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USING ACCORDION THIN-WALLED TUBE AS A HYSTERETIC METALLIC DAMPER

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SUMMARY

Using the energy absorber systems like metallic dampers for controlling the structures vibrations due to earthquake has been discussed during the past decades. In these years different types of metallic dampers have been made and developed. Some types of them have deficiencies and some types are used in constructions and industries.

In this paper, it is tried to introduce a new metallic damper as a supplemental passive energy absorption device for seismic design and seismic retrofitting of structures. Application of this device is in base isolation and chevron bracing in frame stories. A hysteretic system including of accordion thin-walled metallic tube has been suggested for this damper. Finite elements model and nonlinear dynamic analysis have been used in these studies. Analytical behavior of accordion thin-walled tubes like deflections, stress distribution, hysteretic loops, deterioration effects like strength reduction and stiffness degradation, and their capacity of energy absorption due to axial cyclic loads for using as a suggested damper have been studied.

Analytical results show that the suggested system is suitable and usable as a hysteretic metallic damper because of stable behavior in tension and compression and energy absorption.

INTRODUCTION

Traditional seismic retrofitting methods , on one hand , are more or less expensive for existing buildings like strengthening the beam and column elements and connections or adding bracing and shear wall , and on the other hand, make damage to the performance and serviceability of the building during the construction .While modern methods and using new systems in vibration control , not only are economic but also let the building continues its serviceability during the construction process without any huge destruction. So energy absorbing devices for seismic designing and retrofitting the structures are developing fast during the past decades.

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Dampers are one of the types of vibration energy absorbing systems in structures which include different types, velocity dependent dampers like viscose damper, viscoelastic damper and displacement dependent damper like friction damper, hysteretic metallic damper and combined dampers. Dampers were initially used in aviation and nuclear industries. The first building application of these devices was controlling the vibrations against the wind. Using hysteretic metallic dampers idea for earthquake energy absorption in structure was introduced early 1970's. During these years, many proposed mechanisms for these kinds of dampers were studied [1].

In 1990's metallic dampers were used in building construction and seismic retrofitting in some cases. Studies and work progress are still continuing and one faces to new innovation in metallic dampers.

TYPES OF HYSTERETIC METALLIC DAMPERS

Many types of metallic dampers have been developed since 1972. These dampers have energy absorption mechanism in plastic strain and hysteretic behavior and work in bending or torsion deformation due acting load. Tensional and bending beam and U shape bands were among the first dampers which were made for this purpose. Then leaden compression dampers have been manufactured and tested which has axial performance. Dampers with large deformation capacity were the next generation of energy absorption devices, like Min Damper which includes an 80 centimeter diameter metallic hoop and locates under loading along the diameter. Nonlinear horizontally spring damper, bending bar, curved plates, axial radius bars, bars devices and U shape damper, a sort of large deformation dampers were studied by researchers [2]. Although these dampers have various types, but were not broadly developed, not being much welcomed and considered [2].

X and V shape bending plates, known as ADAS and TADAS dampers, are a kind of dampers by small deformation capacity. They have been developed and are used in industry [3].

Honeycomb damper plate, Hourglass-shaped damper, RADAS and E shape damper are the same. Then performance of Lateral deformation of tubes and displacement amplifying systems, kinematically expanding hysteretic damper (KEHD) and composite confined hysteretic damper (CCHD) are studied by some researchers [3].

Although many analytical and experimental studies have been conducted around the world about the hysteretic metallic dampers and various types of them have been developed, but most of them were designed for small deformations and the suggested dampers by large deformation capacity have not been developed , so it seems that developing dampers specially with large deformation capacity is needed with consideration to their points of weakness like instability in repeat ion of cyclic behavior, deterioration, strength reduction and stiffness degradation in dampers materials [4].

PERFORMANCE OF HYSTERETIC METALIC DAMPERS

Physical systems have damping property naturally. Damping is potential of dissipating the energy in the structures which is modeling by various forms like internal viscose damping, external viscose damping, friction damping and hysteretic damping.

Damping has an important role in response reduction in dynamic behavior of structures. Metallic dampers have hysteretic damping. These devices convert the large amount of entrance energy in a structure to the plastic strain energy or hysteretic energy. This energy is unconservative and dissipates in the structure.
If a structural member is considered by elasto-plastic behavior, the member response is completely elastic and conservative for the loads equivalent by stress which is less than yielding stress. In this case there is

no energy dissipation in a load and unloading cycle. When the existing stress goes upper than yielding stress, materials enter to the plastic deformation range, which is unconservative behavior. So a certain energy loses in a member in a loading and unloading cycle. The important part of this energy converts to the heat.

