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Seismic analysis of plan frame with energy dissipation device

Phân tích khung gắn thiết bị tiêu tán năng lượng dưới tác động của động đất

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ABSTRACT

The energy dissipation systems for seismic applications have been under development for several years with a rapid increasing in implementations. Most of energy dissipation devices are used mainly in brace or the base of the building such as metallic or hysteretic dampers and base isolation. The paper studies type of energy dissipation device installed in the beam. The research includes two main points: first, to develop mathematical models for building a structural element with finite element method, and second, to investigate various cases to consider the effect of the device on the frame's response to earthquake actions. A brief summary of the energy dissipation device in an acceptable location in beam and its certain outcomes in design of earthquake-resistant frames are presented.

Key words: Energy dissipation capacity, seismic behaivor, ductility demand, deformation-based method, finite element method

TÓM TẮT

Trong những năm gần đây, các giải pháp thiết kế kháng chấn cho công trình sử dụng thiết bị tiêu tán năng lượng có xu hướng phát triển vượt bậc. Đa số các thiết bị tiêu tán năng lượng được gắn tại thanh giằng chéo hoặc đáy công trình như các thiết bị cản nhớt, cản kim loại hay gối cách chấn. Bài báo nghiên cứu thiết bị tiêu tán năng lượng gắn trong dầm của kết cấu khung bê tông cốt thép. Nghiên cứu bao gồm hai vấn đề chính: thứ nhất, mô hình toán học của phần tử dầm có gắn thiết bị tiêu tán năng lượng; thứ hai, phân tích các trường hợp khác nhau để xem xét ảnh hưởng của thiết bị đến phản ứng của khung dưới tác động động đất. Kết luận cho thấy thiết bị tiêu tán năng lượng có thể được gắn tại dầm và đưa ra một số kết quả nhất định tác động lên kết cấu khung chịu tải trọng động đất.

Từ khóa: Khả năng tiêu tán năng lượng, phương pháp phần tử hữu hạn, thiết kế kháng chấn, thiết bị tiêu tán năng lượng...

1. INTRODUCTION

In the earthquake engineering field, one of the most important challenges has been continually to be the conceptualization, development, and application of innovative earthquake-resistant systems for decreasing the vulnerability of structures and infrastructures and improving the seismic performance and resilience, while keeping construction cost affordable. Seismic isolation and energy dissipation devices without doubt belong to such class of systems. Many theoretical, several studies in the literature, shake-table test results, and by experimental evidence on behaviors during real earthquakes have proven the effectiveness of these technologies in protecting structural components and non-structural elements under seismic action. A traditional earthquake-resistant design philosophy is primarily concentrated on the "life-safety" performance level implying that the structure suffers major damage but does not collapse during a considerable earthquake, so that the residents can leave safely. This is certainly sufficient (and somehow affordable from economic viewpoints) for normal structures. In contrast, a more challenging "functionality" performance level even under strong earthquakes should be solved by a design strategy using energy dissipation devices and/or seismic isolation. This is possibly solved in a twofold manner: (1) by additional damping mechanics involved in a limited number of components or "fuse elements," that is able to replaced easily or whose accumulated plastic deformations can be recovered after the earthquake; (2) by constraining the transmission of seismic energy via low lateral stiffness devices interposed between the main structure and the ground. Overall, both these approaches cause a low-damage structural system in where the structure is able to be designed to remain in an elastic or in a quasi-elastic range of the response. Some years ago, because of causing economic and social impact (hospitals, police stations, power plants, communication centers, etc.), this "high-performance level" design was considered necessary for major structures requiring minimal downtime after the seismic event. Today, the application of seismic isolation (including elastomeric bearings, lead rubber bearings, sliding friction pendulum and adaptive isolation devices) and energy dissipation devices (including metallic, viscous, viscoelastic, friction, rotational and inertial dampers, tuned mass dampers and tuned liquid dampers) has increasingly become common, both for the aforementioned important structures and for normal structures, and specifically those needing retrofitting.

