International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 5 ǁ May 2024 ǁ PP. 250-257

A Review of research on self-centering steel structures seismic systems

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Abstract
Self-resetting steel structure system not only reduces or eliminates the residual deformation of the building structure after an earthquake, but also improves the ability of the building structure to dissipate seismic energy by combining with the energy dissipation and damping device, so it has a good prospect of architectural application. On the basis of a brief description of the basic structure and characteristics of the self-resetting steel structure system, the main structural forms of various structural systems, basic principles and their research status are introduced from the aspects of self-resetting energy dissipation and damping device, self-resetting steel frame system, self-resetting steel frame-supporting system, etc., and finally, the main issues to be researched in the development of the self-resetting steel structure system are put forward. Finally, the main issues to be studied in the development of self-resetting steel structure system are proposed.

Keywords: *Self-Centering, Steel structures, Energy dissipation, Seismic, Residual deformation.*

Date of Submission: 09-05-2024 Date of acceptance: 22-05-2024

I. INTRODUCTION

China is one of the most frequent big countries in earthquakes, and the collapse of building components in earthquakes is often the most important factor that jeopardizes the safety of the people and causes huge economic losses. The traditional steel structure system consumes seismic energy by counteracting the strong ground shaking through its own material characteristics and structural deformation. As shown in Table 1, traditional steel structure systems may not collapse after an earthquake but they often cause large residual deformations and even brittle damage in some weak parts of the structure. These changes, as well as the damage, increase the difficulty of structural reinforcement and repair after an earthquake. Self-resetting steel structure system can reduce or eliminate the residual deformation, so people launched an in-depth study on the self-resetting steel structure system.

Table.1 Residual deformation characteristics of self-centering structures

Structure type	Residual Deformation Characteristics
Conventional steel structure systems	Residual deformation is often large after an earthquake
Self-resetting steel structure system	Reduction or even elimination of residual deformation

In recent years, Chinese scholars at home and abroad have also begun to devote themselves to the development and research of self-centering steel structural systems, proposing structural systems such as self-centering steel frames and self-centering steel frame-braces, and developing and researching energy dissipation and vibration damping devices with self-centering capability.

China has been conducting research on self-centering structural systems since 2010.Zhu [1] briefly introduced the components and basic mechanisms for developing post-tensioning connections and self-centering braces as well as the structural details and seismic performance of self-centering systems proposed in recent years.Chen [2] proposed a new type of prefabricated self-centering steel frames (PSCSFs), and by conducting quasi-static loading tests on the PSCSF specimens to study its cyclic hysteretic response and perform finite element analysis with the help of software to reveal the seismic mechanism of PSCSF.Xu [3] designed a new self-centering energy dissipating (SCED) brace, which utilizes disk-type springs to provide self-centering capability and friction to dissipate energy, and has excellent resilience and small residual deformation during earthquakes.Xiong [4] investigated the self-reclosing concentrically braced frame (SC-CBF) structures for seismic characteristics and the better ductility of SC-CBF structures compared to conventional concentrically braced frame (CBF) structures.

On the basis of a brief description of the basic structure and characteristics of the self-resetting steel structure system, this paper introduces the main structural forms, basic principles and research status of the above structural systems from the aspects of self-resetting energy-consuming vibration-damping device, self-resetting steel frame system, self-resetting steel frame-supporting system, as well as the application examples of the research and development of self-resetting steel structure, and finally The main problems that need to be studied in the development of self-resetting steel structure system are put forward.

II. Composition and Basic Characteristics of Self-Repositioning Steel Structure System

Self-resetting structure is a new structural system that adopts the concept of performance-based design to reduce the strain generated by building members in an earthquake and the residual deformation after the earthquake, and its main force characteristics is that when the external force is gradually withdrawn, the lateral position of the apex of the member can be gradually restored to zero, and the hysteresis curve generated by the member under the action of reciprocating loads is approximated to show "flag" type [5], and this new structural system can effectively limit the "maximum deformation" of the structure and reduce the "residual deformation" of the structure, so it has been accepted by the structural system. "This new structural system can effectively limit the "maximum deformation" of the structure, but also reduce the "residual deformation" of the structure, so by engineers and scholars generally pay attention to.