Figure 1 shows the force-displacement relationship for a metallic damper by elastoplastic cycle behavior. The surface between the hysteretic loops is the density of dissipation energy in the structural member. It is clear that more surface before the fracture point , more loss of energy by damper in yielding and the loss of energy in structure would be increased by repeating the loops or loading and unloading cycle.

Figure 2 illustrates the effect of the metallic damper on reduction of displacement response of a frame [1].

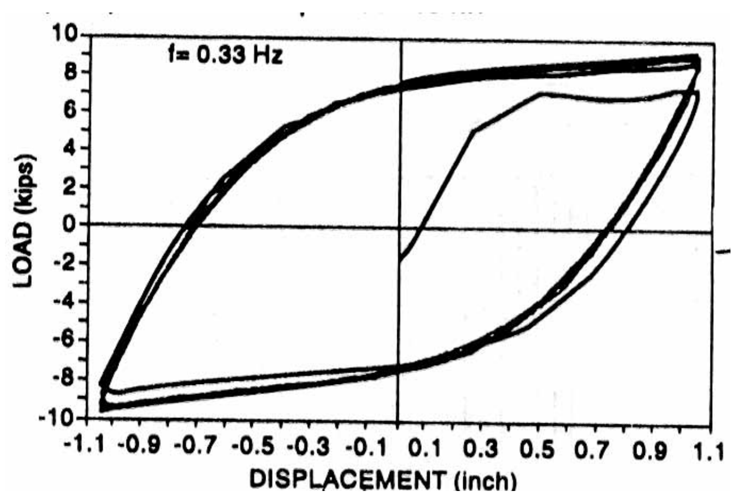

Figure 1:Hysteresis loops of metallic dampers [1]

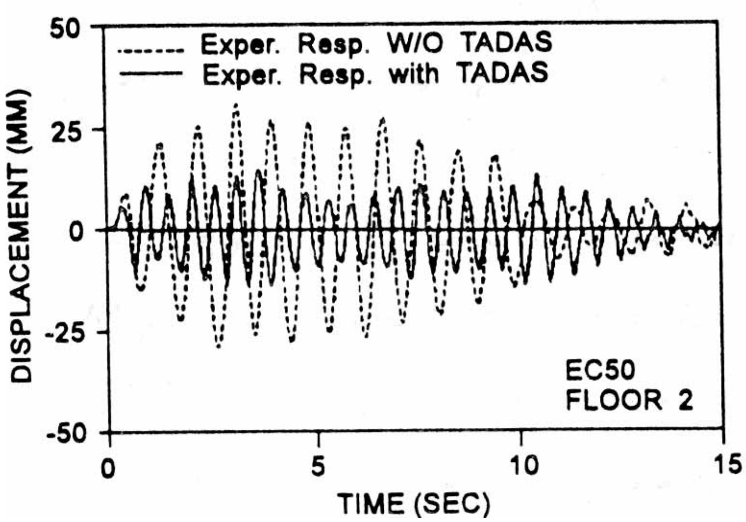

Figure 2: Performance of hysteretic metallic dampers in response reduction of a frame [1]

INTRODUCING THE PROPOSED DAMPER

Using the metallic tubes in mechanical energy absorption systems have been commonly used during recent years. Many researchers including Reid and et al. [5], Ma et al. [6], and Daneshi [7] have studied the performance of metallic thin-walled tubes against the impact. Thin-walled tubes under axial compression are one of the best method for absorbing the energy because of the high capacity in energy absorption and long crippling length. But these systems deform and absorb energy only in impact. These tubes are crashed like accordion during the deformation in the ideal state. In the other words if the thin-walled tubes crash in accordion form , the maximum capacity of forming the plastic hinge could be obtained and they have the maximum rate of energy absorption .So this appropriate deformation mode could be activated by selecting the suitable initial geometric shape for a thin-walled tube.

Daneshi and Hosseinpour [8] analyzed the grooved thin-walled tubes under axial compression force and studied the effect of circular groove which are internal and external every other one on the buckling force, for controlling the deformation and rate of strain. But this mechanism absorbs energy only in compression.

