structural practices

Seismic Dampers

State of the Applications

By H. Kit Miyamoto, M.S., S.E. and Robert D. Hanson, PhD, P.E.

There are over 150 structures in the United States and over 2,000 structures in Japan utilizing dampers to improve seismic response behavior. Damper applications are closely tied to Performance Based Design (PBD). PBD will be a larger part of future seismic engineering, and applications of dampers will be increased to provide safe and cost effective earthquake protection systems.

Introduction

Typical structures may possess 1% to 5% inherent structural damping. This damping may be contributed from architectural components such as partition walls, ceiling, exterior cladding, and mechanical ducts etc. Dampers directly provide an additional damping to the structure in the form of discrete devices. Dampers have been designed to provide 5% to 50% of critical damping for many existing and new structures. Dampers are introduced to reduce or eliminate structural yielding and architectural damage.

The basic philosophy for earthquake resistant design is commonly referred to as **Life Safety Performance**. In a typical design, this means that lateral force-resisting elements such as moment frames, braced frames, and shear walls are designed to yield during a design level seismic excitation. Maximum inelastic drift may be allowed up to 2.5% of the story height. To achieve these drifts, structural yielding (in many cases it occurs at vertical loading carrying elements) and architectural damage absorbs the seismic energy. Intent of the design is to avoid collapse of the structure. *Figure 1* shows the free vibration displacement reduction comparison for 5% and 20% of critical damped structures. The graph shows a drastic difference of the displacement responses.

"…additional damping to the structure in the form of discrete devices."

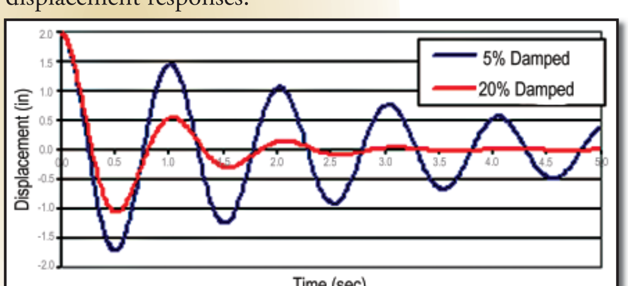

Figure 1

For both new and existing structures, dampers can provide better and more reliable performance than conventional construction. Many devices have been thoroughly tested and a rational design procedure is available. Dynamic response calculations are commonly performed to analyze the damped structure. Many damped structures with 20% damping or higher will keep the structure elastic. Commercial software is available to analyze structures with dampers. However, it is important to work with a building official during the design phase. A qualified peer reviewer is required by all of the current design codes and guidelines.

Damper Types

There are four major groups of dampers used in the United States. Each group of dampers has specific characteristics, advantages and disadvantages for structural applications. Design engineers need to understand the static and dynamic behavior of the device being used.

Fluid Viscous Dampers (FVDs)

FVDs have been widely used in aerospace and military applications since the early 1900's. After the end of the cold war, its technology became available for civilian usage.

Compressible silicon oil flows through orifices with high velocity, generating heat which is radiated into the surrounding air. This hydrodynamic process dissipates the seismic energy. *Figure 2* and *Figure 3* show an FVD installation in a diagonal brace configuration.

FVDs add viscous damping to the structure, and can reduce acceleration and displacement for the most of the frequency range. FVDs are the most useful where engineers desire to reduce displacement without increasing the structure's frequency.

Figure 2: Fluid Viscous Damper

Viscoelastic Dampers (VEDs)

VEDs add both stiffness and damping to the structures using inelastic deformation of polymers. Solid VEDs were used in the World Trade Center in New York for wind response control. *Figure 4* (EERI, 2001) illustrates a common solid VED.

Friction Dampers

Friction Dampers consist of the friction surface clamped together by high strength bolts with slotted holes. Slip force is designed large enough that there is no sliding for wind forces. However, it slips during large seismic excitations. Friction energy dissipates seismic energy through heat. *Figure 5* (EERI, 2001)

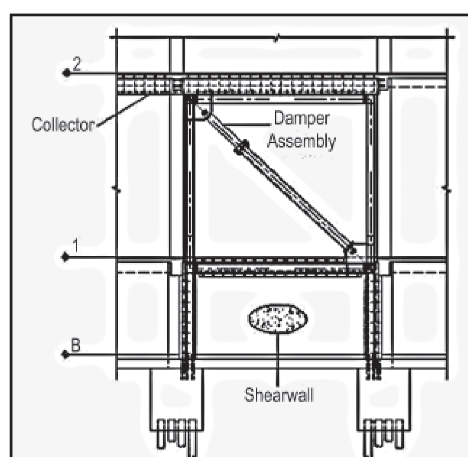

Figure 3: Elevation Detail of FVD

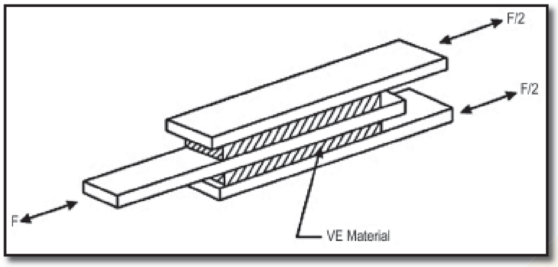

Figure 4: Solid VED (EERI, 2001)

and *Figure 6* show two configurations for a friction damper. This damper provides increased stiffness until it slips, and then it provides energy dissipation to the structure.

