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REVIEW ON STRUCTURAL PERFORMANCE OF BRACED STEEL STURTURES UNDER DYNAMIC LOADING

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Abstract - *Bracing elements in structural system plays a vital role in the seismic behaviour of high rise buildings during earthquake. Eccentric Braced Frame (EBF) configuration is similar to the traditional braced frames with an exception that at least one end of each brace must be connected eccentrically to the frame. It provides excellent energy dissipation and ductility to the framed structure. The bracing pattern and the use of innovative smart materials can extensively modify the seismic behaviour of framed steel structures. Shape Memory Alloys (SMAs) are novel functional materials which have the ability to remember a predetermined shape even after severe deformations. The buckling of the lateral steel braces can be reduced by replacing it with Buckling Restrained Brace. Performance and failures of these types of bracings under the action of seismic loads are discussed in this paper based on various literature studies.*

Key Words: Eccentric Braced Frame, Shape Memory Alloy, Buckling Restrained Braces, Seismic loads.

1. INTRODUCTION

Design of steel buildings for seismic loads is generally based on two performance objectives: (1) elastic response during minor to moderate earthquakes, and (2) collapse prevention during extreme (rare) earthquakes. To meet these objectives, buildings are typically designed with enough lateral stiffness to limit large displacements during minor to moderate earthquakes, and with enough ductility to survive large inelastic displacements and prevent collapse during extreme earthquakes. Such a design is often achieved using ductile braced frame systems. Ductile braced frame systems have both high lateral stiffness and ductility. The high lateral stiffness is provided by a bracing element and the ductility is usually provided by an inelastic mechanism specially designed to isolate frame damage during overloading. Two of the most common types of ductile braced frame systems are eccentrically braced frames (EBFs) and buckling-restrained braced frames (BRBFs).

Eccentric Braces Frames (EBFs) consists of a small connecting link often known as ductile link. This ink provides the essential ductility and the energy dissipation to the structure. Usually EBFs are constructed by providing an eccentricity between the bracing tips and between the brace and the column tip as shown in Figure 1.

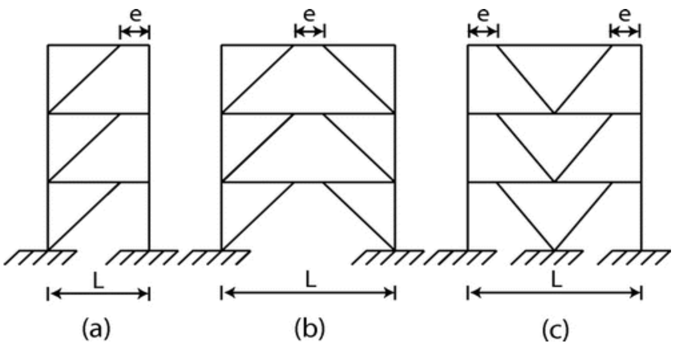

Figure 1: Different types of Eccentric bracings.

Buckling Restrained Braces (BRBs) are normally used to reduce the buckling of conventional steel braces during severe seismic loadings. It consists of a steel core encased with mortar which is again covered with a steel casing. Under seismic load actions the steel core yields and the mortar covering prevents further buckling, Thus the composite action performs well and prevents buckling under severe conditions. The components of BRB are as shown in Figure 2.

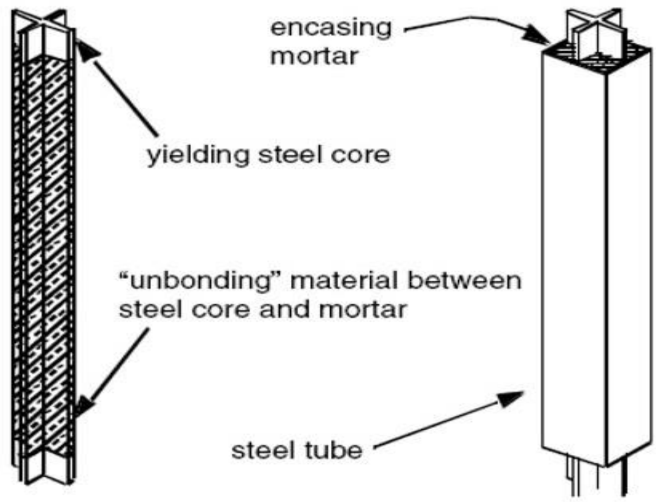

Figure 2: Components of BRB.

