FLUID VISCOUS DAMPING
AS AN ALTERNATIVE TO BASE ISOLATION

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Abstract

Base isolation is an effective way to protect large structures from earthquake damage. It is a costly approach, as the entire structure must be supported on elastomeric or sliding bearings. Viscous dampers distributed throughout an otherwise conventional structure can achieve the same result at significantly lower cost. This paper describes how to install viscous dampers in a structure, and gives several examples.

Introduction

Base isolation of large structures has proven to be an effective way to attenuate seismic excitation. However it can be costly, and can also involve major building modification. It is now possible to secure a comparable degree of earthquake mitigation with fluid viscous dampers located throughout a structure, without having to isolate the building. This paper describes several techniques for doing this, provides analytical back-up and describes several examples of the application of this technology.

Summary

The next section of this paper describes fluid viscous damping, and shows how it works and how it can benefit a structure. A detailed description of a typical fluid viscous dampers comes after this, followed by a comparison of base isolation and fluidic damping as ways to reduce earthquake excitation of structures. Then comes a discussion of design and analysis techniques for fluid viscous dampers.

The last part of this paper covers case histories like the Stockton City Hall and the Pacific Bell 911 facility.

What Is Fluid Viscous Damping

Fluid viscous damping is a way to add energy dissipation to the lateral system of a building structure. A fluid viscous damper dissipates energy by pushing fluid through an orifice, producing a damping pressure which creates a force. These damping forces are 90° out of phase with the displacement driven forces in the structure. This means that the damping force does not significantly increase the seismic loads for a comparable degree of structural deformation.

The addition of fluid viscous dampers to a structure can provide damping as high as 30% of critical, and sometimes even more. This provides a significant decrease in earthquake excitation. The addition of fluid dampers to a structure can reduce horizontal floor accelerations and lateral deformations by 50% and sometimes more.

Fluid Viscous Damper Description

The fluid viscous damper for structures, shown in Figure 1, is similar in action to the shock absorber on an automobile, but operates at a much higher force level. Structural dampers are significantly larger than automotive dampers, and are constructed of stainless steel and other extremely durable materials as required to furnish a life of at least 40 years. The damping fluid is silicone oil, which is inert, non-flammable, non-toxic, and stable for extremely long periods of time. The seals in the fluid viscous damper use a patented high technology design based on aerospace research, and provide totally leak free service. This design has been proven through rigorous testing and has been in use for over 40 years in both military and commercial applications.

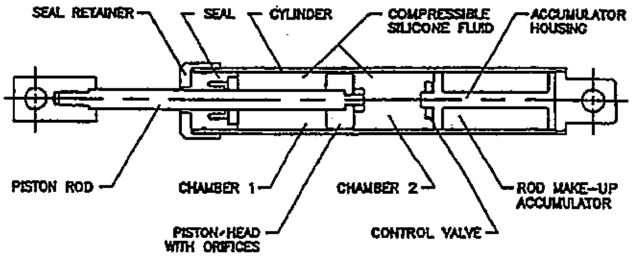


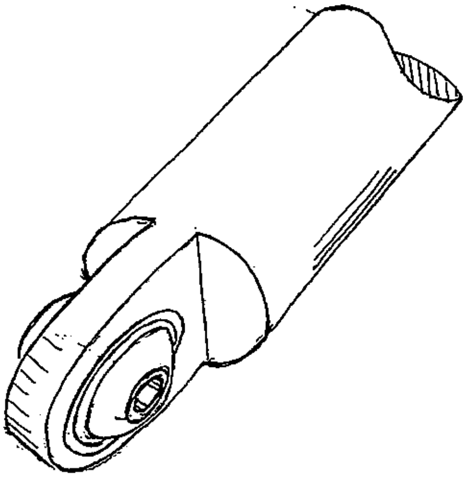
FIGURE 1

The damping action is provided by the flow of fluid across the piston head. The piston head is made with a deliberate clearance between the inside of the cylinder and the outside of the piston head, which forms an annular orifice (See Figure 1). The fluid flows through this orifice at high speed as the damper strokes. The shape of the piston head determines the damping characteristics. The force/velocity relationship for this kind of damper can be characterized as $F=CV^n$, where F is the output force in pounds, V is the relative velocity across the damper in inches per second, C is a constant determined mainly by the damper diameter and the orifice area, and n is a constant exponent which can be any value from .30 to 1.95. The exact value for n depends upon the shape of the piston head. "n" values ranging from .3 to 1.0 seem to work best for structural applications.