Metallic Yielding Dampers (MYDs)

Metallic Yielding Dampers are probably the most familiar to structural engineers, since its concept is the same as typical steel seismic force resistive elements such as steel moment frames and braces. Beam-column connections yield for steel moment frames to absorb the seismic energy. The braces also buckle to absorb the seismic energy. However, the biggest difference between MYDs and typical steel system is the yielding location for MYDs is not in the gravity load carrying elements. One type of MYD is the buckling restrained brace. *Figure 7* illustrates the buckling restrained braces. Concrete encased metal elements yield with a stable manner, without compressive buckling.

"…it is critical to capture the nonlinear dynamic behavior of the structure…"

Design Guidelines and Code

When engineers use dampers, it is critical to capture the nonlinear dynamic behavior of the structure, such as yielding of the seismic force resisting system, the gravity load system, and nonstructural components. Without the knowledge of the expected behavior/performance of the structure, it is not practical to determine the amount of additional damping and stiffness required to achieve the desired performance.

Therefore, Performance Based Design (PBD) is a key for designing structures with dampers. For existing structures, FEMA 273 and FEMA 356 are considered to be state-of-the-art documents. Engineers can use either nonlinear static or dynamic procedures.

A U.S. historical registered building located in Northern California has been renovated using FEMA 356 guidelines. FVDs and FVED are used at the ground floor to mitigate soft/weak story.

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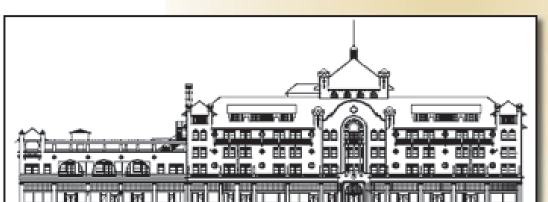


Figure 8: Elevation of Historic Hotel Stockton

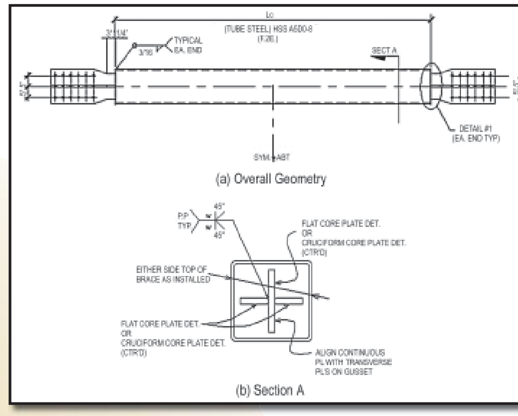
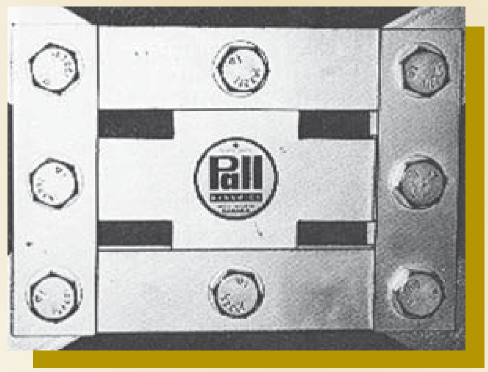
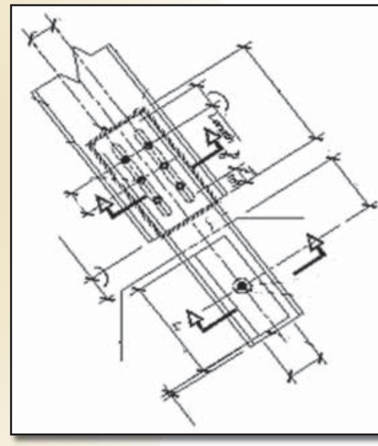


Figure 7: Buckling Restrained Brace





Figures 5 & 6: Friction Dampers

Figure 9a: Structural Framing

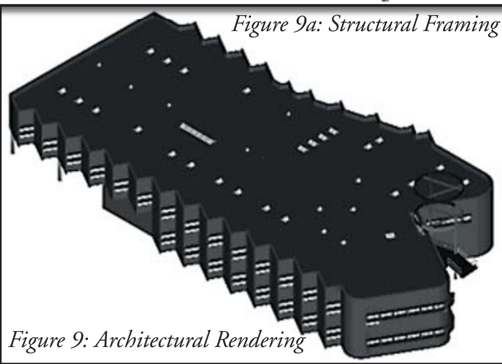


Figure 9: Architectural Rendering

See *Figure 8, previous page* (Miyamoto, Determan, Gilani and Hanson, 2003).

For the new structures, 2003 NEHRP Recommendations (FEMA 450) contains a chapter for designing structures with dampers. The FEMA 450 chapter on supplemental damping is in the process of being accepted into ASCE 7-05. Again, these requirements offer both linear and nonlinear design philosophy.

Figures 9 and *9a* show the new Vacaville Police Headquarters in the Bay Area (Miyamoto and Hanson, 2003). It uses the latest design features available in the 2003 NEHRP Recommendations for the designing of FVDs.

Future Trends

There are over 2000 structures with dampers or isolators in Japan. Japanese Building Code requires incorporation of dampers in all major construction. In the United States, applications of dampers will increase in the near future as new guidelines, codes, and software are readily available for engineers. Using PBD and dampers, it is possible to design safer and more cost effective structures than ordinary code conformed structures.▪

Kit Miyamoto, M.S., S.E., provides expertise in performance based engineering and award-winning seismic designs. A licensed structural engineer in eleven states, Mr. Miyamoto is CEO of Miyamoto International, and adjunct professor at California State University, Sacramento. He belongs to the ASCE 7 Seismic Task Committee.

Dr. Hanson is professor emeritus of civil engineering at the University of Michigan where he was on the faculty for 35 years. He now is a structural engineering consultant in Walnut Creek, California.

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