On the other hands, application of flexible connection in machines and industrial equipments, reminded the selection of accordion shape idea for thin-walled tubes. Common characteristics for thin-walled tubes geometry have shown in figure 3. L, length of tube, R, radius of tube, t, wall thickness, l, length of straight corrugated plate, r, radius of wrinkle plate, N, number of wrinkles along the tube and φ is angle of wrinkles in this paper. It is clear that the behavior of device and its energy absorption rate changes by modifying each above geometric parameters. It is expected that the maximum energy absorption would be derived by optimizing these parameters.

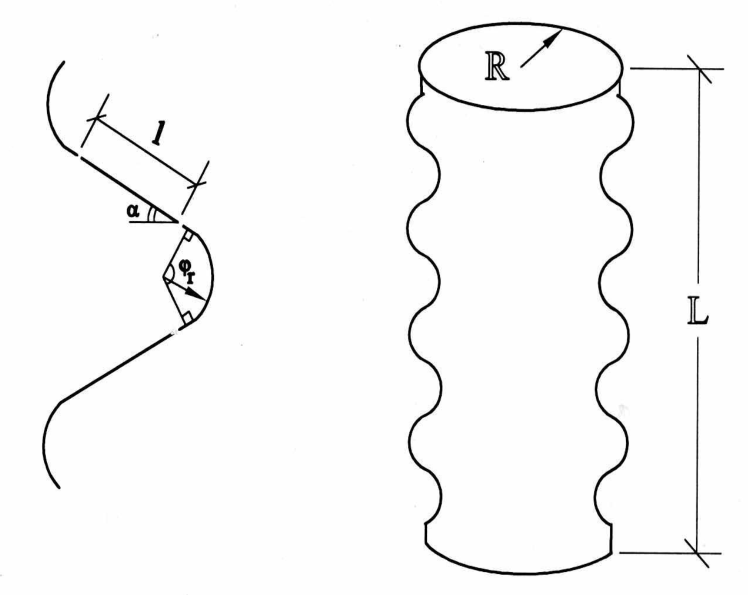

Figure 3: Geometric characteristics of the proposed damper

BEHAVIOR OF ACCORDION THIN-WALLED TUBES

It seems that accordion thin-walled tubes as the hysteretic damper have the same and stable behavior in tension and compression. Also the plastic hinges are extended in the tube's wall by choosing the suitable geometric parameters and maximum capacity of energy absorption could be used. These tubes can suffer the large deformation in addition to be usable in range of demanded displacements of building stories. In the other words they have long crippling length and could be used as the large deformation capable damper [9].

Figure 4 illustrates four various shape for geometry of this type of damper. Selection of suitable shape for the more energy absorption needs the more optimization studies. Only one of the suggested models in figure 4 has been studied in this paper.

