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Passive Seismic Energy Dissipation Mechanisms for Smart Green Structural System (SGSS)

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***Abstract*—**The design philosophy of building structure has been changing time to time. The reason for this is because of an increase of human inertest, an improved building materials and technology that will impact how we live, to speed up construction period and natural effect which includes earthquake disasters and environmental effect. One technique which takes in to account the above case is using a prefabricable structural system. In which each and every structural element is designed and prefabricated and assembled on a site so that the construction speed is increased and the environmental impact is also enhanced. This system has an immense advantage such as: reduce construction cost, reusable, recyclable, speed up construction period and less environmental effect. In this study, it is tried to present some of the developed and evaluated structural elements of building structures.

***Keywords*—**Eccentrically braced frame, Natural disaster, Prefabricable structural, Removable link, SGSS.

I. INTRODUCTION

THE design philosophy and construction technique of building has been changing through time. Green building or green construction is the recent practice and more preferable technique. The U.S. environmental protection agency defines green building or sustainable design, is the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials, and reducing building impacts on human health and the environment over the entire life cycle of the building [1]. According to Western North Carolina Green Building Council, in USA buildings accounts for 39% of total energy use, 12% of the total water consumption, 68% of total electricity consumption and 38% of the carbon dioxide emission [2]. Because the energy consumption of human being is increased, the impact on our natural environment will also increase as many buildings are constructed and emit CO_2 to the environment. So, green building aims to decrease the above problems during the manufacturing, design, construction, and operation of the buildings in which we live.

Smart green structural system (SGSS) is a new concept which can also be taken as an advanced green building construction. This technique provides an additional strategy of reducing construction cost, speed up construction period, and increase the reused and recycled materials. The wastage of construction material on site will be reduced substantially using smart green construction technique and if we use recycled and reused materials in construction project, it can reduce the overall project costs. The amount of materials reused and recycled will be increased significantly by using smart green structural system. Reference [3] investigated the amount of reused and recycled material comparing the existing conventional system and smart green structural system using S-BIM. She found that using smart green structural system will increase the amount of reused and recycled material to about 69%. There are two sources of potential cost savings - reusing construction, demolition and excavation materials, and importing recovered and recycled materials. Both sources are applied in the smart green project. The Korean government supports the best practice construction waste management and resource recovery for construction and demolition projects; therefore, smart green structural system can be effective in this case.

In SGSS, since most structural elements are prefabricated, it is obvious that the construction period will be reduced significantly which intern reduce the construction cost. The philosophy of SGSS is to develop and design each structural element in a safe manner and assemble them in the construction site. This will reduce significant amount of carbon dioxide emitted to the environment during construction. According to U.S environmental protection agency (EPA), using green building will reduce 38% of the carbon dioxide emission compared to the basic construction technique. Using smart green construction system will reduce an additional CO_2 emission.

Under the project called 'development and application of smart green construction technology', different structural components of building structure have been developed and evaluated. The project is run by five different laboratories, which includes: steel structure and earthquake engineering, reinforced concrete composite structure, construction management, Adaptive signal processing laboratories in Chosun University. There is work division for each laboratory. In this study, we will present some of the research works done in steel structure and earthquake engineering laboratory (SSEEL).

II. SOME OF PREFABRICATED OR PREDESIGNED COMPONENTS

Each structural components of the building are evaluated both experimentally and analytically using commercial software's. Fig. 1 shows a 3D building structure with some of structural elements evaluated in SSEEL. The components

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shown in the figure which includes, seismic energy dissipating devises, K-type braces, eccentrically braced frame with removable links, and many others including inelastic buckling behavior of column, column-base connection and beam-column connections have been evaluated. In this paper, we reviewed some of seismic energy dissipating devices.

