Structure and Stress Mechanism of Snti-buckling Support for High-rise Connected Structures

Chenghua Guo*
Liaoning Jianzhu Vocational College, Liaoyang, 111000, Liaoning, China

*Corresponding author e-mail: 35348717@qq.com

Abstract. This article explores the characteristics, composition, and design requirements of high-rise intelligent buildings, analyzes their superiority and social benefits, and studies their construction principles and future development trends. It is people-oriented, device-oriented and function-oriented. The original three major structural systems have been increasingly unable to meet new requirements. This paper seeks a new seismic system that is both safe and able to protect the instruments and equipment inside the building, and can be connected to the main structure of the structure for normal operation and economically. After a thorough discussion of the latest proposed seismic design methods and performance-based seismic design, this paper proposes performance-based structural seismic design countermeasures with the characteristics of high-rise intelligent buildings. Determine the target performance according to the owner's requirements and building functions and investment benefit criteria; then determine the safety indicators of the high-performance intelligent building based on the performance structural design; compare the three optimization decision models for the reliability of the performance-based structural targets; An evaluation model of initial cost, inspection and maintenance costs, and failure loss costs. A reliability optimization decision-making model based on performance and earthquake resistance for a high-rise intelligent building is established. The research results show that the maximum displacement of the model structure in the X direction is 14.8mm and 13.8mm, and the maximum displacement in the Y direction is 13.7mm and 12.9mm, respectively. The maximum displacement of the latter in the X and Y directions is compared with the former. From the perspective of the curve change, the displacement change curve of the anti-buckling support frame is always smaller than the displacement curve of the ordinary support frame.
Keywords: Anti-buckling Support, Steel Frame Structure, Optimized Design, Seismic Performance, Time History Analysis

1. Introduction

The rise of intelligent buildings in China is based on two reasons. One is that with the reform and opening up, China's national economy has continued to develop rapidly, its comprehensive national strength has been continuously enhanced, and people's living standards have been improved. People urgently need to improve and enhance their working and living environments. Architecture is one of the important ways to meet this demand. Now intelligent building has become one of the specific characteristics of the comprehensive economic national strength, and it has become the mainstream of all types of buildings in the world, especially large buildings. How to use foreign technology and foreign advanced design methods to speed up the pace of localization construction, promote the healthy and orderly development of high-rise intelligent buildings in our country, and move towards high speed, high integration, and high performance price ratio. Important tasks facing.

Anti-buckling support refers to the support of soil members in the support. Some of the anti-buckling supports with concrete can now be industrialized and put into a lot of actual projects. This type of anti-buckling support is also the earliest researched one in the world. In terms of the stability of the extension, Jiabin Sun et al. Studied the influence of the buckling-resistant brace and the frame connection on the building. During the test, the problem of instability of the extension was also observed, but the principle of its failure was not essential. Explained exactly [1]; DF Zhang proposed three ways of rotation of the buckling-proof support end by combining experiments and theory, clarified the principle of the failure of the extension, and gave the stability design method of the extension [2]. In terms of local stability, the previous analysis was based on the stability of the struts on the elastic foundation. Andreas Luible et al. Based on this research model, using the anti-buckling support restrained by concrete-filled steel tube as the test object [3]; People take full-angle steel anti-buckling support as the research object, and confirm the local buckling phenomenon of the support through experiments, and give a reasonable width-to-thickness ratio limit to avoid this problem [4]; LI Lin et al. For the buckling problem, a simplified model was used for finite element analysis, and the minimum tube wall thickness formula for avoiding local instability was summarized based on the data results; Guotao Yang et al. Based on local instability characteristics and performed only on locally squeezed areas. The model is simplified, and the minimum thickness of the confined steel tube is determined without local instability of the support [6].

After comparing the current two intelligent building evaluation methods, this paper proposes to use the GBIAM method to evaluate the intelligence level of high-rise intelligent buildings. The seismic effects of equipment systems in high-rise intelligent buildings are discussed, and the seismic fortification of intelligent equipment is discussed.

And explore its construction principles and future development trends. High-rise intelligent building is a multi-disciplinary subject with system integration characteristics. It is equipment-oriented and function-oriented design. It is an inevitable product of adapting to the development of economy and improving living conditions.
2. Proposed Method

2.1 Working Principle of Anti-buckling Support

Before designing the anti-buckling support, you should clearly understand the working principle under load. According to the section of the first chapter, the anti-buckling support, there is a layer between the inner core material and the external restraint member. No bonding materials or voids, and the core material bears all external forces. When an earthquake load acts on the structure, the beams and columns will transmit the axial tensile and compressive force to the buckling-proof support. When the force is small, the internal core material is supported to maintain elasticity. At this time, the buckling-proof support provides the structure with the same resistance as the ordinary support Side stiffness

![Figure 1. Buckling Restrained Brace deformation process](image)