Shape Memory Alloy (SMA) is an innovative smart material which can regain its initial shape even after the removal of loads. Also it has the ability to dissipate energy and regains the structures original shape under the application of severe loads. This property of SMA allows it to use widely in construction of structures which are in seismic prone areas. It can also be used to retrofit the damaged structures.

This paper reviews on various literatures based on the seismic performance of all the three types of braces.

2. LITERATURE REVIEW

2.1. Braced frames

Tremblay et al. (2003) performed an experimental study on the seismic performance of concentrically braced X bracing and single diagonal bracing steel frames with cold-formed rectangular tubular bracing system. The loading sequences used were a displacement historey obtained from non linear dynamic analysis of typical braced steel frames. Results were obtained for different cyclic loading and were used to characterize the hysteretic response, which includes the energy dissipation capabilities of the frame. The ductile behaviour of the braces under different earthquake ground loading were also studied. Simplified models were obtained to predict local buckling failure of bracing and plastic hinge failure as a ductility failure mode. Finally, the inelastic deformation capabilities are obtained before failure for both moment resisting frame and bracing members.

Khatib et al. (1988) analyzed the failure mode observed in special moment resisting braced frame systems with fracture of bracings at the locations of plastic hinges or local buckling. Significant storey drift were observed at a single storey and showed how the failure is concentrated entirely on single floor. The limitations of using moment resisting frames with bracing systems were observed.

K.G.Vishwanath (2010) Analyzed a four storey building taken in seismic zone 4 according to IS 1893: 2002. The performance of the building is evaluated according to storey drift. Then the study is extended to eight storey and twelve storey. X type of steel bracing was found out to be most efficient.

Hanson and Martin (1987); Kelly et al. (2000) Studied the typical failure mode experienced by special moment resisting frames with bracing mainly the damage occurs to braces, columns, brace to frame connections and with base plates.

The study conducted by Ghobarah A. et al., (1997) revealed that the inter storey drift can also be considered as a means to provide uniform ductility over the stories of the building. A storey drift may result in the occurrence of a weak storey that may cause catastrophic building collapse in a seismic event. Uniform storey ductility over all stories for a building is usually desired in seismic design.

Christopoulus et al. (2008) analyzed an advanced cross bracing system which has been used in University of Toronto called Self centering energy dissipating frames (SCEDs). Alike, Special moment resisting frames and Buckling Restrained Braced Frames (BRBs) they also dissipate energy, but they have self centering capabilities which reduce residual deformation after major seismic events.

An extensive analytical study was performed by Tremblay et al. (2008) to compare the Buckling restrained braced frames with self centering energy dissipating frames. The residual deformation of SCED brace frame systems was observed to be negligible under low and moderate hazard levels and wass reduced significantly under MCE or maximum considered earthquake level.

2.2. Shape Memory Alloy

The application of SMA in the passive control of structure is mainly concentrated on the application of various dampers, and some research is to improve the quality of the structure by using the super elasticity of SMA, which makes the structure has higher resistance to the external force, and has a strong ability to self repair after the external force.

Ni Lifeng et al installed a good performance of SMA damper on the model of cable-stayed bridge. The results showed that the damper energy dissipation effect is obvious, the cable-stayed bridge with the same contrast not installed dampers, vibration response of the cable-stayed bridge model was significantly weakened.

He Silong et al heated a buried pre-strain of 1.8% of SMA wire reinforced concrete beams and study on the response of the beam under the static load and the impact load. The results showed that the SMA wire can be applied to the structure of the structure, improve the structural strength and stiffness, reduce the structural static and dynamic response.

E.Effendy studied in combination with low shear SMA through the shear wall diagonally SMA device, and then applied load. The residual deformation of the SMA shear wall was observed to be larger than that of the SMA shear wall in the condition of the super elastic state.

Li hui et al produced two new type of SMA energy dissipation devices by using the super elastic properties of Ni-Ti alloy wire, which are tensile and shear type SMA .The experimental results showed that the vibration damping effect of the shear type energy dissipation device is better than that of the tensile type damper.