When the fluid viscous damper strokes in compression, fluid flows from Chamber 2 to Chamber 1. When the fluid viscous damper strokes in tension, fluid flows from Chamber 1 to Chamber 2. The high pressure drop across the annular orifice produces a pressure differential across the piston head, which creates the damping force.

As the damping orifice is provided by the annular clearance between the piston head and the cylinder body, it is possible to provide inherent thermal compensation by making these two parts from different materials. By choosing materials with the correct thermal coefficients of expansion, it is possible to make the variation in the gap compensate for the variation in fluid properties as temperature changes. Through proper design techniques, variation in damping as small as +/-15% over a temperature range of +20°F to +120°F can be obtained.

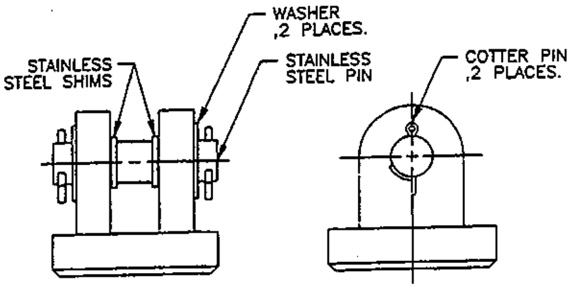
Spherical bearings at each end of the fluid viscous damper permit the damper to angulate relative to the structure without binding. Figure 2 shows a detail of these spherical end bearings. These bearings permit rotation in every direction, which prevents binding in the fluid viscous damper. In some cases there is enough flexibility in the structure to make it possible to solidly mount the dampers, in which case the spherical bearings are either not needed, or may be used at one end only. A typical installation of this type is shown in Figure 7.



SPHERICAL BEARING

FIGURE 2

Figure 3 shows a typical mounting bracket for fluid viscous dampers. This bracket consists of a female clevis mounted to a base plate which in turn welds to the structure. Upon installation the dampers simply slide into the clevises. Once the dampers are in the clevises, insertion of the pins holds them in position. Cotter keys then secure the pins in place. The dampers are always made with enough extra stroke to account for variance in the hole-to-hole distance in the structure.



MOUNTING BRACKET

FIGURE 3

Fluid viscous Damping in Comparison to Base Isolation

Both fluid viscous damping and base isolation have the same objective of significantly decreasing the response of a structure to earthquake excitation. With both fluid viscous damping and base isolation it is possible to have a structure remain within the elastic region, so there is no permanent deformation from a seismic event. Although the objectives are the same, the two techniques differ greatly in their implementation, as described in the following sections.

Base Isolation Techniques

Base isolation reduces structural excitation by physically decoupling the structure from the ground. There are either elastomeric pads or some kind of sliding bearing at the bottom of the structure, connecting it to the foundation. These pads or bearings deflect during an earthquake so the structure doesn't have to. In more technical terms, the addition of base isolation greatly increases the natural vibrational period of a structure, so it is significantly larger than the period of a typical earthquake. There are several different types of base isolation bearings on the market, as well as a number of manufacturers.

Base isolation requires that the entire structure be cut loose and physically separated from the foundation system that is cast into the supporting soil structure. In a refurbishment this involves cutting of all the vertical load columns in the structural system to provide an approximately 18 inch gap between the bottom of the column and the foundation system below. Isolation pads or bearings are then placed in this gap.

The perimeter wall system that is engaged with the foundation must also be cut loose. This can involve major building modifications in existing structures that have perimeter load bearing walls. The isolated structure and the superstructure must then be reworked to remain linearly elastic under the maximum probable event. This is classically done by adding a large number of braced frames or by adding a large number of concrete shear walls.

Fluid Damping Techniques

As with base isolation, fluid dampers greatly reduce the earthquake excitation of a structure and permit it to remain linearly elastic during a seismic event. Fluid viscous dampers work by adding damping to a structure, which significantly lowers its resonant response to an earthquake. The addition of fluid dampers to a structure does not significantly alter its natural period. What it does is to increase damping from the 5% of critical that is usual for structures to anywhere between 20% and 30%, and sometimes even more. Figure 4, from the UBC Building Code, shows the effect of damping on the response of a structure. 30% damping cuts response approximately in half relative to 5% damping.

