's roof structure and cable curtain wall structure



（a）1A-18~1A-K axis between the MQ1a region



（b）1A-K~1A-AE axis between MQ2a region



（c）1A-AE~1A-16 axis between the MQ3a region

Figure 2. Cable curtain wall structure's 3 sections

Ⅲ.THE SIMULATION PROCESS AND RESULTS

A. Initial simulation results

First, the prestress is applied with the level of 10% and 15%, i.e, the prestress is applied 10% of the complete stress at the first step for the three regions, than 15% of the complete stress at the residual steps, shown as table Ⅰ. Under that prestress application steps, the main structure deformation difference of different regions is checked whether it satisfy the permitted one.

Because in the step 3, 6, 9, 12, 15, 18, 21, the prestress of the three regions are equal to each other, there is no inhomogeneous deformation produced in the main structure and it's unnecessary to check these steps. So, only the most unfavorable condition step21is checked.

The results show that the inhomogeneous deformation of the main structure is less than 2mm under the above described prestress level for different regions, which is fully meet the requirements of the main structure.

TABLE Ⅰ. PRESTRESS APPLYING STEPS WIHT THE LEVEL (10% and 15%) FOR DIFFERENT REGIONS

Prestress application step	Applied prestress(KN)and how much it accounts for the finished prestress		
	MQ1a region	**MQ2a region**	**MQ3a region**
1	18 (10%)	0	0
2	18 (10%)	18 (10%)	0
3	18 (10%)	18 (10%)	18 (10%)
4	45 (25%)	18 (10%)	18 (10%)
5	45 (25%)	45 (25%)	18 (10%)
6	45 (25%)	45 (25%)	45 (25%)
7	72 (40%)	45 (25%)	45 (25%)
8	72 (40%)	72 (40%)	45 (25%)
9	72 (40%)	72 (40%)	72 (40%)
10	99 (55%)	72 (40%)	72 (40%)
11	99 (55%)	99 (55%)	72 (40%)
12	99 (55%)	99 (55%)	99 (55%)
13	126(70%)	99 (55%)	99 (55%)
14	126(70%)	126(70%)	99 (55%)
15	126(70%)	126(70%)	126(70%)
16	153(85%)	126(70%)	126(70%)
17	153(85%)	153(85%)	126(70%)
18	153(85%)	153(85%)	153(85%)
19	189(105%)	153(70%)	153(70%)
20	189(105%)	189(85%)	153(70%)
21	189(105%)	189(105%)	189(105%)

B. Second simulation results by adjusting prestress level.

As can be seen from the above analysis, the construction program is feasible when the prestress level is 10% -15% of the total prestress for each step. However, in order to simplify the construction, we can further increase the amount of each class of prestress, instead. Based on past experience in engineering, each prestress level is adjusted to 10% and 30% of the total prestress, thus the number of tension can be substantially reduced. In order to analyze the feasibility of the second construction plan, the method of classifying the tension by 10% and 30% of the total prestress for each step is simulated and analyzed, shown as table Ⅱ.

Due to the condition of the prestress application step1,2,3,12 are the same as Table Ⅰ, and the condition of step 6,9 is more favorable than that of step 21, the situations of these steps are not simulated and analyzed. And only the situation of step 4,5,7,8,10,11 are simulated.

The results show that the prestress applied by this construction program, the inhomogeneous deformation of the main steel structure is still very small, which is less than 2mm. Thus, it's recommended that the prestress being applied by the level of 10% and 30% of the total prestress.

TABLE Ⅱ. PRESTRESS APPLYING STEPS WIHT DIFFERENT LEVEL (10% OR 30%) FOR DIFFERENT REGIONS

Prestress application step	Applied prestress(KN)and how much it accounts for the finished prestress		
	MQ1a region	**MQ2a region**	**MQ3a region**
1（as step1 in table Ⅰ）	18 (10%)	0	0
2（as step2 in table Ⅰ）	18 (10%)	18 (10%)	0
3（as step3 in table Ⅰ）	18 (10%)	18 (10%)	18 (10%)
4	72 (40%)	18 (10%)	18 (10%)
5	72 (40%)	72(40%)	18 (10%)
6	72 (40%)	72 (40%)	72 (40%)
7	126 (70%)	72(40%)	72 (40%)
8	126(70%)	126 (70%)	72 (40%)
9	126 (70%)	126 (70%)	126 (70%)
10	189 (105%)	126 (70%)	126 (70%)
11	189 (105%)	189(105%)	126 (70%)
12 （as step21in table Ⅰ）	189 (105%)	189 (105%)	189 (105%)

C. Final simulation results by adjusting construction sequence

In order to reduce the distance of moving prestress application equipments, the prestress application sequence are adjusted. First part of the prestress is applied from MQ1a region to MQ2a region, then to MQ3a region. After that, another part of prestress are applied for the cables from MQ3a region to MQ2a region, then to MQ13a region. The above process are repeated untill all the cables are tentioned to the designed prestress. The prestress level of each step is the same as the second simulation process. The prestress application with different prestress for the cables of different region is shown in Table Ⅲ. Because the situation of step 1, 2, 3, 6, 7, 8, 9, 12 is the same as table Ⅱ, it's unnecessary to simulate the situation of these steps again. So only the situation of step 4, 5, 10, 11 is simulated.