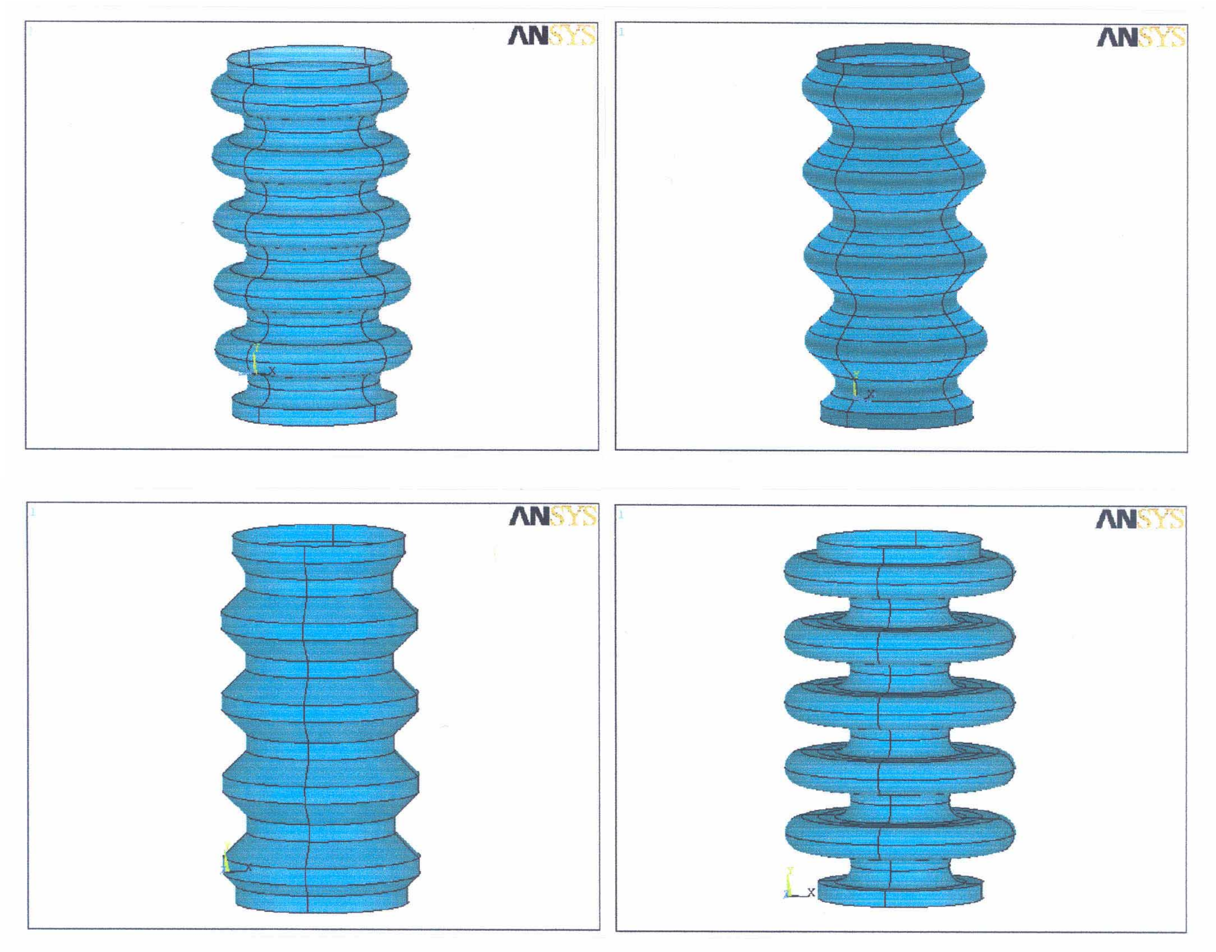

Figure 4: Different proposed shapes for geometry of accordion thin-walled tubes

Analytical Modeling

Analytical modeling has been used for studying the behavior of accordion thin-walled tubes. The studied sample model has been considered by length of 22 centimeters, radius of 10 centimeters, straight corrugated plate length of 2 centimeters, wrinkle plate radius of 1 centimeter, straight plate angle of 45° and plate thickness of 2 millimeters. ST-37 mild steel by yielding stress of 2400 kilograms per square centimeter and young modulus of $2*10^6$ kilograms per square centimeter has been considered for materials. Stress-strain relation of materials is based on the actual behavior of ST-37 building steel and the same in tension and compression.

Modeling has been done by ANSYS 5.4 software and Quadratic Shell Elements have been used for meshing. The element type selection is automatically, but smaller elements in size have been used. Large deformation and nonlinear analysis has been performed because of acting nonlinear strain in plastic hinges. Loading model is cyclic by displacement control of 8 millimeters [10]. Figure 5 shows the analytical model and meshing by Shell 181 Elements.