Typical methods of earthquake resistant design depend on the ductile behavior of the structural members for energy dissipation. When energy dissipation is achieved by inelastic response, the structure is damaged and hence a sufficient seismic design demands that the structure yield and experiences damage without collapse under a disastrous event. In the last decade, seismic design codes have been more and more adopting a capacity design method, which points to control both the location and the form of inelastic behavior. The main pro of this method is that failure mode control cause more reliable and predictable sources of energy dissipation while the final design is less sensitive to the uncertainties combined with ground motion characteristics. The main con of conventional seismic design methods is that the structure is susceptible to damage under the action of major earthquake. The inflicted damage may be repairable or may even be so serious that the structure must be demolished. As a response to the shortcomings inherent in the philosophy of typical seismic design, numerous innovative approaches depend on the incorporation of energy dissipation devices in the structure. The device is used to protect the structure from damage by absorbing energy in elements that are designed to be accessible, easily replaceable or returnable after a major event. By following the latter approach, the load-carrying function of the structure can be separated from the energy dissipation function. Furthermore, the energy dissipation characteristics of the structure can be more easily detailed and optimized.The energy dissipation systems for seismic applications have been under development for several years and continuously implemented in numerous buildings all around the words. The system has been playing an important role in improving the seismic behavior when adding of energy dissipation devices. A lot of devices has been produced with different characteristics and behaviors.

Passive energy dissipation systems for seismic applications have been under development for a number of years with a rapid increase in implementations beginning in the mid-1990s. The fundamental function of a passive energy dissipation system is to decrease the inelastic energy dissipation require on the framing system of a structure (Constantinou and Symans 1993b). Several passive energy dissipation devices are either commercially available or under development. Device that mostly used for seismic protection of structures contain viscous fluid dampers, viscoelastic solid dampers, friction dampers, and metallic dampers. Other devices that could be classified as passive energy dissipation devices (or, more generally, passive control devices) include tuned mass and tuned liquid dampers, both of which are primarily applicable to wind vibration control, decentering dampers, and phase transformation dampers. In addition, there is a class of dampers, known as semi active dampers, which may be regarded as controllable passive devices in the sense that they passively resist the relative motion between their ends but have controllable mechanical properties. Examples of such dampers include variable-orifice dampers, magnetorheologi-cal dampers, and electrorheological dampers (Symans and Constantinou 1999). The growth in application and development of passive energy dissipation devices has led to a number of publications that present detailed discussions on the principles of operation and mathematical modeling of such devices, analysis of structures incorporating such devices, and applications of the devices to various structural systems (e.g., Soong and Dargush 1997; Hanson and Soong 2001). In addition, a state-of-the-art and state- of-the-practice paper was recently published on the general topic of supplemental energy dissipation wherein both passive and active structural control systems were considered (Soong and Spencer 2002). Using passive energy dissipation devices in a structure is mainly to minimize damaging deformations in structural components. The degree to which a certain device is able to achieve this goal relies on the inherent properties of the basic structure, the properties of the device and its connecting elements, the characteristics of the ground motion, and the limit state being considered. Given the large alternatives in each of these parameters, it is usually needed to perform an extensive suite of nonlinear response-history analyses to verify which specific passive energy dissipation system is best matched for a given case.

In spite of the large number of studies carried on the seismic behaviors of structures where passive control devices installed in their brace or base of the building, this paper focuses exclusively on the case of passive energy dissipation devices applied in an acceptable location in beam and their building structures for seismic response control providing a concise summary in study.

2. FINITE ELEMENT FORMULATION

Consider the new beam element has been installed energy dissipation device (EDD), with damper coefficient C, connecting joints i and j, is defined in the x, z plane as shown in Figure 1 where the nodal displacements, given by the transversal displacement and rotations at node i and j, are collected in the vector $u = \{v_i, \phi_i, v_j, \phi_j\}^T$.