2.1 Composition of Self-Repositioning Steel Structure System

As shown in Fig. 1, the self-resetting steel structure is mainly composed of three basic parts. The first basic part is the basic structure that can be swayed, such as beam-column nodes, column foot nodes, and bearings. The second basic part is the self-resetting elements, such as prestressing tendons, prestressing strands, shape memory alloys, etc. The third basic part is the replaceable elements. The third basic part is the replaceable energy dissipating elements or devices, such as angles, energy dissipating bars, anti-flexural braces, dampers, etc. In order to realize the self-resetting energy-consuming capability of the structure, one of these three parts is indispensable.

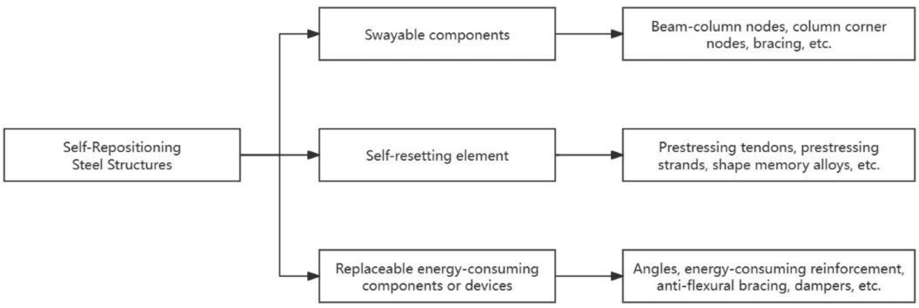

Fig.1 Basic composition of self-centering steel structures

At the same time, if the shape and material of some or more of these components are changed, different new self-resetting steel structure systems can be produced. For example, according to the shape characteristics of the components, the location of the relaxation constraint can be changed; through the study of high-performance materials, the pre-stressing material can be selected to be more adaptable to the structural system; different energy-consuming elements or devices can be added to the structural system. The different self-resetting structural systems are, in the final analysis, the product of the combination of the three basic components.

2.2 Basic Characteristics of Self-Repositioning Steel Structural Systems

Self-resetting steel structure system has the following basic characteristics.

(1) Based on the traditional seismic structure and pre-stressed structure, the main objective is to reduce or eliminate the residual deformation of the traditional structure and improve the energy dissipation capacity of the structure.

(2) The structural stiffness can be adjusted by adjusting the resetting element and energy dissipating element or device according to the seismic requirements of the structure, so as to make the structure produce different self-resetting capacity.

(3) Plastic deformation and damage of the structure are concentrated in the energy-consuming elements or devices, which ensures the flexibility of the main structure (beams and columns) and reduces the difficulty of recovery of the structure after the earthquake; (4) The structure can be stiffened by adjusting the resetting element and the energy-consuming element or device to meet the seismic requirements of the structure.

(4) The energy-consuming part can be replaced, which reduces the difficulty and cycle of repairing the building structure after the earthquake; (5) Self-expanding elements or devices can be replaced, which reduces the difficulty and cycle of repairing the building structure after the earthquake.

(5) Self-resetting steel structure of different forms, but some of the components can be prefabricated in the factory processing, thus greatly reducing the difficulties in the field welding. Of course, in the post-tensioned prestressing nodes must be on-site tensioning prestressing strands, and at the same time in order to reduce the prestressing loss, but also increased the requirements of the strand anchorage distance.

