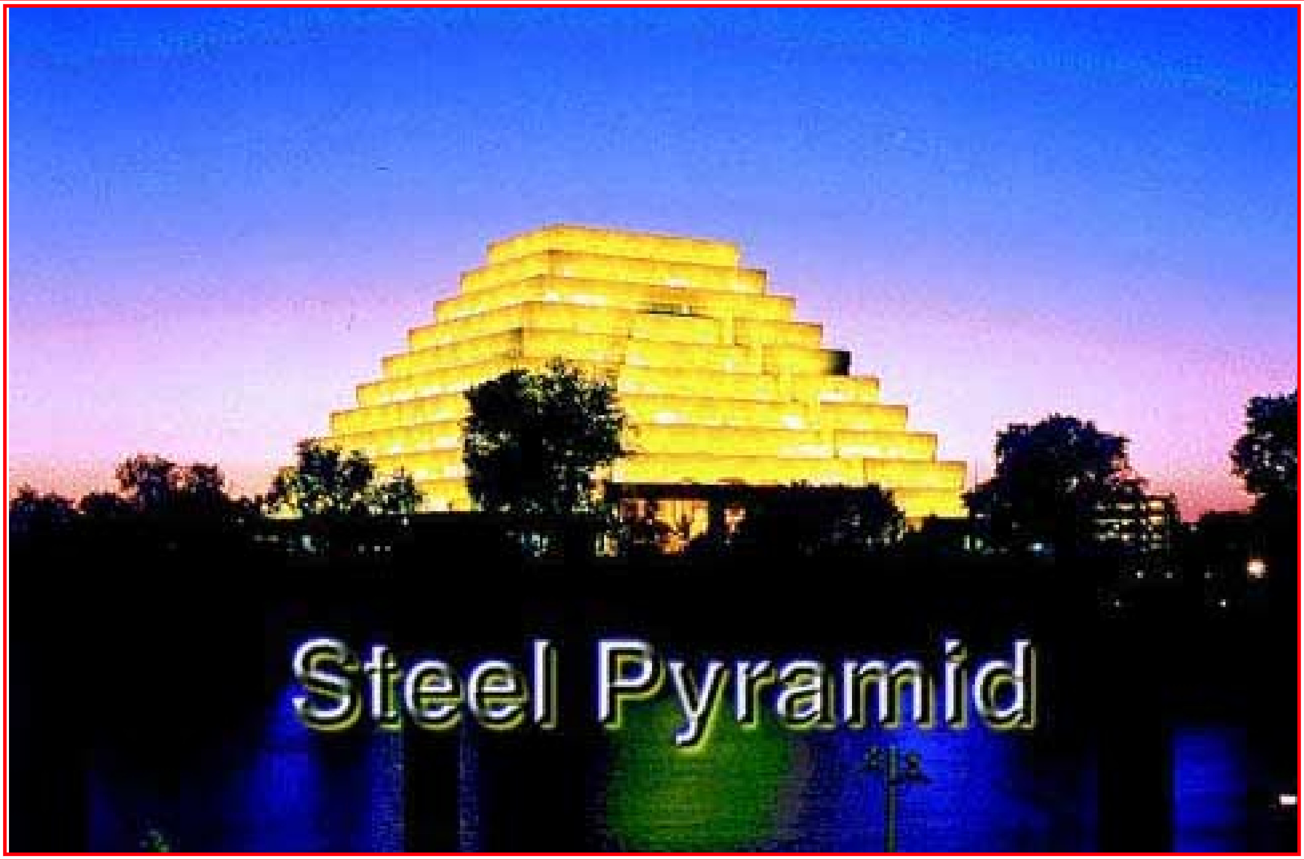


Fluid viscous dampers are designed to control this complex building's response during a sesmic event

By H. Kit Miyamoto, S.E. and Roger E. Scholl

REMINISCENT OF AN ANCIENT MAYAN TEMPLE, THE NEW NATIONAL HEADQUARTERS for The Money Store, in West Sacramento, CA, is one of the first new buildings in the United States to use seismic dampers to control a building's response during a seismic event. The 11-story pyramid-shaped steel moment frame building occupies approximately 450,000-sq. ft., including a partial basement and exterior deck areas.