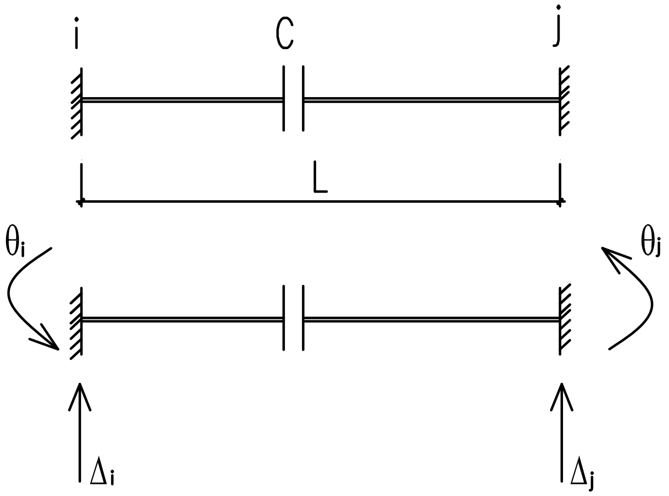


Figure 1: New beam element

In fact, the beam is mainly subjected to the combined action of bending moment, shear and axial force, thus the stress state of the device in the actual structural is very complicated. To evaluate the mechanical property of the device, the load boundary conditions including pure-shear and bending-shear loads are considered. The axial force in the device is less significant, therefor, the axial force is not considered.

Using the displacement method to determine the stiffness matrix [K] of beam element, the resulting member stiffness matrix is symmetric about the diagonal:

$$[K]=\begin{bmatrix} \dfrac{2}{L.\left(\dfrac{L^2}{6EI}-\dfrac{2}{CL}\right)} & \dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & -\dfrac{2}{L.\left(\dfrac{L^2}{6EI}-\dfrac{2}{CL}\right)} & \dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} \\ \dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & \dfrac{\dfrac{L}{3EI}-\dfrac{1}{CL^2}}{\dfrac{L}{EI}\left(\dfrac{L}{12EI}-\dfrac{1}{CL^2}\right)} & -\dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & \dfrac{\dfrac{L}{6EI}+\dfrac{1}{CL^2}}{\dfrac{L}{EI}\left(\dfrac{L}{12EI}-\dfrac{1}{CL^2}\right)} \\ -\dfrac{2}{L.\left(\dfrac{L^2}{6EI}-\dfrac{2}{CL}\right)} & -\dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & \dfrac{2}{L.\left(\dfrac{L^2}{6EI}-\dfrac{2}{CL}\right)} & -\dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} \\ \dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & \dfrac{\dfrac{L}{6EI}+\dfrac{1}{CL^2}}{\dfrac{L}{EI}\left(\dfrac{L}{12EI}-\dfrac{1}{CL^2}\right)} & -\dfrac{1}{\dfrac{L^2}{6EI}-\dfrac{2}{CL}} & \dfrac{\dfrac{L}{3EI}-\dfrac{1}{CL^2}}{\dfrac{L}{EI}\left(\dfrac{L}{12EI}-\dfrac{1}{CL^2}\right)} \end{bmatrix} \quad (1)$$

Where:
E: The modulus of elasticity;
I: The cross sectional moment of inertia;
L: Beam length;
C: Damper coefficient.

3. MODELLING AND ANALYSIS OF FRAMES

The buildings considered are assumed to be located in Dien Bien, Viet Nam with a site classification of D. The Figure 2 illustrates the framing plan of 10-storey 3-span building with the typical storey height is 3.5 m and spans of 6 m and 1.8 m. The cross sections of beams and columns are as shown in Figure 2. The material utilized for beams and columns is concrete, which has Young's modulus E of 36,000 MPa. The inelastic behavior of the short beam is simulated as Figure 4. Other beams and columns are modelled by normal beam elements with the linear behavior. Mass assigned in A and D are the same with value of 68.1 kg. In addition, B and C is assigned with mass of 83.3 kg.