III. Self-resetting energy-consuming vibration damping device for steel structures

Energy-consuming seismic damping technology, mainly used in specific parts of the building structure to increase the energy-consuming device or energy-consuming components, to provide the necessary additional stiffness or additional damping effect to the structure, under the influence of strong earthquakes, mainly through the use of energy-consuming components to consume the energy input into the structure to reduce the structural dynamic response, in order to better safeguard the safety of the main structure of the building, it is a highly efficient, safe, economic and increasingly improved It is an efficient, safe, economical and improving technology for seismic damping in construction engineering. Passive energy dissipation and damping devices, such as dampers, under the influence of the earthquake itself will be permanently deformed, thus affecting the effective play of its building damping effect or affecting the normal use of the structure. Therefore, the research on energy dissipative damping devices with self-resetting function is also increasing day by day, and its core idea is to introduce smart materials (SMA) or prestressing elements into the passive energy dissipative damping devices to reduce or offset their residual deformation, so as to produce self-resetting energy dissipative damping device.

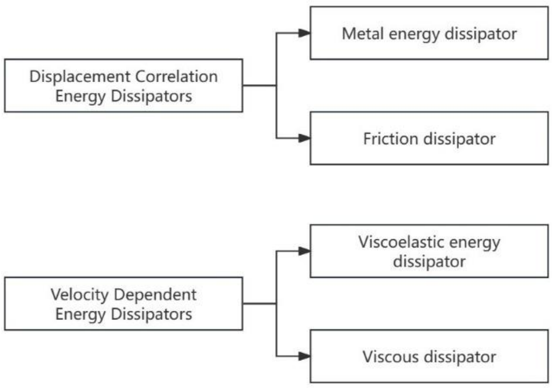

Fig.2 Classification of energy dissipators

As shown in Fig. 2, the energy dissipation damping devices researched and developed by domestic and foreign experts, scholars and R&D technicians can be broadly categorized into displacement-related energy dissipators and velocity-related energy dissipators. Displacement-related energy dissipators include metal energy dissipators and friction energy dissipators. The energy dissipation characteristics of these two types of energy dissipators are mainly related to the relative displacements between the two ends of the energy dissipators, which is why they are called displacement-related energy dissipators, or hysteretic energy dissipators. Velocity-dependent energy dissipators include viscoelastic energy dissipators and viscous hysteresis energy dissipators. The energy dissipation characteristics of these two types of energy dissipators are mainly related to the relative velocity between the two ends of the energy dissipator, so they are called velocity-dependent energy dissipators.

Table.2 Residual deformation characteristics of self-centering structures

Types of Energy Dissipators	Energy dissipation mechanism
Metal Energy Dissipators	Dissipation of energy by plastic hysteresis when the metal material yields.
Friction Energy Dissipators	Utilizing the sliding friction formed between the metal material bonding member and the friction plate under a certain preload to dissipate energy.
Viscoelastic Energy Dissipators	The use of elastic and viscous characteristics of polymers constitute the visco-elastic materials and restraining steel, and through the visco-elastic materials produced by the shear deformation or tensile deformation to dissipate energy

Viscous dissipators	Utilizing the pressure difference generated by the relative motion between the piston and cylinder barrel to force the viscous fluid material to pass through the damping holes, and thus forming a damping force, thus using viscous energy dissipation to dissipate energy.

The energy dissipation mechanism of each energy dissipator is shown in Table 2. The metal energy dissipator is a vibration damping device that utilizes the plastic hysteresis change generated when the metal material yields to dissipate energy. The friction energy dissipator is a vibration damping device that utilizes the energy dissipated by the sliding friction formed between the metal material bonding member and the friction plate under a certain preload force. Viscoelastic energy dissipator is a vibration damping device that utilizes viscoelastic materials and restraining steel made of polymers with dual characteristics of elasticity and viscosity, and dissipates energy through the shear deformation or tensile deformation generated by the viscoelastic materials. The viscous energy dissipator is a vibration damping device that dissipates energy using viscous energy dissipation by forcing a viscous fluid material to pass through a damping hole by squeezing the pressure difference generated by the relative movement between the piston and the cylinder barrel, thereby creating a damping force.

In addition, based on the energy dissipation mechanisms and characteristics of the above energy dissipators, researchers have studied and developed a self-resetting composite energy dissipator with multiple energy dissipation mechanisms [6]. This paper focuses on self-resetting energy dissipative dampers, self-resetting energy dissipative supports, and self-resetting energy dissipative hybrid devices.