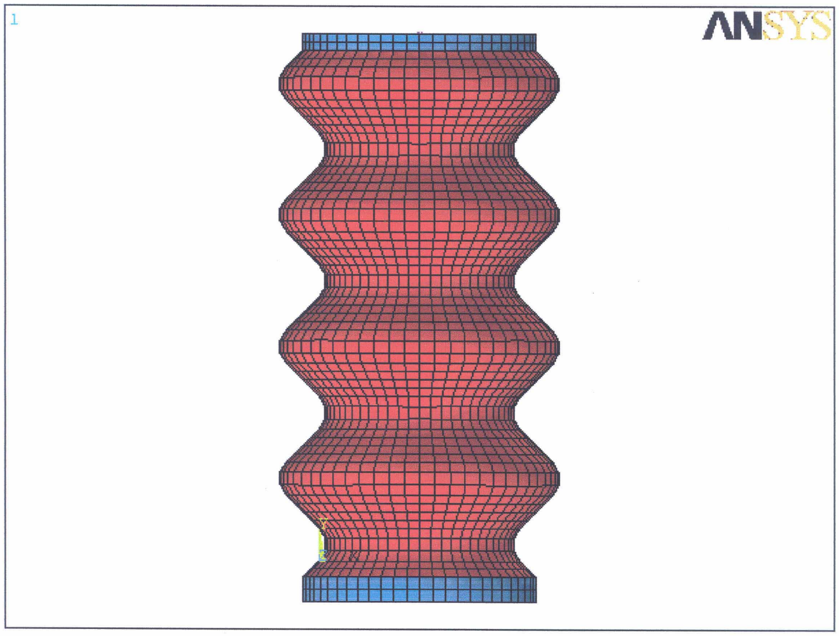

Figure 5: Finite Elements model of accordion thin-walled tube by Shell Element, ANSYS Ver. 5.4

Analytical Results

Initial analysis results show the suitable behavior of metallic accordion thin-walled tubes in cycle deformations. Figure 6 deals with the axial deformation of model under acted maximum load and in small axial deformation range. It seems that the considered tube has larger plastic deformation capacity. Complete plastic hinges occur in peak points of corrugates by acting the axial load and tube is shortened like accordion. If thickness and another geometric parameters are designed correctly, it will be supposed that thin-walled tubes have energy absorption capacity until contacting the peak points corrugates.

So proposed damper could be a large deformation energy absorption. Of course, more investigation is needed to prove the very performance, specially in view point of strength reduction in high vibration cycles and being torn of tube section. Performance of these tubes has been studied only in small axial deformation range in this paper.

Figure 7 illustrates the stress distribution in accordion tube’s wall based on Von Misses criteria. It is considered that the stress ratio in peak points of corrugates and their close regions have been reached to yielding limit. Yielding regions have been developed by acting the more axial force and this means of more energy absorption in axial deformation of the tube.