The ground floor footprint is 300' by 300'. There is a 10' setback at each story, and the uppermost floor footprint is 90' by 120'. The typical story height is 14', with the exception of the height between the first and second level, which is 16'. The total height of the structure is 156'. The typical floor system consists of structural steel beams (including W30x116, 124, 132, and W33x141) with 3¼" lightweight, cast-in-place concrete over 3" x 20 ga. metal deck. The structure's lateral system consists of elastic steel moment frames with fluid viscous dampers (FVDs). The typical column sizes were W14x370 and W14x398. The structure is supported on approximately 580 12"-square prestressed, precast piles, embedded approximately 75' into the ground. The geotechnical engineers, Wallace-Kuhl, determined that a site coefficient of S2 was appropriate for this stiff, sandy soil site.

DESIGN CRITERIA

Earthquake performance, cost effectiveness and architectural requirements were the primary considerations in designing this building. Additionally, the owner wanted to minimize disruption of business operations after a major seismic event.

Faced with these requirements, the use of the current Uniform Building Code (ICBO, 1994) was insufficient, since it did not address the performance objectives in quantifiable ways. Furthermore, its design philosophy relies heavily on plastic hinge formations within the structural elements to absorb the seismic energy. This increases the uncertainty of the structure's non-linear behavior. Therefore, the design team and the owner agreed that all structural members and connections shall remain below yield levels for the Design Basis Earthquake (DBE). The maximum inter-story drift ratio shall be less than 0.005 at the DBE to protect non-structural elements. An unreduced Time History Analysis shall be utilized to study the actual behavior of the structure during the DBE. The Design Basis Earthquake is defined as a seismic event with a 10% probability of occurrence in a 50-year duration. This event is consistent with the 'Blue Book' of Structural Engineers Association of California.

Site-Specific Analysis

The geotechnical consultant performed a site-specific ground motion study for this site. Historically, the most significant ground shaking activity occurred during the Vacavill-Winters event (Richter magnitude 6.75) in 1892, which had an epicenter approximately 22 miles west of the site. Deterministic and probabilistic analysis were performed to estimate the Peak Ground Acceleration (PGA). These analysis revealed that a 0.17-g DBE rock site acceleration would occur from an event of 6.5 magnitude on the Dunnigan Hills fault. Since the California Division of Mines and Geology has estimated the maximum credible earthquake (MCE) for this fault to have a magnitude of 6.5 to 6.75, the DBE and MCE are approximately equal in magnitude.

Actual California earthquake times histories were utilized to develop site specific response spectra. These ground accelerations were selected based on events 15 to 25 miles from the recording station, at an alluvium underlain station, and from an event with a similar fault mechanism (thrust faults). Each orthogonal pair of time histories were scaled to reflect a PGA, and each of the six time histories were then processed using the computer program SHAKE. The SHAKE program computes the response of horizontally layered soil deposits subjected to vertically propagating shear waves. The analysis revealed a 0.38g PGA for the site-specific response spectrum. Finally, the synthesized time history was calculated from this response spectrum for design purposes.

Lateral Force Resisting System

Numerous lateral systems were considered to satisfy the design requirements set forth by the owner and the design team. Conventional shear wall, as well as eccentric and concentric braced frames were rejected because they caused two problems: the extent of the structural and non-structural damage after a seismic event was potentially great, since stiffening the building caused the natural period of the structure to shift to the high acceleration spectra range, and the amount and location of shear walls and braces would interfere with tenant improvements. Base isolation was also rejected as a potential solution because: the additional cost was greater than 5% of the total construction cost, and the effectiveness of the isolation was found to be not substantial for this long period building.