3.1 Self-Resetting Energy Dissipative Dampers

This paper takes self-resetting shape memory alloy (SMA) dampers as an example, SMA is a class of special sensitive materials with excellent shape memory properties, superelastic deformation properties, damping properties, and corrosion resistance, and the recoverable strain of its filaments is even able to reach 6% to 10%.The application of SMA in self-resetting structures mainly relies on its excellent ultra-high elastic deformation properties and large damping properties, the research work is mainly along the following lines: using ultra-high elastic SMA bolted or pre-stressed tendons connected to self-resetting energy-consuming nodes, and using various types of SMA wire or rods made of SMA. The research work is mainly carried out along the following two lines: the use of ultra-high elasticity SMA bolted or prestressing tendon connected self-resetting energy-consuming nodes, as well as the use of SMA filaments or rods made of various types of self-resetting energy-consuming dampers (including self-resetting support). The main advantage of dampers using SMA is that the residual deformation of the dampers after an earthquake is small and they can generally continue to be used without change.

Table.3 Development of self-centering shape memory alloy damper

Time	Discoverer	Structural composition
1995	Clark [7]	A group of superelastic materials SMA
2000	Dolce [8]	Two sets of superelastic material SMA
2008	Ma [[9]	Two sets of pre-stressed SMA, two pre-compressed springs

In the 1990s, scholars developed a large number of shape memory alloy dampers, which utilized the superelasticity and memory effects of shape memory alloys to achieve self-resetting and control residual deformation of the structure after the earthquake. As shown in Table 3, in 1995, Clark [7] firstly invented a damper using SMA, and by introducing the superelastic material SMA into the damper, it possessed a good consuming force.In 2000, on the basis of Clark et al.'s research, Dolce [8] firstly invented a self-resetting damper, and by adding one more set of SMAs, one set of SMAs was used as a self-resetting device, and another set of SMAs was used as a self-resetting device, and the other set of SMAs were used as a self-resetting device. reset device and another set of SMAs as energy consuming devices, so that the damper also has the self-reset function and energy consuming capability. As a result, different structural forms of self-resetting SMA dampers have been developed, in which the restoring force is mainly provided by the SMAs. 2008, Ma [9] invented a self-resetting SMA damper consisting of two pre-stressed SMAs and two pre-compressed reeds. The two pre-compressed reeds provide the resetting capability and the two morphology memory alloy wires increase the energy dissipation capability. The time course analysis of the steel frame installed with the damper shows that the maximum floor displacement and interstorey displacement angle are effectively controlled under both multiple earthquakes and fortification earthquakes, and there is no residual deformation in the structure, so the self-reclosing effect is good.

Table.4 Deficiency of self-centering shape memory alloy damper

Inadequate	Specifics
Problem 1	Inability to provide sufficient lateral stiffness, support capacity, hysteresis characteristics
Problem 2	Operating performance is greatly affected by temperature
Problem 3	Shape memory alloy devices are expensive

The above shape memory alloy dampers perform well in controlling the structural response and reducing the residual deformation of the structure, but there are problems as shown in Table 4. First, the self-resetting shape memory alloy damper cannot be used as a support because it cannot provide sufficient lateral stiffness, bracing capacity, and hysteresis characteristics for the structure; second, the operating performance of the self-resetting shape memory alloy damper is greatly affected by temperature because the performance of shape memory alloy deteriorates dramatically at low temperatures; and lastly, self-resetting shape memory alloy devices are costly, and thus cannot be used as engineering commonly used self-resetting damping devices.

Although the above mentioned shape memory alloy dampers cannot be used as the main lateral force resisting components in structural systems, the related research work has laid a solid foundation for the proposal and development of self-resetting energy-consuming supports.

3.2 Self-resetting energy-consuming support

In 2008, Christopoulos [10] firstly proposed the concept of self-resetting energy-dissipative bracing (SCEDB), which can be self-resetting without relying on shape memory alloy materials, and at the same time can provide support capacity and stiffness for the main body of the structure, which creates a good start for the research of self-resetting energy-dissipative bracing.