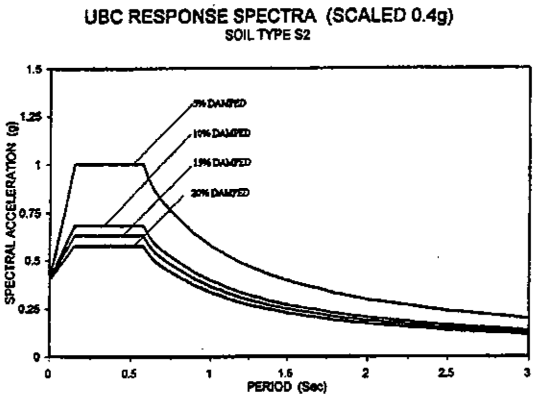
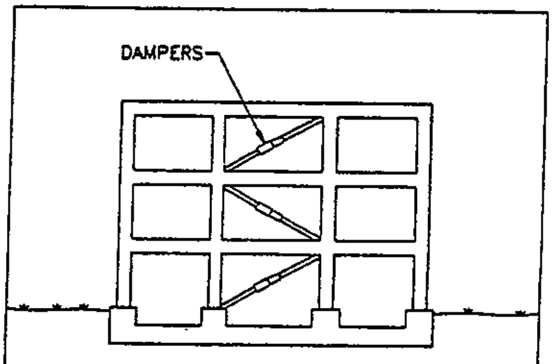


FIGURE 4

Fluid viscous dampers can be designed into both new buildings and existing structures. As they are relatively small and inconspicuous, they can be incorporated into a structure without compromising its appearance. This is especially useful in the refurbishment of historically significant buildings. They can also be added without significant structural modification in most cases.

Fluid viscous dampers can be installed as diagonal members in several ways, or can tie into chevron braces. They can also be used as the two elements of a chevron brace. Figures 5, 6, 7, 8 and 9 show typical fluid damper installations.



DIAGONAL BRACING WITH DAMPERS
FIGURE 5

Figure 5 shows the incorporation of a fluid viscous damper into the diagonal element connecting a beam-column joint at one level of a moment frame structure to the adjacent beam-column joint at the next level. Connections of this nature can be designed into a new structure, or could be added to an existing structure. This was done in the case of the Stockton City Hall refurbishment, described later in this paper. Figure 6 shows a detail of this particular configuration. Figure 7 shows another way that fluid viscous dampers can be installed in diagonal braces.

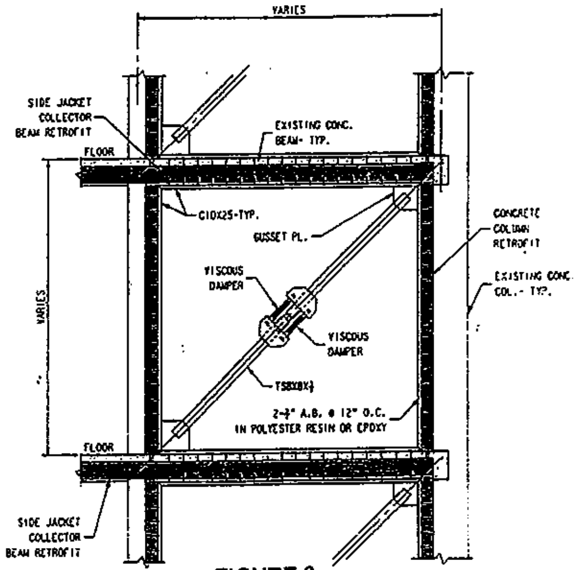


FIGURE 6

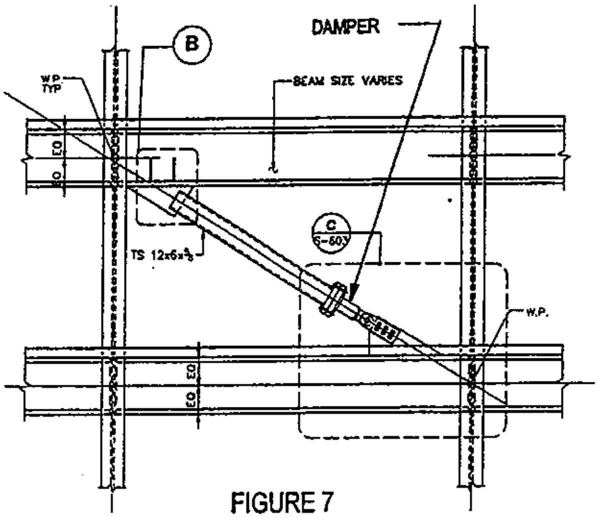
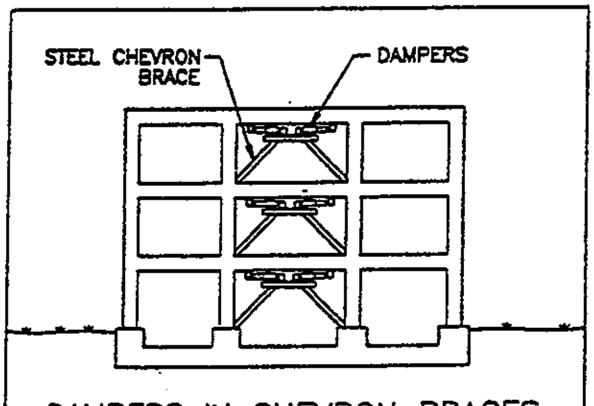