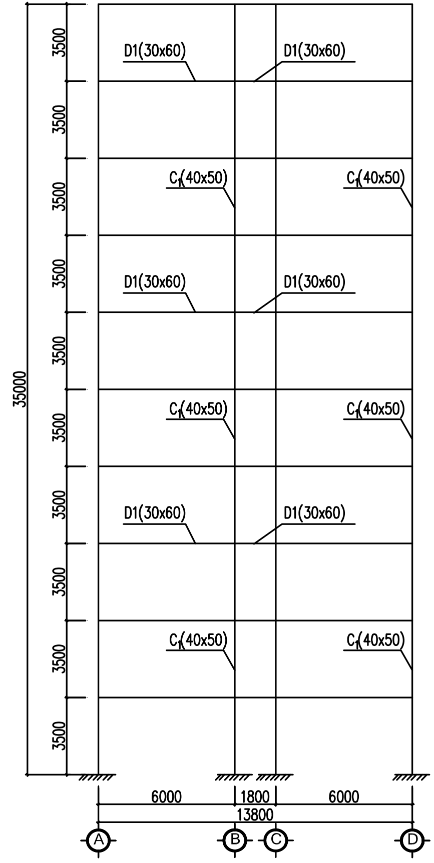


Figure 2:10-storey frames

The model is investigated and stimulated using a tool developed under Mathlab system with several cases of the energy dissipation devices (EDD) mentioned afore section which has force-displacement relationship as shown in Figure 4 below and their characteristic of Q = 40 KN, K1 = 132,5 KN/cm, and K2 = 15,5 KN/cm assigned at the middle span of 1st- 3rd floor. Assumed that the stiffness matrix of beam at the middle span wherein assigned with the energy dissipation device are equal to the equation (1) above. Ground motion used in this study is occurred at Dien Bien in 2001 (Figure 3).

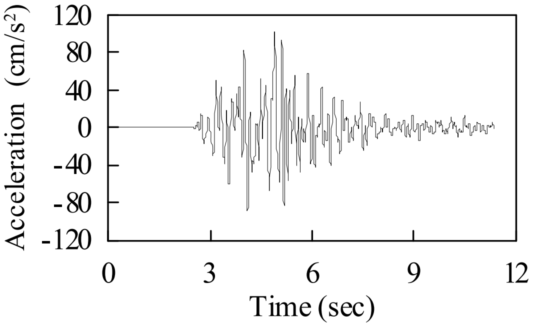


Figure 3: Acceleration time history of ground motion

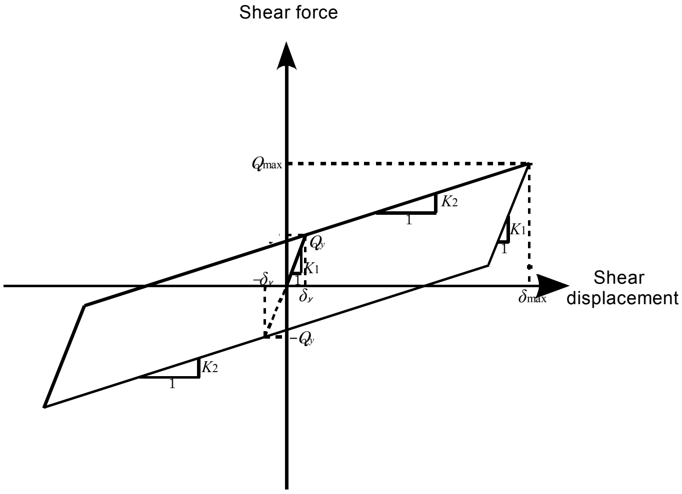
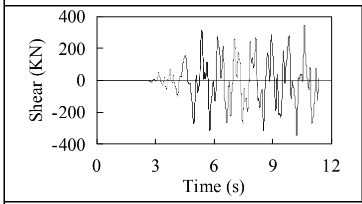
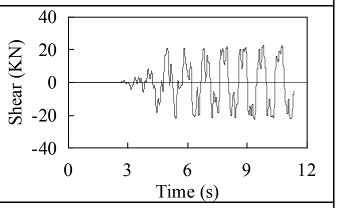
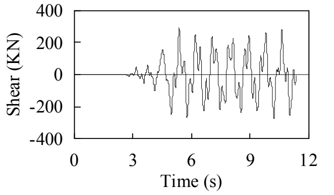
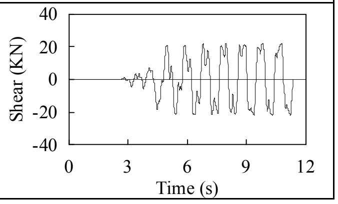


