Seismic Response Analysis of Buckling Restrained Frames

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Abstract. The frame structure system uses additional buckling restraint support, which greatly improves the shear strength and lateral stiffness of the entire structure, and plays a positive role in reducing the displacement between layers and the overall displacement of the structure. When the additional buckling restraint support is used in the frame, the hysteresis curve of the system is fuller, which greatly improves the energy consumption capacity of the structure. The descending section of the stent skeleton line breaks through the traditional limitations, and its descending degree slows down as the displacement increases. The lateral stiffness of a buckling restrained frame is poor, and usually requires large beam and column sections to meet the requirements. Under the action of earthquakes, the support of buckling restrained frames is prone to buckling and instability, resulting in a sharp decline in its seismic resistance. The purpose of this paper is to analyze the seismic response of buckling-restrained frames. In terms of methods, this article mainly starts from the design method and principles of buckling restrained braced steel frame, and then designs and discusses the buckled restrained braced steel frame. Then it designs the BRB size and uses the Perform-3d software to build a nonlinear structural model. Use time history analysis to analyze some possible problems in the building. In terms of experiments, this paper mainly analyzes the seismic response of a building, and introduces the situation of the building and its analysis in terms of earthquake prevention. From the four strong earthquake records recorded in this paper, it can be seen that the maximum value of the seismic acceleration time history increases with the increase of the earthquake intensity. And the earthquake impact of rare earthquakes will be greater than that of more frequent earthquakes under the same intensity. From the data of structural analysis, the period of the original structure is greater than the period of the BRB structure under the same mode shape. As the mode shape increases, the period difference decreases and converges.

Keywords: Buckling Constraint, Hysteresis Curve, Lateral Stiffness, Seismic Response

1. Introduction
At present, the frame structure is still one of the most widely used structural systems in civil buildings. As the height of the structure increases, a simple frame structure cannot meet the seismic requirements specified in the code. Therefore, various common civil building systems are derived from the pure
frame structure, including frame shear wall system, frame support system, frame core pipe system, etc. The traditional seismic methods of strengthening the frame structure by bending include adding reinforced concrete seismic walls, increasing the cross section, sticking steel, carbon fiber board, wrapping steel, etc. However, because the cross-sectional size and reinforcement ratio of the buckling restrained structure after reinforcement cannot meet the requirements of the code, there are limitations in engineering applications. Support frame systems are also widely used in seismic reinforcement works. However, since the traditional support frame will bend when the support frame is compressed, it is often necessary to increase the cross-section to meet the design requirements, which seriously reduces its practicality and economy. Since then, many scholars in the United States, Japan, and other places have studied the instability and damage characteristics of braces, and have proposed flexion-restricted braces, referred to as BRB.

There are many measures and methods for earthquake resistance of structures, such as vibration isolators, shear walls, supports, steel frames, etc. At present, the most common measure to improve the seismic performance of steel structures is to increase the central support in the steel structure frame. However, traditional steel supports have some shortcomings. Steel supports are prone to buckling under axial pressure. The strength of the buckled steel bracket will seriously affect the structure. The overall lateral rigidity of the system and the inability to fully utilize the performance of the steel due to the premature buckling of the stent greatly reduce the efficiency of steel use. In the early Beiling earthquake and Kobe earthquake [1]. Many buildings were severely damaged, including some with central support. The main feature of this type of building damage is the inability of the central support to work. The steel structure is lightweight, high strength, and good seismic performance. Pure steel frames have poor lateral stiffness and usually require large beam and column sections to meet the requirements [2]. The support of the steel frame under the central support is prone to buckling and instability under strong earthquakes, resulting in a sharp decline in its seismic resistance. The eccentric support of the steel frame solves the problems in the above structural system to a certain extent, but the support still has asymmetric buckling and tensile and compression hysteresis performance under strong earthquakes [3]. In order to improve the mechanical properties of the brace and prevent it from buckling under earthquakes, a buckling restrained braced steel frame system has appeared. This system has been widely used in developed countries, and domestic applied research is being developed.

In terms of methods, this article mainly starts from the design method and principles of buckling restrained braced steel frame, and then designs and discusses the buckled restrained braced steel frame. Then it designs the BRB size and uses the Perform-3d software to build a nonlinear structural model. Use time history analysis to analyze some possible problems in the building. In terms of experiments, this paper mainly analyzes the seismic response of a building, and introduces the situation of the building and its analysis in terms of earthquake prevention.