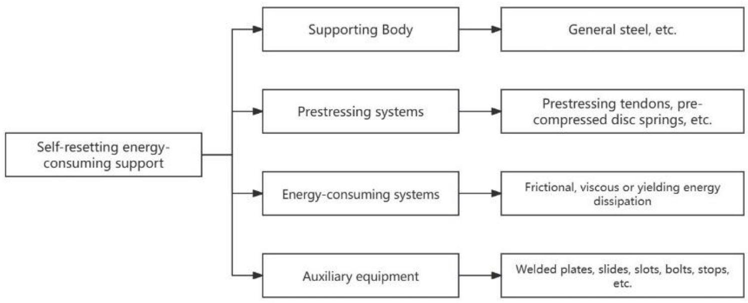

Fig.3 Composition of self-centering energy dissipation brace

As shown in Fig. 3, the self-resetting energy-consuming support consists of four parts: the support body, the prestressing system, the energy-consuming system and the auxiliary device. The main body of the support is made of ordinary steel, which is used to provide the support stiffness in the initial state. The prestressing system relies on the elastic deformation of the resetting material to provide resetting force for the support, which is the key structure to reduce the residual deformation of the support after the earthquake. The prestressing system can be constructed using prestressing tendon structure with elastic deformation in tension or prestressing disc spring structure with elastic deformation in compression. For example, the specific material of the prestressing tendon structure can be shape memory alloy, prestressing steel strand or high-performance composite fiber material. The energy-consuming system can adopt friction energy-consuming mechanism, viscous energy-consuming mechanism or metal yielding energy-consuming mechanism, etc., to provide sufficient energy-consuming capacity for the support. Auxiliary devices are welded plates, sliders, slots, bolts, stops, and other components that improve the integrity of the support and assist in achieving the intended function.

3.3 Self-resetting energy-consuming mixing device

Liu [11] provided a hybrid self-recovery damper that can combine SMA filaments (bundles) and viscous fluid dampers, and the researchers confirmed that the hybrid self-recovery damper possesses good damping and vibration isolation characteristics.In 2010, Yang et al. investigated and evaluated a hybrid device provided in the braced frame with both energy dissipation and self-recovery capabilities. The hybrid device has three main components: SMA bundles for improved recovery, energy-consuming braces, and high-strength steel for traction movement of the device. The device can be mounted on beams and columns of building elements or used as a support for building elements. The basic design of the device is given, and a three-story member equipped with the device is designed and analyzed for elastic-plastic and kinetic energy, which shows that the system not only has the same energy dissipation capacity as that of the flexural restrained bracing system, but also possesses self-resetting properties. The results show that the system not only has the same energy dissipation capability as the flexural restrained brace system, but also has the self-resetting capability.

IV. Self-resetting steel framing system

4.1 Self-resetting steel nodes

In the Northridge earthquake in the U.S. and the Kobe earthquake in Japan, many brittle damage phenomena that were not taken into account in the design of traditional steel reinforced structural nodes appeared. In order to reduce the maximum deformation of the steel frame structure generated during the earthquake and the residual deformation after the earthquake, experts and scholars were inspired by the excellent seismic performance of the traditional prefabricated unbonded prestressed concrete frames, and developed a brand new steel reinforced with the ability of self-reset frame beam-column node-post-tensioned prestressed (PT) node. The design of this type of node can effectively reduce the residual deformation of building members after an earthquake, and has good prospects for architectural applications.

The basic structure of this type of node is mainly composed of high-strength non-bonded prestressing strands arranged around the column length and anchored to the inner flange of the column and the outer flange of the beam; the left and right flanges of the beam are connected to the column by angle irons, and the middle of the angle irons and the flanges of the beam and column are connected by angle irons. In general, the use of prestressing strands applied to the prestressing type, so that the column flange and beam tight buttresses, in order to improve the contact stability, and to prevent the column web and beam flange vertical touch (there are cases will be caused by the column web localized in the load when the overall buckling), in the column flange and the beam flange to join between the cushion wood and the corresponding increase in the cushion wood roughness on the outside to increase the friction with the column flange coupling, the The friction and the angle can share the vertical shear force. Another major characteristic of the angle is energy consumption, because under large loads or displacement forces, the plastic deformation of the node is mainly concentrated at the angle, thus utilizing the high yield of the angle to consume energy.