The results show that the prestress applied by this construction program, the inhomogeneous deformation of the main steel structure is still very small, which is less than 3mm. Thus, it's recommended that the prestress being applied by the repeated sequence: MQ1a region to MQ2a region to MQ3a region to MQ2a region to MQ1a region.

Ⅳ.CONCLUSIONS

From the above analysis, the following conclusions can be drawn:

The times of prestress application for the cables can be reduced near to 50% by adjusting the prestress application level of each step from 10% and 15% to 10% and 30% of the total prestress of the cables, which effectively reduces the difficulty of construction.

The distance of moving prestress application equipments can be greatly reduced by adjusting the prestress repeated application sequence from MQ1a region, MQ2a region, MQ3a region, MQ1a region to MQ1a region, MQ2a region, MQ3a region, MQ2a region, which will greatly improve the speed of construction.

During the process of prestress application for the cables of curtain wall, it's necessary to adjust the prestress level of each step and adjust the sequence of prestress application with the condition that only small inhomogeneous deformation of the main structure being induced by the uneven prestress. This will greatly reduce the construction difficulty and improve the construction speed.

ACKNOWLEDGEMENTS

This work was financially supported by China Postdoctoral Science Foundation funded project and Beijing Postdoctoral Research Foundation

TABLE Ⅲ. PRESTRESS APPLYING STEPS WIHT DIFFERENT LEVEL (10% OR 30%) FOR DIFFERENT REGIONS

Prestress application step	Applied prestress(KN)and how much it accounts for the finished prestress		
	Part of MQ1a	**Part of MQ2a**	**Part of MQ3a**
1（as step 1 in table Ⅱ）	18 (10%)	0	0
2（as step 2 in table Ⅱ）	18 (10%)	18 (10%)	0
3（as step 3 in table Ⅱ）	18 (10%)	18 (10%)	18 (10%)
4	18(10%)	18 (10%)	72(40%)
5	18 (10%)	72(40%)	18 (40%)
6（as step 6 in table Ⅱ）	72 (40%)	72 (40%)	72 (40%)
7（as step 7 in table Ⅱ）	126 (70%)	72(40%)	72 (40%)
8（as step 8 in table Ⅱ）	126(70%)	126 (70%)	72 (40%)
9（as step 9 in table Ⅱ）	126 (70%)	126 (70%)	126 (70%)
10	126(70%)	126 (70%)	189(105%)
11	126 (70%)	189(105%)	189 (105%)
12（as step 12 in tableⅡ）	189 (105%)	189 (105%)	189 (105%)

REFERENCES

[1] Wu Lili. "Research on Wind-induced responses and wind-resistant design methodology of monolayer cable net for glass facades". Beijing: Doctoral dissertation of Tsinghua University, 2006.

[2] Wu Lili, Wang Yuanqing, Shi Yongjiu, “Influence of stiffness of glass panels and joint constraints on dynamic properties of monolayer cable net for point-supported façade”, Journal of Shenyang Jianzhu University, Vol.21, 2005, pp.432-436.

[3] Li Yong. "Study on seismic properties and a-seismic analysis method of sing1e-layer cable net for PGCW". Beijing: Master Degree dissertation of Tsinghua University, 2009.

[4] Zhang Yongjun, Zou Qing, Li Xingpo, “The influence of cable net on the dynamic characters of main structure”, Low Temperature Building Technology, Vol.10, 2012, pp. 50-52.

[5] Feng Ruoqiang, Ye Jihong, Wu Yue, “Seismic response of cable net façade”, China Civil Engineering Journal, Vol.43, 2010, pp. 67-73.

[6] Feng Ruoqiang, Wang Xin, Ye Jihong, “Seismic behavior of cable net façade”, Journal 0f Vibration Engineering, Vol.26, 2013, pp. 477-486.

[7] Feng Ruoqiang, Wu Yue, Shen Shizhao, “Nonlinear response spectrum of cable net façade”, China Civil Engineering Journal, Vol.45, 2012, pp.30-41.

[8] Yue Lijie, Liu Junjin, He Ping, “The application of spring devices in supporting structures of glass curtain wall”,Building Science, Vol.27,2011, pp. 76-79.

[9] Zhao Yifeng ,Liu Jian, Luo Chiyu, “The Research of Current Status and Progress of Glass Curtain Wall with Single Layer Plane Cable Net on Wind Resistance and Seismic Resistance”, South China Journal of Seismology, Vol.34,2014,pp.118-122.

[10] [10] Zhang Yu. "The study of single-layer plane cable net curtain wall performance". Shenyang: Shenyang University of Technology, 2014.