2. Method

2.1 Design Methods and Principles of Buckling Restrained Braced Steel Frames

The buckling braced steel frame model is designed based on the method of lateral stiffness ratio. In the design of the buckling restrained support steel frame, it is necessary to ensure that the support can fully exert its performance:

(1) The support is required to yield before the frame part, consume energy, reduce the energy transmitted to the frame part, and protect the frame;

(2) Reasonably grasp the cross-sectional area of the support. If the cross-sectional area of the support is increased, the lateral stiffness of the structure will also increase. With the same horizontal load, the lateral displacement of the frame will be reduced, but the stiffness will be reduced. Increasing the seismic effect on the entire structure will increase[4-5]. Therefore, the degree of matching between the stiffness of the support and the frame has an important effect on the seismic response of the entire structure.
The expression of the lateral stiffness ratio of the supporting steel frame structure is as follows:

\[ k_b = \frac{2EA \sin \theta \cos^2 \theta}{E \sin \theta \cos^2 \theta} \frac{1}{h} \]  

(1)

Among them, \( k_b \) provides the elastic level of lateral stiffness for the support. \( \theta \) is the inclination of the buckling support; \( h \) is the height of the column. For elastoplastic time-history analysis, according to the requirements of a large earthquake, the reasonable value of \( k_b \) is determined to be between 0.5 and 2 [6-7].

2.2 BRB Size Design

First determine the cross-sectional area of the brace. The stiffness of the buckling restrained brace and the frame needs to introduce a parameter to represent the ratio of the nominal lateral stiffness of the brace to the frame column.

\[ \lambda_{b,v} = \frac{k_{b,v}}{d} = \frac{h^2}{6} \frac{(EA)}{(EI)} \cos^2 \theta \]  

(2)

In actual use, the stiffness of the column needs to be corrected. When the linear stiffness ratio of the beam and column is greater than 3, the corner of the joint can be ignored, and the lateral stiffness \( D = \frac{12EI}{h^3} \) of the frame is obtained according to the inflection point method. When the linear stiffness ratio of the beam and column is not very large, the lateral stiffness can be modified according to the simplified calculation method proposed by Japanese scholars [8].

The structural stiffness changes gradually as the floors should follow a trapezoid, and the nominal side-to-side stiffness ratios of different floors are different. The value taken from the input can reflect this change process [9]. Based on the idea of energy equivalent and displacement control, the hysteretic energy dissipating effect of anti-buckling support in the structure is equivalent to viscous damping based on the capacity equivalent principle, and then the response spectrum is reduced according to the equivalent damping ratio to obtain the large earthquake condition. The bottom shear force is assigned to each floor according to the basic mode shape as the equivalent load under the condition of large earthquakes. Finally, the difference between the displacement of each floor under the action of the equivalent load and the target displacement is checked. According to the difference, the buckling restraint support interface was adjusted [10].

Inter layer ductility ratio of each layer of the structure:

\[ \mu = \frac{u_T}{u_v} \]  

(3)

In the formula: \( u_T \) is the target displacement, and \( u_v \) is the displacement when each layer of buckling restraint support enters yield. It is preferable to set \( u_T = (1/70 - 1/50)h \) according to the specific fortification target setting [11-12].

2.3 Establishment of Nonlinear Model

The non-linear structural model is built using perform-3d software. This software is a professional analysis software, which is mainly used for engineering earthquake resistance. perform-3d is mainly used for structural performance evaluation to verify the rationality of structural design, find weak links in the structure, and provide basis for design. The beam and column elements in the structural model are FEMA, beam / column, and steel type. The element is to calculate the bending moment curvature
relationship of the beam and column. Multiply the curvature by the length of the plastic hinge to obtain the required bending moment rotation relationship, so as to simulate the corner deformation of the beam and column. The floor uses driven constraints to select the nodes of each floor to make them move together, that is, it is assumed to be a rigid floor, and the representative value of the gravity load of each floor is concentrated on the floor centroid. BRB uses default elements in perform-3d, its stiffness value is the default value, and the strengthening factor of steel under reciprocating action is 1.25. The assembly of the BRB assembly includes: a core, an elastic rod, and a rigid end region.

2.4 Time-course Analysis
The purpose of time history analysis is to find the weak layer or potential weak link of the structure under the action of earthquake, and determine the yield mechanism of the structure. The lateral load applied to the structure acts on the center of the mass of each layer. In this paper, a common lateral load distribution of a structure is defined, namely an inverted triangle load distribution. Considering that the structure height does not exceed 40 m, the structure mass and stiffness are uniformly distributed along the height, shear deformation is the main factor, and the structure response is less affected by higher-order vibration modes, so it is more reasonable to simulate the effect of earthquakes on the structure.

3. Experiment

3.1 Experiment Purpose
Analyze the seismic response of an anti-buckling restrained frame of a building, and analyze the data to obtain the results.