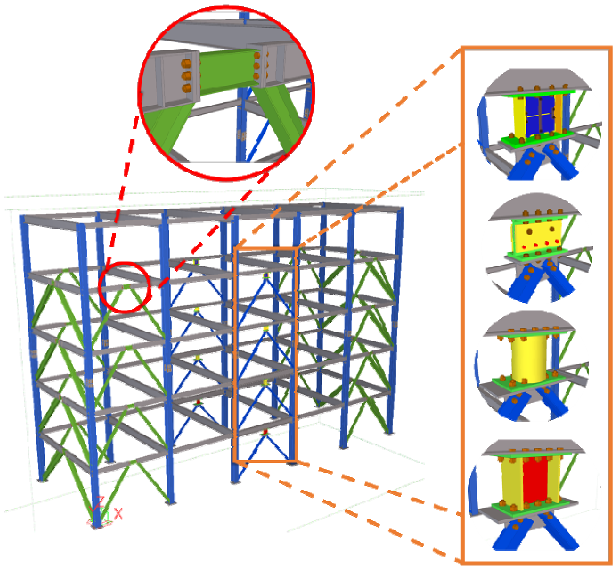

Fig. 1 3D smart green building model

III. SEISMIC ENERGY DISSIPATION SYSTEMS

Energy dissipating devices provide the structure with large amounts of vibration energy is dissipated whereby damages to the major structural components could be minimized. So that the structure to be safe in earthquake or to satisfy the using requirement in wind. There are different techniques of structural controlling mechanism. However, they all categorized as active, semi-active, passive and hybrid structural control systems. Each of them has their own advantage and disadvantage but here we concentrate on the behavior of some of passive energy dissipating systems.

A. Hysteretic Devices

Hysteretic device is type dissipation device that use hysteresis of material as a source of energy dissipation. Yielding metallic damper is the most used dissipating device because of easy to design and also it is inexpensive [4]. The concept and experimental work of metallic energy dissipating device was began by Kelly in 1972 [5] and Shinner in 1975 [6]. Inelastic deformation of structural members can dissipate a significant amount of the input earthquake energy. The inelastic response or hysteretic behaviors of some of these devices are summarized in Fig. 2. Among these plastically deformed members that dissipate seismic energy are shear panel damper and circular hollow section damper which are presented in the section below. The main disadvantage of using metallic dampers is that they absorb energy only when they go through inelastic deformation. However, low yield strength steel is used as a material for the hysteretic damper because it has better inelastic deformation capacity. That is why the use of low yield point steel as seismic energy dissipation is given much attention [7]-[9]. Recently, SPD made of low yield point steel was used in construction of high-rise reinforced concrete apartment buildings and steel bridges in Japan [10].

B. Shear Panel Damper

Reference [7] presented the deformation mode, hysteresis behavior and energy dissipating capacity of shear panel damper taking into account different parameters. Depending on the depth- thickness parameter, three different failure mode of SPD is obtained from both experimental and analytical results. These failure types are presented in Fig. 3: Failure type I: failure at the center of the panel, Failure type II: failure at the corners of the panel and Failure type III: fractured at the welded part of the flange to the end plates. The sectional property of the panel and the hysteresis loops varies with the failure types. For instance, the panel of failure type I yields with buckling and strength degradation. The hysteresis loop forms pinching at initial displacement due to out-of-plane buckling effect. Failure type III is classified as compact section and shows stable hysteresis loops before final failure.

The yield strength, which is taken as the shear yield strength of SPD categorized as compact considering von Mises yield criterion, is given by:

$$F_y = \frac{\sigma_y}{\sqrt{3}} dt \tag{1}$$

where d and t are width and thickness of plate respectively, and fy is the tensile yield stress of plate. The corresponding displacement at yield can be expressed as a ratio of yield strength to lateral stiffness in (2) The lateral stiffness is defined in terms of modulus and thickness of the panel as $k_d = Gt$ [11].

$$u_y = \frac{F_y}{k_d} = \frac{\sigma_y d}{\sqrt{3}G} \tag{2}$$

The yield strength calculated in (1) didn't consider the effect of flange. Schmidt and Dorka proposed the shear yield strength including the effect of flanges. Equation (3) expresses the shear yield strength where first term of the equation gives the web yielding, while the second term represents the flange mechanism [12].

$$F_y = \sigma_y \left(\frac{t_{web} d}{\sqrt{3}} + \frac{b.t_{flange}^2}{d} \right) \tag{3}$$

where d: depth, b: flange width, t_{fange}: flange thicknesses and t_{web}: web thicknesses.

