Analysis on cooperative working performance of curtain wall glass and steel hanging columns

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Abstract. The curtain wall of Xi'an Silk Road International Conference Center is a large-span combined steel column supported glass curtain wall system. The curtain wall glass is directly installed on the steel hanging columns of the external suspension structure, and there are no curtain wall hanging columns that are independent of the main structure. The vertical, tangential and radial deformation of the steel hanging columns under service load may lead to vertical shear, in-plane extrusion, in-plane sliding and out of plane bending of the curtain glass. Therefore, finite element model of curtain wall glass was established using the finite element program ABAQUS. Considering the four possible failure modes of the curtain glass, the collaborative working performance of the curtain wall glass under the most unfavourable deformation conditions of steel hanging columns was analyzed.

1. Introduction of the glass curtain wall system
The external curtain wall of Xi'an Silk Road International Conference Center is a large-span combined steel column supported glass curtain wall system with a special-shaped curved surface. The curtain wall span is 189m and the height is 37.3m to 46.7m. In order to meet the requirements of the architectural design effect, the curtain wall glass is directly installed on the steel hanging columns of the external suspension structure, and there are no curtain wall hanging columns that are independent of the main structure. Compared with the conventional glass curtain wall system, new requirements have been put forward on the installation accuracy of the steel hanging columns and the cooperative working performance between the curtain wall glass and the steel hanging columns. The standard partition size of curtain wall glass is 2400mm × 3500mm, and its main features are as follows: hollow double laminated ultra-white glass was used in the curtain wall system, which integrated safety, lighting, sound insulation and self-explosion protection together. The vertical keel of the curtain wall was replaced by the steel hanging columns, and the glass was supported by cantilevered steel plate welded on the steel hanging columns.

2. Analysis of the most unfavourable deformation of curtain wall hanging columns
Based on the calculation and analysis of the whole structure model under the load combination without earthquake operated by Zhou[1], it is found that the maximum vertical relative deformation of the adjacent curtain wall columns appears in the situation listed in the following table 1 and figure 1.

Table 1. Corresponding situation of coordinated deformation and failure mode of curtain wall glass and steel hanging column.

| Failure mode of curtain wall glass | Coordinated deformation mode of | Location of maximum deformation occurs | Maximum coordinated deformation |
|-----------------------------------|---------------------------------|----------------------------------------|-------------------------------|

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3. Mechanical performance analysis of curtain wall glass

3.1 Model of curtain wall glass
Considering the structural characteristics and calculation conditions, numerical simulation on the curtain wall glass of Xi'an International Conference Center was carried out using the finite element program ABAQUS. The size of glass panel is 2400mm × 3500mm, the width of adhesive strip is 12mm, and the thickness is 8mm. Because the upper and lower layers of double-layer glass are not related to each other, only one side need to be calculated, and the 8 (TP) + 1.52pvb + 8 (TP) side was selected for analysis[2]. The finite element model of curtain wall glass is shown in figure 2, the parameters were set as follows:

Glass parameters: elastic modulus is 72000Mpa, Poisson's ratio is 0.2.
Strip parameters: elastic modulus is 7.8MPa, Poisson's ratio is 0.47.

Element and mesh: solid element is used which was divided into 8 layers along the thickness direction.
Contact setting: smooth contact is set between two layers of glass, and the contact surface cannot be separated.
Boundary condition: since the glass panel only adheres to the adhesive strip on both sides, the upper and lower sides are free ends, and the displacement in the plane (U2) and out of the plane (U3) are constrained by the width direction of the adhesive strip on the left and right sides[3-4].

The geometric nonlinearity was also considered. After parameter setting was completed, the model is as shown in figure 3.
3.2 Vertical shear analysis
According to table 1, the maximum vertical relative deformation of the unit curtain wall glass panel is 25mm. Based on the given boundary conditions, the calculation results are as follows:

The maximum deformation of the whole glass panel is only about 5mm, but the vertical deformation of the end rubber strip is up to about 25mm due to its small elastic modulus.

The maximum Mises stress of the curtain wall glass is 1.0 MPa (figure 4- figure7), which appears at the junction of glass and rubber strip. According to the Technical code for glass curtain wall engineering (JGJ 102-2003) [5], the design value of side strength of glass with thickness of 8mm is 19MPa. Therefore, the overall stress level is small, and the safety of the glass can be guaranteed.

3.3 In plane extrusion analysis
According to the supporting structure of the curtain wall glass, there are still 12mm margins on both sides of the depth of the glass entry groove, that is, 24mm tangential deformation space exists. Therefore, the in-plane squeezing problem does not occur.

3.4 In plane slippage analysis
The depth of the glass that has entered the groove is 23mm on both sides, that is, there is a 23mm tangent outward deformation space. Therefore, in-plane slippage will not occur.
3.5 Out of plane bending analysis

According to table 1, the maximum radial relative deformation of unit glass panel is 150 mm. The calculation results are as follows:

The maximum value of total deformation is 150.5 mm, among which the maximum value of in-plane tangential deformation caused by bending is about 5.4 mm, which is less than 23 mm into the groove depth, so the glass will not slide due to bending deformation.

The maximum Mises stress of the curtain wall glass is 0.048 MPa, which appears at the junction of glass and rubber strip (figure 8-figure 11). Therefore, the overall stress level is small, and the safety of the glass can be guaranteed.

4. Conclusion

Using the finite element program ABAQUS, an accurate finite element model of the curtain wall glass of the Xi'an Silk Road Conference Center was established. Focused on four possible failure modes of curtain wall glass such as shear failure of glass caused by vertical deformation of curtain wall column, extrusion failure of glass caused by tangential internal deformation of curtain wall column, sliding of glass caused by the outward deformation of curtain wall column and out of plane bending of glass caused by radial deformation of curtain wall column, finite element analysis were carried out. The results showed that under the most unfavorable deformation condition of steel hanging column in normal operation stage, the curtain wall glass will not be damaged by in-plane extrusion or in-plane sliding, the vertical shear deformation and out of plane bending deformation are also very small, the wall glass and steel hanging columns work well together, and the structure is safe and reliable.

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