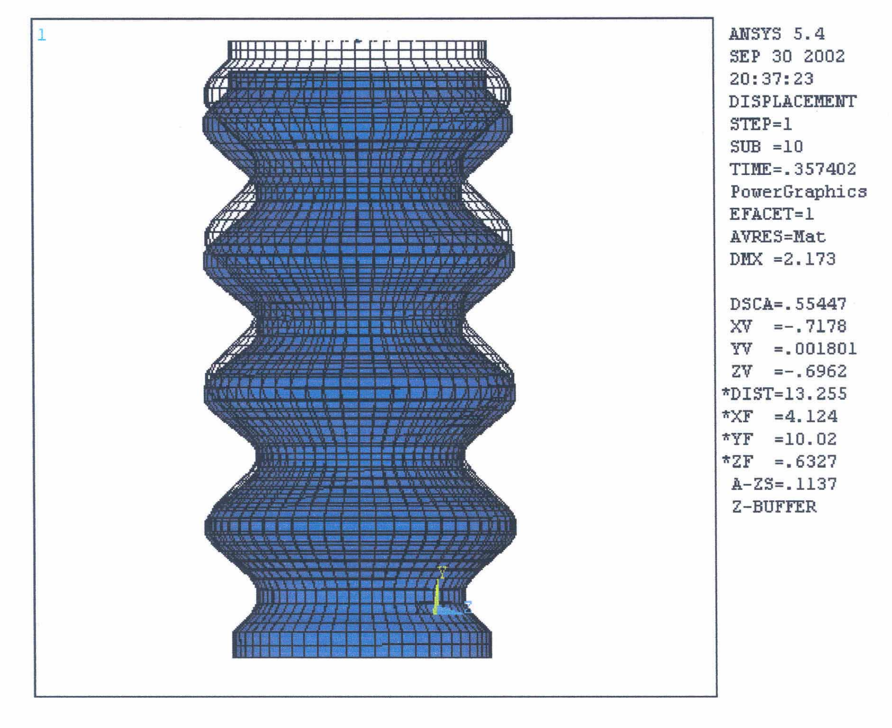

Figure 6: Axial deformation of accordion thin-walled tube

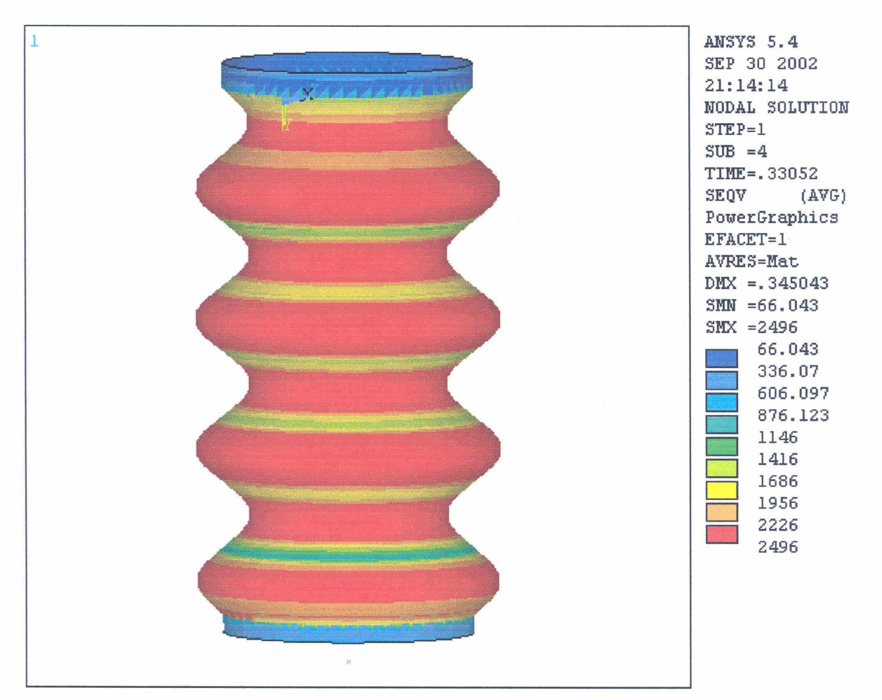

Figure 7: Stress distribution based on Von-Misses in the thin wall of accordion tube

Figure 8 shows the hysteretic behavior of studied thin-walled tube in axial deformation mechanism and during one loading and unloading cycle. The same behavior of the device in tension and compression is clearly seen in the curve. This device which is deflected 8 millimeters in its axis, has been suffered 4 ton axial load approximately. Energy absorbed density by yielding the steel materials in corrugates of accordion thin-walled tube is shown by confined surface in hysteresis loops.

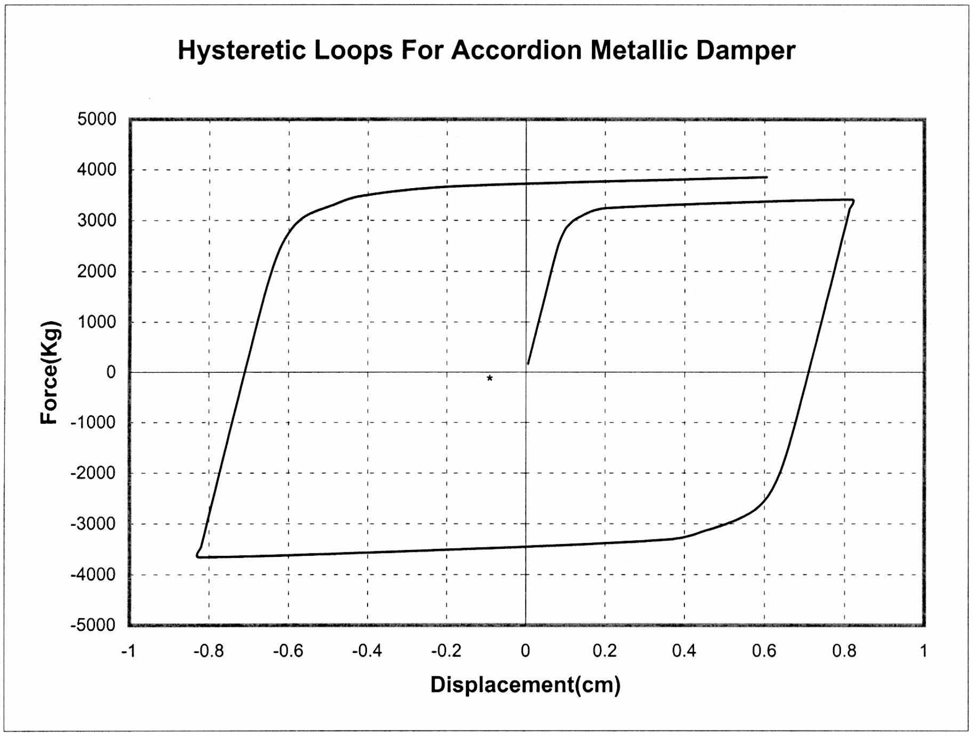

Figure 8: Hysteretic behavior of accordion thin-walled tube in axial deformation in one cycle