Steel moment frames with Fluid Viscous Dampers (FVDs) were elected as the best alternative for the following reasons:

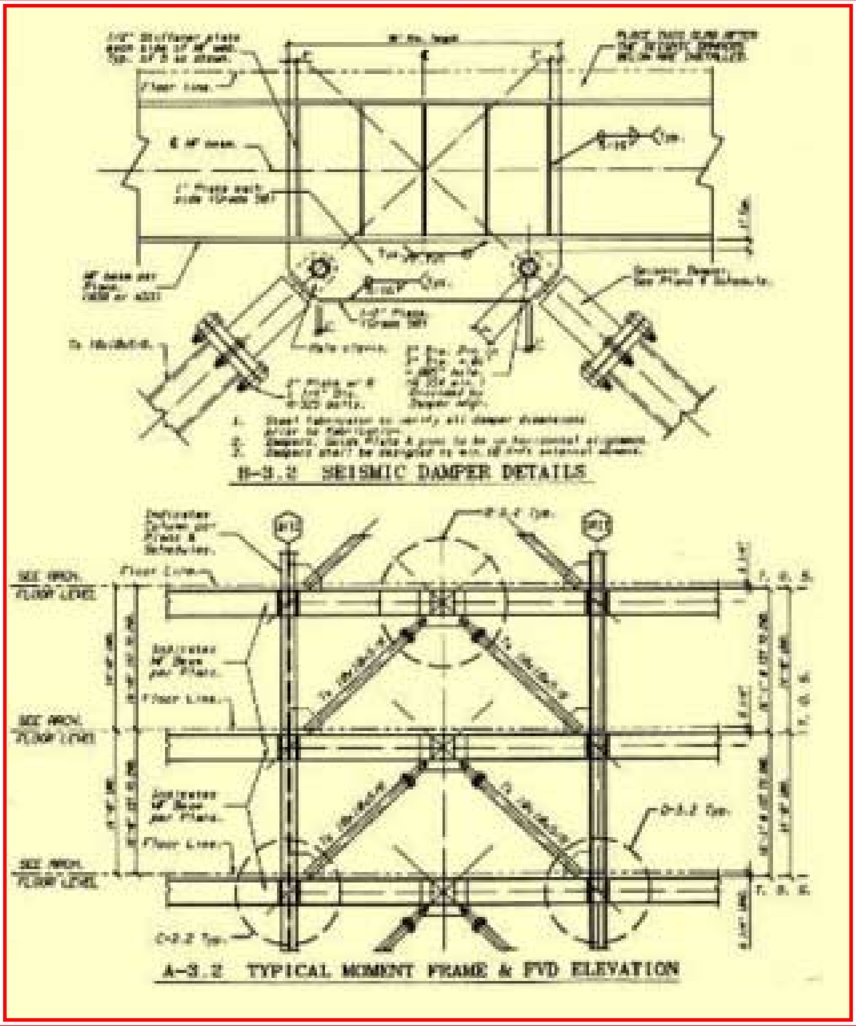
1. The additional cost for FVDs were less than 1% of the total construction cost.
2. The natural period of the structure was kept out of the high acceleration spectra range, yet FVDs controlled displacement.
3. The choice of location for mounting the FVD braces was more flexible than conventional braces, since the force in FVDs is out phase with the frame forces.
4. Plastic hinge formation within structural elements and connections were prevented.