FIGURE 7

Figure 8 shows how fluid viscous dampers can connect the apex of a chevron brace to the adjacent beams. The relative motion between the apex and the beam drives the dampers. In general two dampers connect to each apex, one operating in compression and the other in tension. This is the configuration used in the Pacific Bell 911 building, which is also described later in this paper. Figure 9 shows a detail of this configuration.



DAMPERS IN CHEVRON BRACES
FIGURE 8

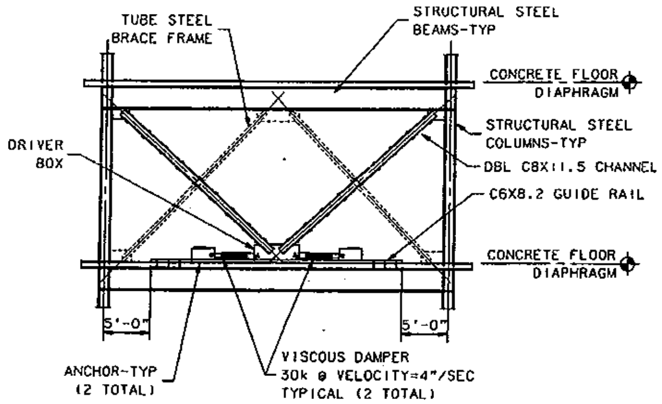


FIGURE 9

It is also possible to use a modification of the chevron brace, in which both bracing beams contain fluid dampers. In this case both beams connect to the structure at both ends with spherical bearings and mounting brackets.

This type of connection can also be used for diagonal members, as shown in Figure 7. In this case one end of the damper has a spherical bearing and the other end has a flange that attaches rigidly to the diagonal beam.

Design and Analysis Techniques for Fluid Viscous Dampers

The technique for placing fluid viscous dampers in the lateral system for a given structure begins with the assumption that the lateral force resisting system will remain linearly elastic within the design level earthquake excitation (the 475 year event). This means that there is no permanent deformation of any structural member, and no structural repair required after the event.

Time history analysis of the lateral system is required to design the damping system. This analysis determines the inter-story velocities at which the fluid viscous dampers need to operate, as well as the required strokes and force levels. There are several readily-available computer programs to perform time-history analysis. Examples are ETABS-6 by Professor Wilson at Cal Berkeley, and SAD-SAP by Computer Structures Incorporated.

In order to implement time-history analysis the structural analyst must obtain a minimum of three acceleration time histories for the given project site, generated by a geo-technical expert. Guidelines produced in 1993 by the Passive Energy Subcommittee of the Structural Engineers of Northern California require the engineer to use the worst (or maximum stress and deflection case) of the three events in his design.

Once the inter-story velocities are determined, the engineer can size the fluid viscous dampers by using a lateral force demand which ranges from 3% to 5% of the building weight above the plane of the fluid viscous dampers. Once the engineer has a maximum velocity and an approximate force level he can then size the fluid viscous dampers. Using the initial force level and velocity determined for each story by the computer model, the engineer can then ascertain new interstory displacements. These inter-story displacements determine the stroke (or displacement) demand that each fluid viscous damper must provide.

At this point the structural engineer has the total force level, the velocity level and the stroke for each level of dampers. This is all that is necessary for the manufacturer to estimate production costs and the damper envelope.

Case Histories

This section presents a number of examples of the application of fluid viscous dampers to structures. Some of the structures are new, and some are refurbishments. Some of these examples are studies only, while others are actual buildings that now have fluid viscous dampers installed.

Stockton City Hall

A study of possible methods of refurbishment of the Stockton City Hall considered base isolation, fluid viscous damping and conventional stiffening. The main purpose of this study was to estimate the costs of each type of rework. It was found that conventional stiffening and the addition of fluid viscous dampers had about the same cost, while base isolation cost around 40% more. It was also found that overall life cycle cost was much less with fluid viscous dampers, as they permitted the structure to remain linearly elastic. This eliminated the need for major structural repairs after a significant seismic event.