Kuang Yachuan, Ou Jinping developed a smart concrete beams with damage self repair function. The room temperature in the austenitic state of shape memory alloy and contains repairing adhesive repair fiber tube embedded in the concrete tension zone or easy to produce crack position, using shape memory alloy superelastic characteristics and limited recovery generation larger driving force characteristics, control and restore the structure and component of the deformation and deflection, reduce the impact of the typhoon, earthquake, structure to improve the anti disaster ability, ensure the safety; using adhesives for repairing of crack filling, repair characteristics, strength recovery of concrete, improve the durability of the structure. The experimental results showed that the shape memory alloy significantly improves the deformation capacity of the beam. When the external force is gone, the deflection of the beam in the shape memory alloy is quick recovery, the crack is closed.

Cui di et al developed the SMA concrete beam with the super elastic shape memory alloy wire as the main reinforcement. The test was carried out by using the single point load test, and the bearing capacity, the residual deformation and the residual crack of the beams were compared with the same size and the same ratio of the reinforced concrete beams. The influences of SMA on the mechanical properties of the beams were analyzed. The results showed that the SMA strand can reduce the residual deformation and residual crack, improve the self repairing ability of concrete beams. Compared with ordinary reinforced concrete beams, the bearing capacity of SMA concrete beams increases more significantly.

Di Shengkui et al studied the performance of a prestressed bridge embedded with SMA achieving the purpose of monitoring and repairing cracks. The effect of slip between SMA wire and concrete was considered, and the results showed that the pre tension should be controlled at 20% ~ 30% of the ultimate tensile strain. For a particular SMA pre stretching length and the increase in cross-sectional area of the alloy wire can enhance the performance.

Seelecke et al. [2002] studied the influence of a superelastic SMA element on dynamic response of a single-degree-of-freedom system representing a multi-storey building undergoing earthquake excitation. The aim of work was to numerically study the variation of the SMA element's geometry in order to find the optimal system performance. Comparisons made with the same system equipped with the SMA element not experiencing any phase transformations highlighted how the superelastic hysteresis was effective in reducing the oscillations caused by the ground motion.

Krumme et al. [1995] examined the performance of a sliding SMA device in which resistance to sliding was achieved by opposite pairs of SMA tension elements. Experimental results reported temperature insensitivity, frequency independence and excellent cyclic behavior. Furthermore, numerical analyses showed good performance of the new isolation system in limiting the inter storey drift of concrete buildings.

Adachi and Unjoh [1999] developed an energy dissipation device for bridges using SMA plates. The device was designed to take the load only in bending and its damping characteristics were determined through both cycling loadings and shake table tests. Experimental results showed that the SMA damper, which worked as a cantilever beam, could reduce the seismic response of the bridge and that its performance was more effective and efficient if the SMA material displayed the shape-memory effect. Finally, numerical simulations of a simplified bridge model further confirmed the feasibility of such a device.

Valente et al. [1999], Dolce et al. [2000] and Bruno and Valente [2002] studied in great detail the possibility of using special braces for framed structures utilizing SMAs. Due to their extreme versatility, they could obtain a wide range of cyclic behaviour (from supplemental and fully recentering to highly dissipating) by simply varying the number and/or the characteristics of the SMA components.

The idea of using SMA-based bracing system as a damper device for the structural vibration control of a frame was also considered by Han et al. [2003]. They carried out an experimental test on a two-storey steel frame equipped with eight SMA wires. The researchers focused on free-vibrations, concentrating on the decay historey shown by the frame with and without the SMAs. Results highlighted that the frame equipped with the innovative damper took much shorter time to reduce its initial displacement than the uncontrolled frame (i.e. frame without the damper). Furthermore, finite element analyses of both the uncontrolled and controlled frame subjected to the El Centro ground motion confirmed the effectiveness of the innovative device in reducing the structural oscillations.

Ocel et al. [2004] evaluated the feasibility of a new class of partially restrained connections by using SMAs in their martensitic form. The proposed connection consisted of four large diameter SMA bars connecting the beam flange to the column flange and was serving as the primary moment transfer mechanism. The researchers tested it in both quasi-static and dynamic conditions and focused attention on its cyclic performance. The connection exhibited a high level of energy dissipation, large ductility capacity and no strength degradation after being subjected to cycles up to 4% drift. Following the initial testing series, the tendons were then heated above the transformation temperature to evaluate the potential for recovering the residual deformation. The connection was then retested and exhibited nearly identical behavior to the original one with repeatable and stable hysteretic behavior. Moreover, additional tests performed under dynamic loadings carried out to examine the effects of the strain-rate in the performance displayed similar behavior to quasi-static tests, except for a decrease in the energy dissipation capacity.