4.2 Integral Study of Self-Repositioning Steel Frames

The effects of nodes generally have only localized effects, whereas the effects of ground vibration are directly applied to the members as a whole, so it is necessary to consider the overall mechanical properties and energy dissipation capacity of steel frames installed with these nodes.

Table.5 Study on integral design of self-centering steel frame

Time	Discoverer	Overall model	Experimental method
200	Rojas[12]	Six-story, four-span	Seismic simulation calculations
2007	Graloc [13]	Five stories and four spans	Nonlinear time course analysis

As shown in Table 5, Rojas [12]successfully simulated the beam-column nodes of a steel frame installed with bonded external prestressing reinforcement diameters and friction-type dampers using fiber simulation techniques. Subsequently, a six-story, four-span steel frame with such nodes was designed based on performance engineering and seismic simulations were performed. The experimental results show that the main technical indexes of the frame, such as tensile strength, fault displacement, local deformation, self-resetting capacity and energy consumption, have all obtained satisfactory results. Even under the influence of major earthquakes, the inelastic deformation range of the frame can be reasonably limited, while the self-resetting function has not suffered too much.Gralock[13] studied the structural characteristics of the self-resetting frame system in depth, and according to the characteristics of this type of frame system, especially the overall frame control system to make the overall design, and gives the system design workflow and the proposal of the relevant parameters of the formula, and finally the design of a frame system, especially the overall frame control system, and the design of the system design workflow and the proposal of the relevant parameters of the formula, and finally the design of the system design workflow and the proposed parameters of the system. Finally, a five-story, four-span steel frame model was analyzed by nonlinear force time course, and the conclusions of the displacement time course analysis were compared with the actual engineering design requirements, thus confirming the operability and validity of the whole system design process and design specifications. The above study proves that the overall seismic energy dissipation capacity of steel frames equipped with self-resetting steel nodes has been greatly improved.

V. Self-resetting steel frames - bracing system

The traditional frame-support system is limited in deformation capacity before the support yields, and the strength of the support yields and then decreases dramatically. The excellent performance of steel frames with self-resetting and energy-consuming characteristics also shows the prospect of its wide application in supporting members. Specifically, they can be categorized into the following three kinds of self-resetting support systems.

5.1 Self-resetting frame concentric support system

Conventional materials are supported in two ways, one of which is the self-recovering and energy-consuming properties of the support material itself. This type of support combines friction components, viscous dampers and yielding components in parallel, followed by external prestressing restraints along the length of the support, thus combining the advantages of energy dissipation and self-recovery.

Another type of self-restoring concentrically braced frame system (SC-CBF) proposed by Roke [14] utilizes vertically arranged external prestressing directly applied to the whole of the supporting members to achieve the self-restoring property of the structure. Due to the high demand for overall support stiffness, some heavy strut structures also have a weight strut outside the column to carry the overall weight of the sway system, and several energy-consuming elements can be placed between the weight strut and the original column to improve the overall energy consumption characteristics of the structure. The external prestressing bundles can be placed at the ends of each span, or in the middle of a span, in order to reduce the structural requirements for the lifting width of the columns at the ends. According to the traditional concentrically supported frame system, the overall deformation energy is limited before yielding and the rigidity strength is greatly reduced after yielding, Roke designed a class of concentrically supported sway frame system with the ability of self-resetting, and a six-floor-high self-resetting concentrically supported frame system to do the nonlinear seismic time-history analysis of the structure, the results show that this type of support frame system before and after the damage have better overall deformation energy, and also can more The analysis results show that this kind of supporting frame system has better overall deformation performance before and after damage, and it can also inhibit the residual deformation induced by seismic loads more effectively. The above studies show that the self-resetting frame concentric bracing system has good self-resetting and energy dissipation capabilities.