The Stockton City Hall is a 102 ft. x 170 ft. three story non-ductile concrete frame building with brick infill. It was built in 1926.

Analysis indicated the need for the following linear fluid viscous dampers in the North-South direction:

Capacity	Veloc.	Location	Quantity
160,000 lb.	3 ips	1st to 2nd floor	8
100,000 lb.	3 ips	2nd to 3rd floor	4
90,000 lb.	3 ips	3rd floor to roof	4

The total force levels required from the dampers in the East-West direction are the same. The number and size of the dampers were changed to accommodate architectural constraints, as shown in Figures 10, 11 and 12. This particular installation used the split diagonal damper configuration shown in Figure 7.

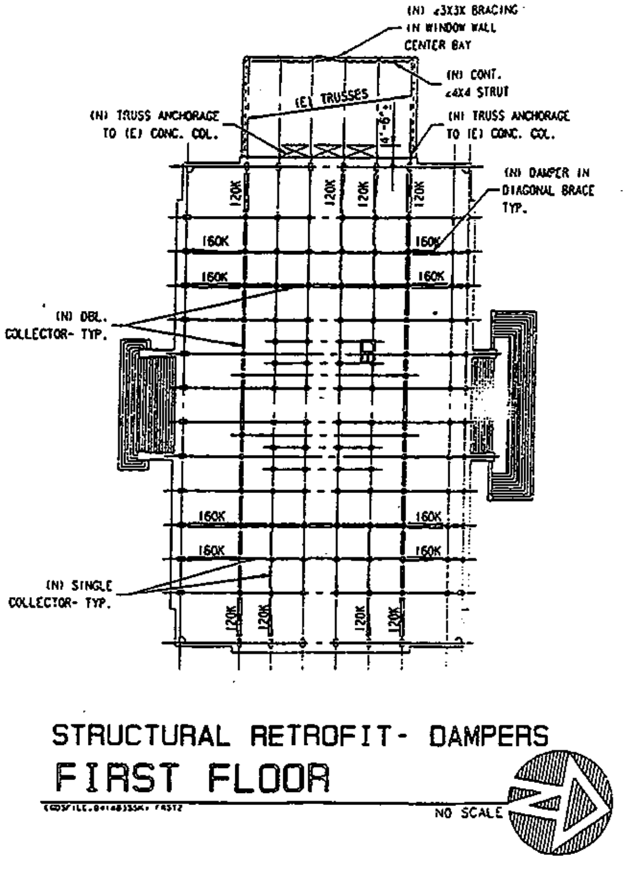


FIGURE 10

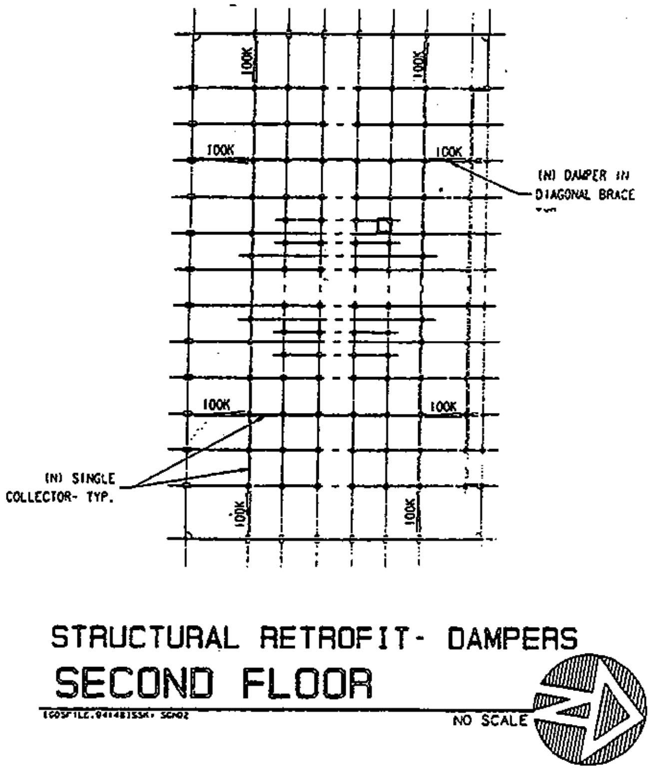


FIGURE 11

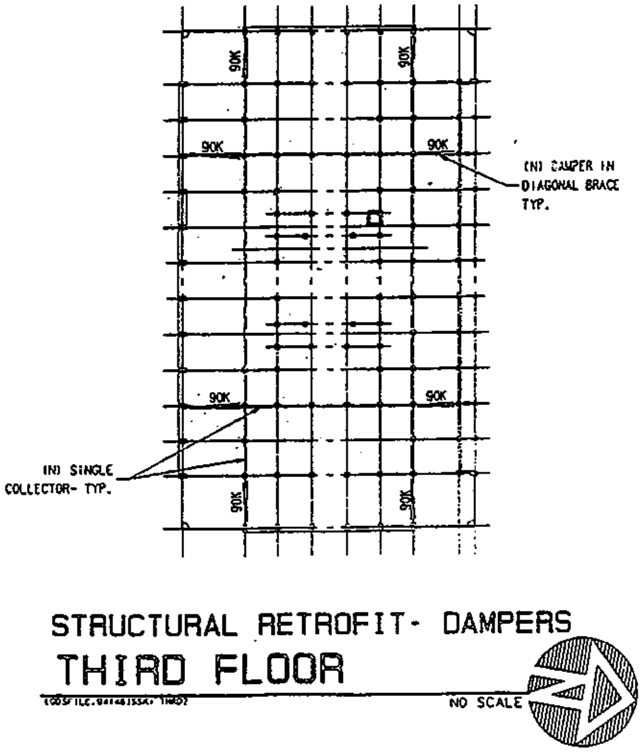


FIGURE 12

Steel Moment Frame Hospital

A five story existing moment frame hospital structure requires rework to make the joints adequate under seismic excitation. In this particular case base isolation is not an acceptable alternate due to high construction costs and loss of use of the facility. To cut loose the building and then add bracing at all levels to make the structure perform elastically is simply not economically feasible.

In this particular case it was found that conventional retrofit would cost six to eight million dollars, compared to two million dollars for the addition of fluid viscous dampers. In addition, the structure with dampers does not oscillate nearly as much during a seismic even as a conventionally retrofitted structure, resulting in minimal damage to the occupants and the infrastructure. This type of conclusion is typical of structures with a non-ductile steel moment frame problem. In this case it was found that adding fluid viscous dampers at two levels in the five story hospital structure was all that was required to provide an acceptable and implementable solution.

This five story structure has a 200 ft. x 200 ft. plan. The owner wants to add two stories to the hospital. In order to add these two stories using conventional methods all of the 480 moment frame joints in the building would have to be strengthened per the Northridge Earthquake Retrofit demands. The alternative solution of adding fluid viscous dampers turned out to be more attractive. By adding 100 