2.2 Stability Theory of Anti-buckling Braces

1) Overall stability of anti-buckling support

The core material for anti-buckling support is generally made of steel with low yield strength, and its bending stiffness is small. When the pressure is applied to both ends of the support, the core unit is easy to yield. If the rigidity of the peripheral restraint members is insufficient, it is easy to cause the component The deformation shown in Figure 2 is called the overall instability. Therefore, the overall stability design of the anti-buckling support member is for peripheral restraint members. In this section, the theoretical formula of the critical load of the overall instability is derived through the simplified calculation of the buckling-resistant support forces.
Figure 2. Buckling Restrained Brace overall instability diagram

(2) Stability of the buckling-resistant core unit

Figure 3 depicts the instability of the core unit intuitively. Generally speaking, the stability of the core unit means that when the elastic constraint stiffness provided by the inner surface of the restraint member is insufficient, it is likely that the core core material will generate a single or multiple half waves Bend and this phenomenon only exists on the core unit.

Figure 3. Instability of the core unit

When the core element touches the concrete or mortar, use q to represent the load acting on the core element by the concrete or mortar, then \( q = cy \), define the elastic constraint stiffness \( c = E \frac{(1-v)}{(1+v)(1-2v)} \), \( v \) is Poisson's ratio, and bring it into the equilibrium equation, which can be obtained:

\[
P = \frac{n^2 \pi^2 E I_1}{I^2} + \frac{c I^2}{n^2 \pi} \quad (1)
\]

Here, \( P \) is the buckling load of the core element, and its value is related to the two parameters \( c \) and \( n \) in the formula, where \( n \) is the half-wave number at buckling, and then the derivative of \( n \) is obtained according to \( \frac{dP}{dn} = 0 \):
\[ n = \frac{\sqrt{c / E_c I_1}}{\pi} \quad (2) \]

The final buckling load is approximately

\[ P_{cr} \geq \frac{2}{\pi} c E_c I_1 \quad (3) \]

To avoid buckling of the core unit before its yielding, let \( P_{cr} \geq F_y \) and replace the

\[ c = E_c \frac{(1 - v)}{(1 + v)(1 - 2v)} \]

Into

\[ E \geq \frac{F_y^2 (1 + v)(1 - 2V)}{4E_c I_1 (1 - v)} \quad (4) \]

Therefore, when the elastic modulus of concrete or mortar meets the conditions of the above formula, theoretically, the problem of instability of the core unit can be avoided.

2.3 Mechanical Properties of Anti-buckling Support Frame Structure

The anti-buckling support frame system is composed of the main frame and BRB. Under different fortified earthquakes, the behaviors of the two are different [7], so the mechanical model of the system is usually composed of the interlayer model of the structure and The restoring force model of the support is superimposed, and the specific situation should depend on different fortification targets. The frequent earthquake, the body frame and the support should be in the elastic stage, this time, the initial displacement of the support \( U_{by} \) yield should be greater than the first phase displacement between the \( U_1 \) target layer, thus ensuring the structure when the main body is elastically deformed, is supported in elastic deformation stage, will not affect the overall structure of the anti-side stiffness between the stiffness \( K_1 \) layer system may be expressed as:

\[ K_1 = K_f + K_b \quad (5) \]

Additional damping ratio of energy dissipating components

In a shock-absorbing building, the damping ratio added to the structure by energy-dissipating members is usually used to measure the energy dissipated. The value of the seismic influence coefficient can be directly calculated by adding the damping ratio [8]. Therefore, the selection of a suitable damping ratio is the key to the design of energy-absorbing and shock-absorbing buildings.
The formula for estimating the effective damping ratio is also given in the resistance regulations as follows:

\[ \xi = \frac{\sum W_{cj}}{4\pi W_s} \]  

(6)

- \( W_{cj} \) - hysteresis energy of the jth energy dissipation component under the target displacement;
- \( W_s \) - Total strain energy of a shock-absorbing structure at a target displacement.

2.4 Time History Analysis

The elastic time history analysis method divides the duration of the ground motion at the same time interval [9], and the acceleration changes linearly with time.

\[ Mu_t + Cu_t + Ku_t = P_t \]  

(7)

In the formula: \( M, C, K, P_t \) - system total mass matrix, damping matrix, stiffness, dynamic load; there are many methods for the integral calculation of the motion equation, such as Newmark method, Wilson method, etc., are implicit algorithms.

3. Experiments

3.1 Experimental Methods

Based on the optimization design method of the previous chapter, this chapter uses a steel frame office building as a design example to design an anti-buckling support with a relatively ideal cross-sectional area. YJK software is used to establish a herringbone ordinary support steel frame and anti-buckling support steel frame two structures, and perform modal and response spectrum analysis on the structures to verify the correctness of the designed structure. In order to study the seismic performance of two structures under seismic excitation, ABAQUS was used to analyze the time history of the two supporting system models respectively [10], and the response of the two building models was evaluated by comparing the response indicators under frequent and rare conditions. The seismic performance further explains the BRB's ability to reduce vibration during the earthquake.