The corresponding shear yielding stress calculated from the von Mise's yield criterion in terms of yield strength as in (4):

$$\tau_y = \frac{F_y}{\sqrt{3}} \tag{4}$$

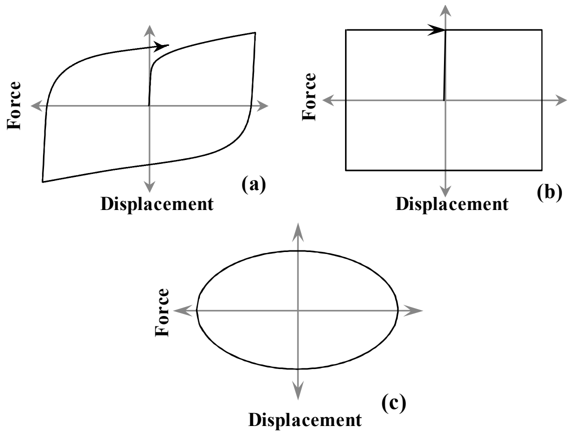

Fig. 2 Hysteretic behavior (a) hysteretic loop of yielding metallic damper, (b) hysteretic loop of friction damper and (c) hysteretic loop of viscous damper

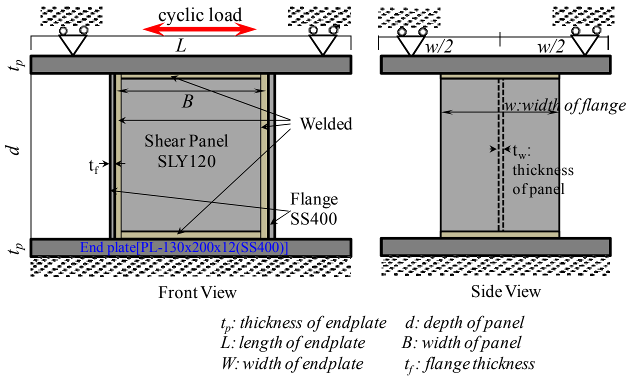

Fig. 3 Detail of Shear Panel Damper

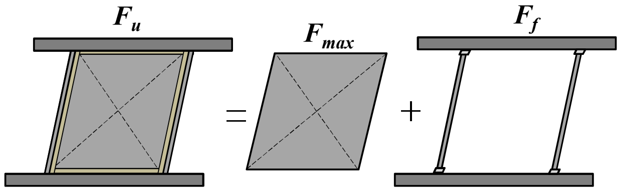

Fig. 4 Deformation mode of SPD

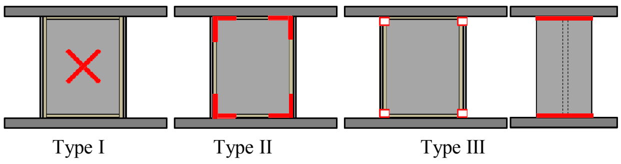
Type I Type II Type III

Fig. 5 Failure types of shear panel damper

C. Circular Hollow Section Damper

Reference [8] evaluated the structural performance of circular hollow section (CHS) damper and recommended the effective size in terms of height to diameter ratio as $H/D = \sqrt{3}$. This size of CHS damper satisfies the von Mise's yield stress criteria and both bending and shear stresses resisted.