dampers, each with 120,000 pound capacity at 3.0 inches/second, it was possible to maintain flange stress at 20 ksi for the 475 year earthquake and at 25 ksi for the 975 year event. These low stress levels mean that the existing 480 beam-column joints do not need to be strengthened or modified in any way. In this particular application, the 50 dampers in each direction will be installed in the configuration shown in Figure 9.

Hotel Building

A hotel in Sacramento is a 80 ft. x 120 ft. seven story building. It has an internal diagonally braced frame that was added to what was originally a concrete frame building. Refurbishment of this building is planned, although delayed. In this proposed rework, the dampers will be installed around the existing chevron braces at the first three floors. Resulting refurbishment cost with dampers is approximately 60% of what the cost would be with conventional stiffening, and resulting performance during a seismic event is significantly improved.

17 Story Mid-Rise Steel Moment Frame.

This 120 ft. x 320 ft. structure has strong beams and weak columns throughout its moment frame system. 852 beam column joints required strengthening when a conventional retrofit was considered, which would have cost approximately five million dollars. Adding linear fluid viscous dampers at grade through fourth, sixth, eighth, tenth, twelfth, fourteenth and sixteenth floors cut the cost of the modifications in half.

Pacific Bell 911 Facility

The addition of fluid viscous dampers to the Pacific Bell 911 Facility in Sacramento is unique because the dampers were designed into the structure after the framework was already in place. The owners of the structure elected to add dampers and the associated chevron braces (See Figure 9) as an addition to the structure to keep the structure within the linear elastic range during a major seismic event. The addition of the dampers also enabled the occupants and equipment within the structure to survive and keep working under the emergency conditions of an earthquake.

Conclusions

Fluid viscous dampers can be added to either a new or an existing structure to greatly improve structural performance during a seismic event. They offer an attractive alternative to base isolation in terms of cost and ease of installation.

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