3.2 Experimental Collection

This project is a steel-framed office building with 5 structural layers, each with a height of 4m and a total height of 20m. The structural is 46.2m long (7 spans) and 19.8m wide (3 spans). As the planar span of the structure is large, a herringbone-type anti-buckling restraint support is set on each of the edges around the model. The design life of this structure is 50 years, the seismic fortification is 8 degrees (0.2g), the design earthquake group is the first group, the site category is Class II, the snow
load is 0.50kN / m², the basic wind pressure is 0.55kN / m², 1~7-layer dead load is 5kN / m², the live load is 2kN / m², the roof is 0.5kN / m², the floor thickness is 120mm, and the concrete strength is C20. The beams and columns are all H-shaped steel and just connected.

4. Discussion

4.1 Form Analysis

Table 1. Frame component information

| Component name | High(h) | Flange width(b1) | Flange high(t) | Web thickness(tw) |
|----------------|---------|------------------|----------------|------------------|
| Frame column   | 600     | 470              | 23             | 15               |
| KJL1           | 600     | 250              | 15             | 9                |
| KJL2           | 550     | 230              | 15             | 9                |
| Secondary beam | 500     | 230              | 12             | 9                |

As shown in the table above, the structural plane is 46.2m in length (7 spans) and 19.8m in width (3 spans). The planar span of the structure is large. Therefore, herringbone anti-buckling restraint supports are set on the side spans around the model.

Table 2. The first six cycles of a common support frame

| Mode of vibration | Cycle | UX quality participation factor | UY quality participation coefficient | RZ quality participation coefficient |
|-------------------|-------|---------------------------------|-------------------------------------|------------------------------------|
| 1                 | 1     | 0.6254                          | 0                                   | 0.00                               |
| 2                 | 0.6241| 0.00                            | 0.76                                | 0.00                               |
| 3                 | 0.3476| 0.00                            | 0.00                                | 0.76                               |
| 4                 | 0.2347| 0.14                            | 0.00                                | 0.00                               |
| 5                 | 0.2147| 0.00                            | 0.14                                | 0.00                               |
| 6                 | 0.1427| 0.00                            | 0.00                                | 0.14                               |

From the results in Table 2 above, it is observed that the first six periods of the two structures are very close, indicating that the stiffness of the two models is similar. The first three order periods of the extracted structure are 0.6583s, 0.6236s, 0.3881s, and the cycle ratio is 0.59. The cycle ratios meet the requirements of the specification, and the quality coefficients are all above 90%.

4.2 Response Spectrum Analysis

Horizontal displacement and inter-layer displacement angle.
Figure 4 compares the horizontal displacement of the floor of the ordinary support frame structure and the anti-buckling support frame structure. The maximum displacements of the two model structures in the X direction are 14.8mm and 13.8mm, and the maximum displacements in the Y direction are 13.7mm and 12.9mm, respectively. The maximum displacements of the latter in the X and Y directions are respectively reduced by 6.76% and 5.80% compared to the former. From the perspective of the curve change, the displacement change curve of the anti-buckling support frame is always smaller than that of the ordinary support frame. Displacement curve, but there is not much difference between the two.

5. Conclusions

This article mainly summarizes the basic theory and mechanical properties of anti-buckling braces, and introduces the design method and mechanical model of BRB frame structure. After a series of basic studies, an optimal design method based on target displacement is concluded. Taking the actual project as an example, this method was used to optimize the design of the cross-sectional area of the BRB. The ABAQUS software was used to establish a buckling-resistant steel frame and a normal steel frame with a herringbone layout. The seismic performance of the two types of structures was compared. Finally, the dynamic responses of five different arrangements of BRB steel frames under the El-Centro seismic wave were compared. The main conclusions are as follows:

When subjected to an earthquake load, the buckling-proof support in the structure will take the lead in dissipating energy and protecting the main structure. Its working principle mainly depends on the deformation of the core material inside the support. During the design process, it must be ensured that the support cannot When instability occurs, at the same time, in the calculation and analysis, it is necessary to derive formulas for important parameters such as clearance, equivalent cross-sectional area, equivalent stiffness, and bearing capacity, and determine accurate component parameters for overall structural calculation.

The design of the pure steel frame structure according to the structural plane information can determine the cross-sectional dimensions of the beams and columns, and then the lateral stiffness of
each layer can be obtained. Using the optimization design method based on the target displacement, the nominal stiffness ratio of the top layer is initially selected. The stiffness of the top support can be obtained, and then the total cross-sectional area of each support can be further solved, and the ideal support area can be determined through trial and error. In order to study the shock absorption capacity of the BRB, an ordinary support frame is added for comparison. The same cross-sectional area as the anti-buckling support is selected. The analysis model is established using the YJK software. The modal analysis and response spectrum analysis are performed separately. The first six order periods are similar, and the obtained inter-layer displacement angles, floor displacements, and base shear forces are not much different, and the structure has no sudden change in stiffness. The rationality of the designed structure can be determined.

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