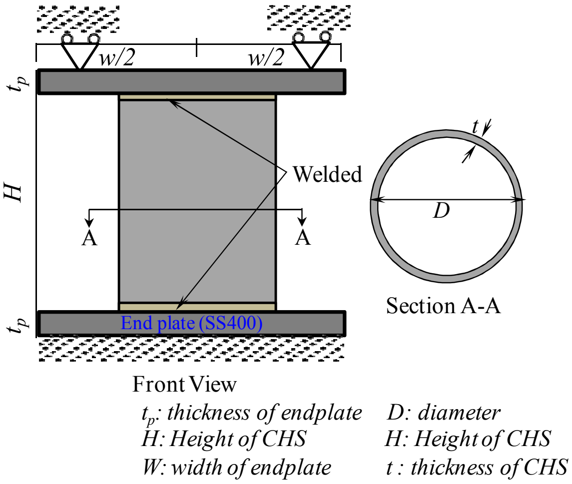

Fig. 6 Detail of circular hollow section (CHS) Damper

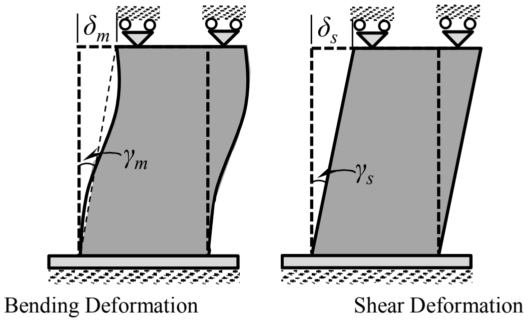

Fig. 7 Deformation mode of CHS damper

The failure mode of CHS damper is different depending on the height to diameter ratio. Specimen having H/D greater than $\sqrt{3}$ the failure is bending failure and the failure for specimen having H/D less than $\sqrt{3}$ is shear failure. The hysteresis behavior of effective size CHS damper considering diameter to thickness ratio (D/t) was also evaluated. Depending on the D/t ratio variable, we found three types of hysteresis behavior. These are: yielding prior to buckling without strength degradation yielding prior to buckling with strength degradation and yielding with buckling and strength degradation which forms pinching at initial displacement.

$$\frac{h}{r} = \frac{H}{D} = \sqrt{3} \tag{5}$$

Depending on the aspect ratio, height to diameter ratio, the deformation mode of CHS damper is different. Fig. 7 shows the bending and shear deformation mode of CHS damper. In Fig. 7 the bending deformation (δ_m) for H/D > $\sqrt{3}$ and shear deformation (δ_s) for H/D < $\sqrt{3}$ are given by (6) and (7) respectively.

$$\delta_m = \frac{QH^3}{12EI} \tag{6}$$

$$\delta_s = \gamma_s H \tag{7}$$

where Q: the applied shear force, H: height of CHS damper, E: young's' modulus, I: second moment of inertia, γ_s: shear angle of rotation.

D. Shear Friction Damper and Variable Resistance Friction Damper

Friction damer was developed and used in many building structurs in many ways. Friction dampers can be applied in chevron bracing in partition, with X-bracing and also with single diagonal bracing. However, some of these dampers are not replaceable. Friction damper called shear friction damper developed in SSEEL shown in Fig. 8 can be replaceable. Reference [13] evaluated shear friction damper which provide a rectangular hysteresis loop, giving the maximum energy dissipation per cycle, but they possess no centering capacity.

Fig. 8 Shear friction damper

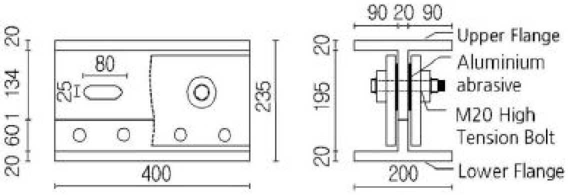

Fig. 9 Detail of shear friction damper [13]

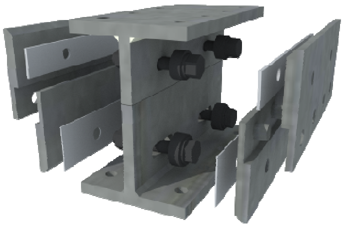

Fig. 10 VRF damper skiagram

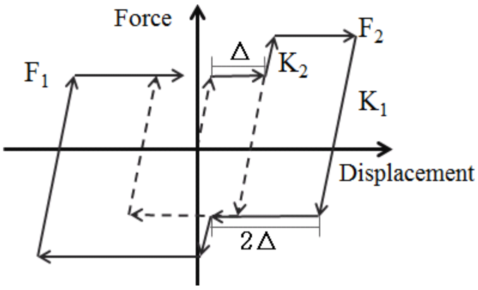

Fig. 11 The hysteresis response behavior of VRFD

Figs. 8 and 9 show skiagram and detail of shear friction damper presented in [13].

Another type of friction damper called variable resistance friction damper (VRFD) also developed in SSEEL, shown in Fig 10. Reference [14] developed and evaluated the performance of variable resistance friction damper (VRFD). The advantage of VRFD over the conventional friction damper presented above is its effective way to protect buildings from both high and low earthquakes, winds and other types of dynamic excitations. As shown in the hysteresis response behavior of Fig. 11, the resisting capacity has two parts, the high and low resistance part, two different stiffnesses K_1 and K_2 which have two yielding points. The yielding force at first stiffness (K_1) is the low resisting part and the yielding force at second stiffness (K_2) is the high resisting part which gives VRFD dynamic load resisting capacity. The frictional force resisted by both shear friction damper and VRFD can be expressed as in (8) using Coulomb's law of friction.

$$F = \mu \times C \tag{8}$$

where F is frictional force, μ is coefficient of friction, and C is compressive force.