APLICATION AND RECOMMENDATION

Conducted analytical studies have been performed only in one loading cycle. In order to ensure the stability of behavior of proposed damper and studying the strength reduction and deterioration, it is required to conduct the nonlinear dynamic analysis. Also experimentally studies of behavior of accordion thin-walled tubes, will illustrate some unknown aspects of analytical modeling. Assessment of application of this damper as a energy absorption system with large deformation capacity is suggested, as well.

Traditional methods of seismic designing and seismic retrofitting of structures are gradually losing their significance by development of using modern system specially dampers [11 and 12]. As such, for having access to suitable behavior in structure with more safety and low expenses, new approaches must be searched. It seems that accordion metallic damper is applicable in seismic retrofitting of different kinds of structures. The location of installation of this damper has been illustrated in figure 9. This device could be installed between the chevron bracing connection and story beam in building structures. The damper is under axial force by acting the lateral load to the frame and absorbs energy proportional to the amount of deformation.

It can be used in frames by large deformation mechanism, because of high performance of this damper in deformation. Also this damper can control the absolute displacements of structure by planting the damper in the connection of frames and shear wall.

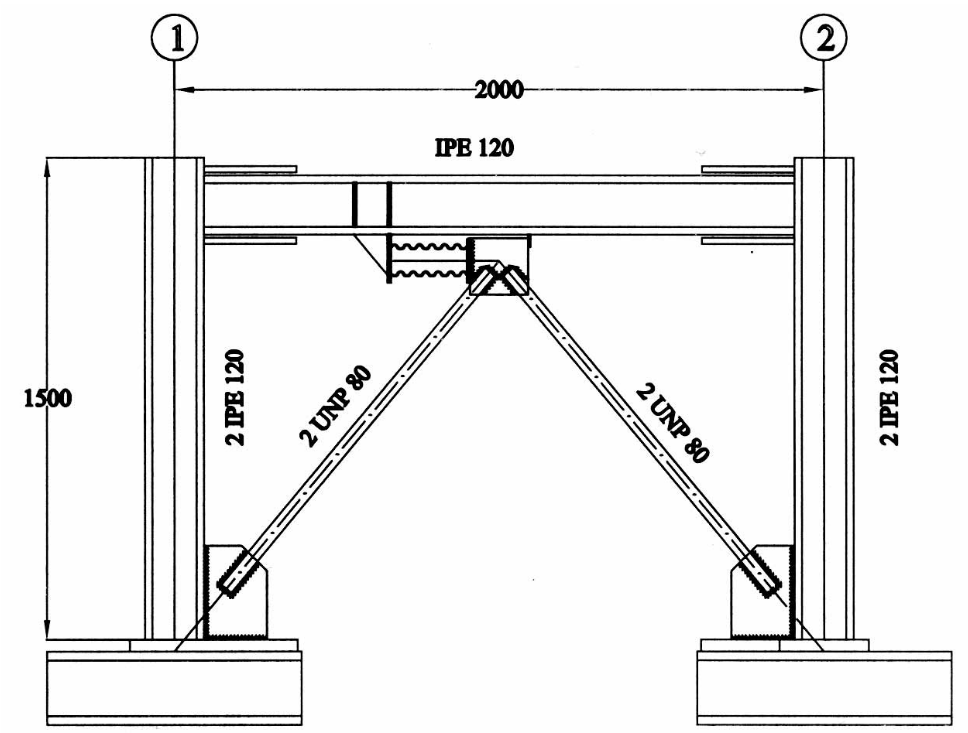

Figure 9: Application of proposed damper in seismic retrofitting of frames

CONCLUSIONS

Based on the conducted studies, the results are obtained as follows:

1- Most developed metallic dampers are applicable in small deformation range. So metallic dampers which could suffer big deformation in the stable state and absorb the energy, are required.

2- Numerical studies and nonlinear analysis show that accordion thin-walled tubes can be used as hysteretic metallic damper

3- Accordion metallic damper can be used for retrofitting the existing structures against the earthquake.

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