Figure 4: Force-displacement relationship of energy dissipation device

Beam without EDD	EDD at 1st - 3rd floor
1stfloor	
	
2nd floor	
	

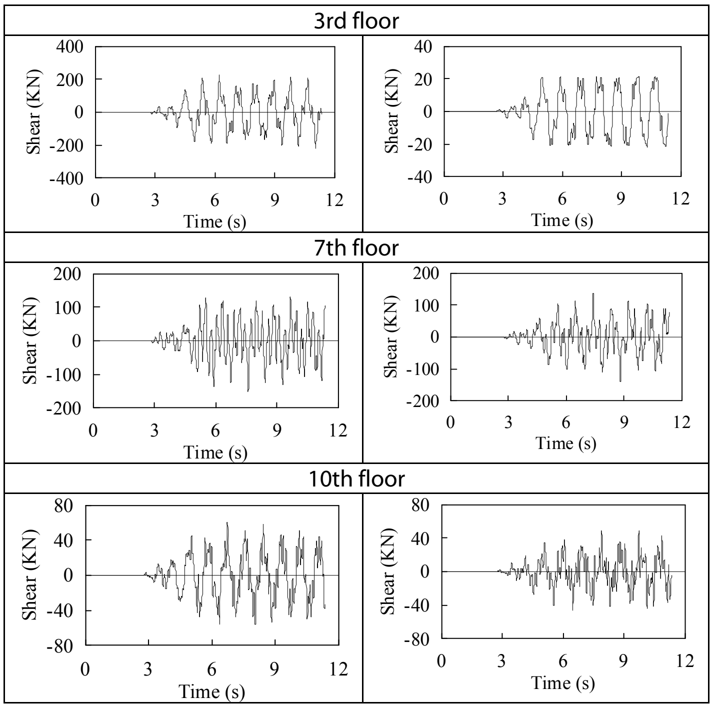


Figure 5: Shear force responses at the middle beam of 10-story frame

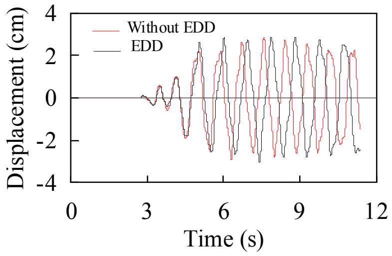


Figure 6: Peak Displacement of 10-story frame

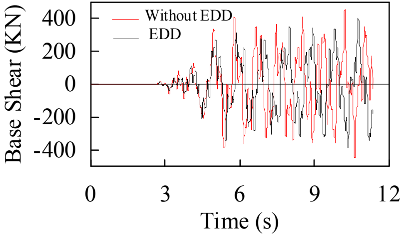


Figure 7: Base shear of 10-story frame

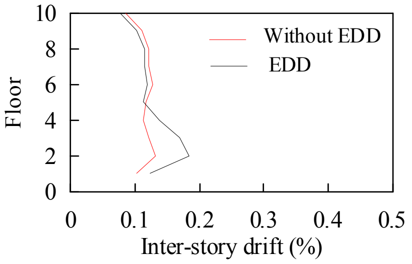


Figure 8: Peak drift responses of 10-story frame

Figure 5 shows the shear force of the short beam at floors 1,2,3 wherein a dissipation device installed and that in floors of 7, 10 - without a dissipation device. It can be clearly seen that when attaching the device to the beam, the force is greatly reduced. The peak displacement of the building in the case with and without the dissipation device is equivalent to 2.88 cm and 2.84 cm, respectively as shown in the Figure 6. In addition, shear force at the bottom of the building is reduced from 450 KN to 397 KN when attaching energy dissipation equipment to the 1,2,3 floor (Figure 7). Inter-story drift of a building (Figure 8) when a device is attached to dissipate energy only decreases at the upper floors (6-10) but at the floor where equipment is attached, it increases compared to normal.

4. CONCLUSION

The paper discussed the literature, methodologies regard to the energy dissipation devices applied in earthquake-resistant structure. Additional, the model is built in different way with previous regarding studies by assigning the energy dissipation devices at the beam and investigated with its different locations and characteristics. Thus, some initial results figure out that the stiffness matrix of new beam element, which has energy dissipation device as shown in the equation (1). When installing the energy dissipation device, it can be clearly seen that a significant change in beam shear force, bottom shear force of the building. However, there are still many limitations on inter-story drift and the top displacement that does not change significantly. To be able to achieve better results which has more value in the literature and more practically applicable in practice need further studies in the future.

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