3.2 Experimental Design
A building is composed of two buildings in area A and B, with a total area of 26.9 square millimeters, and a gap between the buildings. Frame B is used for frame shear structure in area B. Frame structure is planned for area A. The height of the first to sixth floors of Building A is 4.6m, 4.9m, 4.3m, 4.5m, 4.2m, and 4.8m. The total structural height is 27.3m. According to the relevant standards, the building in Area A is classified as a type B building. It is located in octave. According to the requirements of relevant codes, it is roughly calculated that the cross-section size of the column needs about 0.6 ~ 0.9m, which is economical and reasonable. The buckling restraint support is not only flexible in its location, so it is finally determined as a concrete frame structure with additional buckling restraint support. The buckling restraint support is divided into different functions, which can be divided into three types: damper, energy consumption type and load bearing type. The support just improves the rigidity and bearing capacity of the system, and it can be supported with load-bearing restraints. The restrained support should not only improve the lateral stiffness and bearing capacity of the system, but also shoulder the vibration energy dissipation effect, and energy-consuming buckling restraint support should be used. The design method of buckling restrained support type damper is the same as that of displacement type damper. Here, instead of energy-consuming restraint support, it provides structural steel in small earthquakes, large energy-consuming, load-bearing and damper-type support steel core materials with elongations of 27%, 32%, and 36%, respectively.

4. Discussion

4.1 Buckling Constrained Support
The stiffness and bearing capacity of ordinary support after buckling will decrease, and its hysteresis performance will be poor under repeated action. In order to solve this problem, the buckling of the stent is restrained by the outer sleeve of the stent, so the buckling restraint stent is composed of three parts, that is, the core, the restraint, and the layered, that is, the buckling. Constrained support structure. The core unit, the core material, is the main stress unit. Depending on the type of use, the
core material can be made of low yield point steel or ordinary low carbon steel and high strength steel. For energy dissipative buckling restraint support, the core material is usually made of steel with low yield strength. The core plate itself is an external buckling restraint mechanism that prevents buckling of the core plate, which is mainly composed of a shell and a filler material and a filler. The material can be mortar or concrete. The layered unit is an expansion material or a narrow air layer between the core material and the external restraint mechanism. It is mainly used to replace the axial force transmitted to the external restraint machine when the core plate is subject to the axial force.

4.2 Time History Analysis

Compared with the revitalization decomposition response spectrum method, the structure response obtained by time history analysis changes with time, and the structure response obtained by time history analysis is more discrete. Therefore, whether it is elastic time-history analysis or elasto-plastic time-history analysis, it is necessary to select appropriate seismic waves for structural time-history analysis, so as not to produce large discrete results, affecting overall judgment and improving analysis efficiency. According to the selection principle of seismic waves, seven seismic waves were selected, including four actual strong seismic records and three seismic waves generated manually by software. The average seismic influence coefficient curve of the seven time-history curves should be consistent with the modal decomposition response spectrum method in a statistical sense. For the above two structures, elastic time history analysis under frequent earthquakes and elastoplastic time history analysis under rare earthquakes are performed. The maximum time history of seismic acceleration used in the time history analysis is 68 cm / S2 under frequent earthquakes and 320 cm / S2 under rare earthquakes. The seismic responses of the two structures are analyzed and compared. As shown in Table 1.

| Earthquake effect         | 5 degrees | 6 degrees | 7 degrees | 8 degrees |
|---------------------------|-----------|-----------|-----------|-----------|
| In case of earthquake     | 8         | 21        | 38        | 92        |
| Rare earthquake           | 56        | 97        | 185       | 336       |

4.3 Structural Analysis Results

The structural analysis results can be extracted and checked in the Perform-3d post-processing module. The visual analysis results help to more accurately grasp the structural response. The structural analysis results will be explained from the following, including the modal data of the structure.
Figure 1 lists the modal parameters of the original structure and the BRB structure. The period of the original structure is greater than the period of the BRB structure in the same mode. From the data in the figure, as the mode shape increases, the period difference continues to increase. Decreased and tends to converge.

5. Conclusion
In terms of methods, this article mainly starts from the design method and principles of buckling restrained braced steel frame, and then designs and discusses the buckled restrained braced steel frame. Then it designs the BRB size and uses the Perform-3d software to build a nonlinear structural model. Use time history analysis to analyze some possible problems in the building. In terms of experiments, this paper mainly analyzes the seismic response of a building, and introduces the situation of the building and its analysis in terms of earthquake prevention. From the four strong earthquake records recorded in this paper, it can be seen that the maximum value of the seismic acceleration time history increases with the increase of the earthquake intensity. And the earthquake impact of rare earthquakes will be greater than that of more frequent earthquakes under the same intensity. From the data of structural analysis, the period of the original structure is greater than the period of the BRB structure under the same mode shape. As the mode shape increases, the period difference decreases and converges.

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