5.2 Self-resetting frame eccentric support system

The dissipative section of the eccentric bracing system produces plastic deformation under the influence of an earthquake.In order to reduce the residual deformation of the dissipative section after an earthquake, Cheng [15] applied the idea of self-recovery to eccentric bracing to form a self-recovery eccentric bracing system (SC-EBF). In this system, by relaxing the contact surface constraints between the energy dissipating columns and the adjacent beam segments, the prestressing reinforcement diameters can provide self-recovery capability when the structure generates displacements, resulting in rotating nodes similar to PT nodes. First, Cheng et al. conducted lateral cyclic loading experiments on five foot-size single-story, single-span eccentric bearing members with the addition of friction dampers or angles to the energy-dissipating elements to increase the energy-dissipating capacity of the system. The main experimental variables were the type of energy dissipating device, the clamping capacity of the damper and the size of the angle. Then, the theoretical derivation of the force-displacement relationship of the system was carried out. Finally, the analytical conclusions were compared with the experimental results. The results show that the system is capable of structural self-recovery, and the stress-displacement relationship of the EBF can also be obtained using the analytical model provided by Wenshan Middle School et al. The seismic characteristics of SC-EBF can also be improved by adding energy-consuming devices in the building structure. The above studies show that the self-resetting frame eccentric bracing system has good self-resetting and energy-consuming capabilities.

5.3 Self-Repositioning Flexion Restraint Brace

Miller [16] investigated the basic principles and seismic characteristics of self-resetting buckling restrained brace (SC-BRB).SC-BRB is based on the traditional ordinary buckling restrained brace and introduces the superelastic material morphology memory (SMA), whose design and fabrication can be directly used in the design and construction method of the existing ordinary buckling restrained brace.

Under the influence of earthquakes, the SC-BRB structure mainly utilizes the deformation dissipation of the buckling-bound support, and the pre-stressed SMA structure provides the restoring ability to suppress the deformation. The researchers also designed a one-half scale-down module to check and improve the numerical simulation model of SC-BRB, and carried out a nonlinear dynamic system analysis of the system to further explore the design, structural characteristics, and analytical modeling methods suitable for the self-resetting buckling-restrained braced frame system. The above studies show that the self-resetting flexural restraint brace has good self-resetting and energy-consuming capabilities.

VI. Conclusions and outlook

As an effective form of high-performance seismic system, the self-resetting steel component system also has the advantages of fast recovery and replaceability, which has good prospects for the development of architectural applications. At present, foreign scholars have conducted several researches in this field, but in general, it is still in the initial stage, especially in China, which has not been able to carry out more extensive and systematic researches in this field. Therefore, in order to promote the development of self-replacing steel structure system in China, more in-depth research on the following issues is needed.

(1) The research and development of some self-recovery steel structure systems mentioned in this paper are still in the stage of initial experimental and theoretical research and analysis of structural subcomponents, and some of the systems are only definitional knowledge, and there are very few research results on the structural system level. Therefore, further in-depth research is needed to study the overall seismic characteristics of various types of self-resetting steel structure systems, and to refine the in-depth study of self-resetting nodes and the response of equipment in the structural system.

(2) At present, all kinds of self-resetting structural energy dissipation devices must be made of intelligent material SMA, which is expensive and therefore difficult to be widely promoted in the actual engineering use. At the same time, due to a lot of self-resetting steel plate bearing system and hybrid equipment structure is still relatively complex, and it is difficult to apply directly to the actual construction. For this reason, it is necessary to develop and research in-depth the self-reclosing steel structure system and equipment with simple structure and low cost, and at the same time, to make the structural components replaceable as much as possible in order to minimize the maintenance difficulties after the structural earthquakes.

(3) There are some actual engineering cases of self-resetting steel structure in the world, but there is still a long way to go before it can be widely used. There is still a certain gap between China and the international first-class level in the actual engineering application of self-resetting steel structure. Combined with China's economic level and actual demand, it can be prioritized to be practiced in the projects of key fortification category and above, such as medical buildings, school buildings, bridges and underground stations.

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