Dolce et al. [2005] performed shake table tests on reduced-scale RC frames endowed with either steel or superelastic SMA braces. The experimental outcomes showed that the new bracing system based on SMAs may provide performances at least comparable to those provided by currently used devices, also in absence of design criteria and methods specifically addressed to the new technology. With respect to steel braces, the innovative bracing configuration presented excellent fatigue resistance and recentering ability. Due to this property, since the vertical-load-resisting structural system is always restored at its initial shape at the end of the action, it was then possible to allow for great ductility demand in RC members. Accordingly, such approach highlighted the advantage of needing no strengthening of the frame then resulting more attractive from an economic point of view.

2.3. Buckling Restrained Braces

Kimura et al. in 1976 performed the first test on steel braces encased in filler mortar steel tubes without the de-bonding agent. This research was extended by Fujimoto et al. in 1988 by testing it with the de-bonding agent (Xie, 2005). The BRB system is then first used in Japan for its energy dissipation mechanism in conjunction with moment braced frames in 1988 (Hussain et al., 2005). By 2000 the BRB system is the most widely used type of damper in high-rise buildings constructed in Japan.

In 1999, the first test of the BRB system was conducted at UC Berkeley. The tests conducted demonstrated good performance of the BRB system under various loading histories. In 2000, the first BRB system is applied in North America as a primary lateral resisting system at UC Davis (Hussain et al., 2005).

At 2004, full-scale testing of Special Conventional Braced Frames (SCBF) by UC Berkeley demonstrated poor inelastic performance due to inherent buckling behaviour. In contrast, the laboratory results showed that the BRB frame system demonstrated a superior performance compared to the SCBF system. The tests also revealed that failures of the system were mostly located in supplementary elements of the BRB frame, which in turn, contributed to the out-of-plane buckling of the connection. (Hussain et al., 2005).

There have been many studies done to confirm the behaviour and performance of the BRB system; however, large scale BRB frame tests have shown poor performance. Several of these studies, such as that conducted by Roeder et al. (2006), found that gusset plate distortion and brace instability, considered as an undesirable mode of failure, has been observed as a storey drifts between 0.02 and 0.025 radians.

Prominent and recent large-scale tests were conducted by Fahnestock et al. (2007). These experimental evaluations were conducted to demonstrate the performance of the system when subjected to multiple earthquake simulations and investigated the poor performance at storey drifts between 0.02 and 0.025 radians.

In 2003, a comprehensive analytical study was conducted by Sabelli et al. (2003) to determine the seismic response of three and six storey CBF buildings utilising BRB. The research concludes that the BRB managed to overcome problems usually associated with the special and conventional types of CBF.

Deulkar et al. (2010) used five different configurations for their study on the BRB system to help with vibration control. The projects compared the reduction in roof displacements obtained from analyses of different bracing configurations and found that the inverted V-bracing has the least roof displacement of the tested configurations.

Hussain et al. (2005) found that there are three common configurations for BRB end connections. These connections have been developed by three major manufacturers of BRB. One configuration, manufactured by Nippon Steel, has a typical standard bolted connection, while Core Brace has developed a modified bolted connection. Another BRB manufacturer, Star Seismic, has developed a true pinned connection.

3. CONCLUSIONS

From the literatures reviewed it was revealed that the use of braced frames increases the seismic performance of steel buildings. The performance of eccentric braced system was better than concentric braced frames due to the presence of eccentric links. Short links or shear links shows better plastic rotation than the flexural links in eccentric braced frames.

SMA shows wide range of applications in resisting the seismic forces. They can be used as actuators, rebar, braces, dampers etc for better energy dissipation. SMAs can also be used for retrofitting purposes. Buildings with SMA devices show less damages under the action of severe earthquake ground motions.

The concept of the BRB system is simple and well understood however; there are many configurations and methods by which to construct the system. The reliability and the performance of the BRB and its superior seismic response compared to other bracing systems have been confirmed by many experimental tests and analytical modelling. The primary elements of the BRB system have been kept the same, while recent tests focused on the improving the performance of the system by determining its optimal configuration.

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