The coefficient of friction between bolt tension and plate surface at the low-resistance part is unstable, which was determined to be wear caused by Burr on the friction surface due to repeated behaviors. The coefficient of friction at high-resistance part was confirmed to be reduced by about 12% reduction which is calculated using (9):

$$\mu = \frac{F}{m \times N \times T} \tag{9}$$

where μ is coefficient of friction, F is slip force, m is the number of friction surfaces, and T is bolt tension, N: number of bolt

E. Replaceable Link Beam

The research on eccentrically braced frame (EBF) has been started in mid-1970. The link beam in eccentrically braced frame is used as energy dissipation member. According to the dissipative design philosophy, structural damage in buildings design can be significant in moderate earthquakes. The repairing cost of the damaged members is an expensive operation if the damaged member is not isolated from the main structures. However, if the dissipative members (damping devices) can be isolated to from the overall building structure, these members can be removed and replaced after an earthquake. By doing these the repairing cost will greatly decreased and the interruption of building use can also be reduced.

According to AISC, the link rotation angle shall not exceed the following values depending on the length of link. $e \leq 1.6 {}^{M_p}\!/\!{}_{V_p}$, rotation 0.08rad and $e \geq 2.6 {}^{M_p}\!/\!{}_{V_p}$, rotation 0.02rad; where M_p: nominal plastic flexural strength, in (N-mm), V_p: nominal shear strength of an active link, in (N) [15].

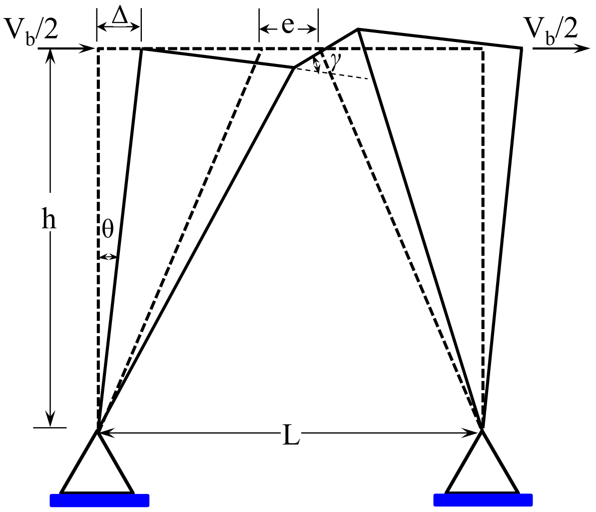

Fig. 12 Typical deformed eccentrically braced frame

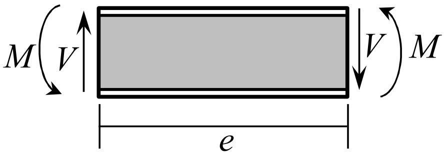

Fig. 13 Equilibrium of link

For removable link the performance requirements are they must be designed and detailed to achieve ≥ 0.08 radian plastic rotation (shear mode) under the design level or greater earthquake [16]. Inelastic demand must be limited to the link element; the rest structural members should remain elastic. The ease of removal and replacement post earthquake should also taken into account.

Reference [17] shows the cyclic plastic deformation of active links in steel eccentrically braced frame (EBF). Time history analysis on EBF with removable active link of G+10 building and presented the response considering different input El centro was also conducted. Steel eccentrically braced frame under different cyclic loading pattern is also evaluated [17]. Using EBF with removable active link beam is good both for seismic resistance and to easily remove and replacement after post earthquake.

The typical deformation of EBF is shown in Fig. 12. Taking the free diagram of the active link, the force act on it is shown in Fig. 13. The link rotation 'γ' can be calculated from the deformed shape in terms of deformation (Δ), length between column (L), length of frame (h) and link length (e) as in (10):

$$\gamma = \frac{\Delta * L}{e * h} \tag{10}$$

IV. CONCLUSION

Using smart green structural system in building design and construction will reduce the overall cost. It also reduces the environmental impact as it reduces the carbon dioxide emission. On the other hand, since the philosophy of smart green structural system is designing and prefabricating the structural elements, the construction period of the building is reduced significantly which in turn reduce the project cost.

ACKNOWLEDGMENT

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