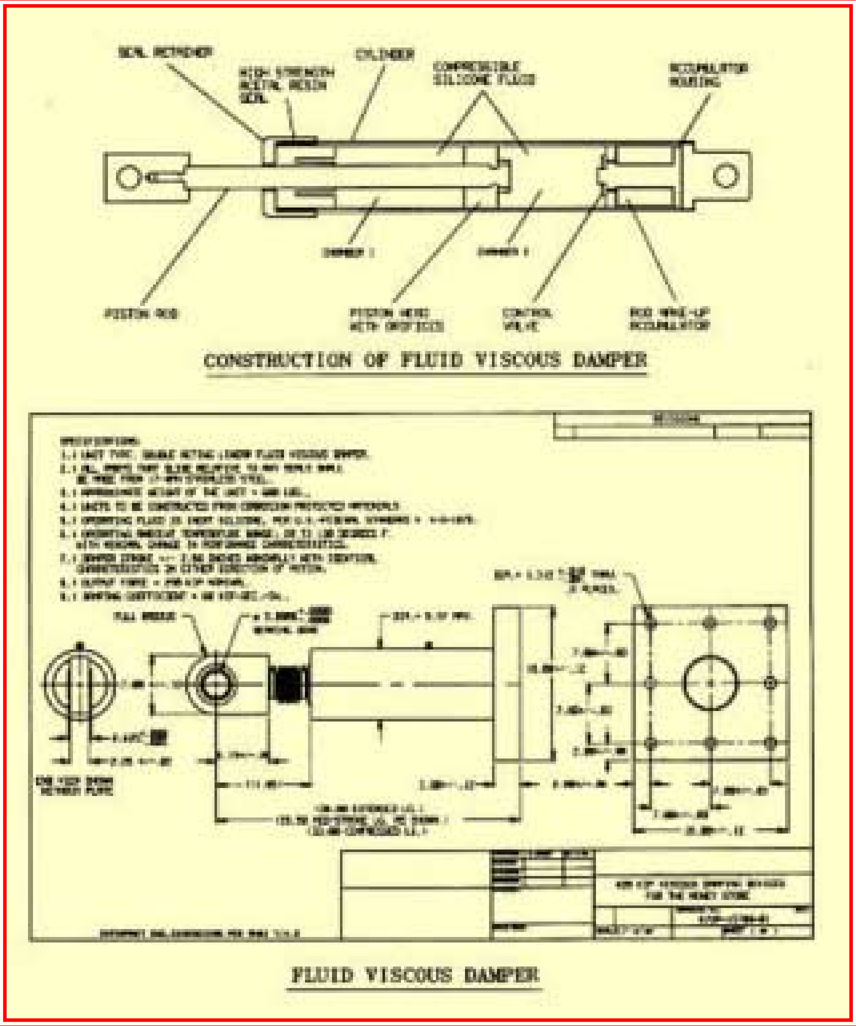
More than 500 welded moment connections are distributed throughout this structure for increased redundancy. The design team and the owner agreed to reinforce the 6th and 7th level connections with cover plates to provide ductility, while the other welded connections remained non-reinforced. This decision was based on the following:

1. The stress level of the connections are less than 50% of yield, and the story drift ration is limited to less than 0.005 for the DBE/MCE events. According to the latest research data, damage to welded connections would not take place for this stress and drift level.
2. The 6th and 7th level connections reached 80% of yield at DBE/MCE events. The cover plates are provided extra safety factor.
3. Based on the design team's recommendations, the owner decided that reinforcing all connections would increase the cost substantially without any benefit to the structure's behavior and performance during the DBE/MCE events.

Fluid Viscous Dampers

Fluid Viscous Dampers were selected over other damping devices for several reasons. Since FVDs are velocity-dependent systems, the forces are out of phase with the axial loading of the columns, and the change in the natural period of the build-





ing is insignificant. Additionally, the long history of military application proved the system's reliability. The devices selected were provided by Taylor Devices Inc. from North Tonawanda, NY. Fluid Viscous Dampers operate on the principle of fluid flowing through orifices. A stainless steel piston travels through chambers filled with silicone oil, which flows through an orifice in/around the piston head. During a seismic event, the seismic energy is transformed into heat, which dissipates into the atmosphere. The orifice construction utilized in FVDs is similar to that of classified applications for the U.S. Armed Forces, and is considered state-of-the-art.

Design Procedures

In order to expedite the plan approval process and determine a design starting point, steel moment frames were designed to conform to ordinary steel moment frames, as specified by the 1994 UBC, discounting the effect of FVDs.

The studies previously conducted have indicated that the required frame member sizes with 15-20% critical damping were approximately equal to UBC member sizes designed for a Rw=6 toRw=12. Code design criteria is as follows:

1. Seismic zone = 3
2. $R_w = 6$
3. Three dimensional dynamic analysis
4. Maximum allowable drift ratio = 0.004

Using the determined member sizes, time history analysis were performed to study the effects of FVDs. FVD design criteria is as follows:

1. Maximum allowable drift ratio = 0.005
2. All members, connections, and foundations are to remain elastic using the following LRFD strength factors: 1.2 DL + 0.5 LL +/- 1.0 EQ 0.9 DL +/- 1.0 EQ
3. The FVD capacity and its connections are designed for 1.5 times the design force.

4. The allowable damper displacement is 2.0 times the design displacement.

Two different mathematical models of the building were constructed to study the effect of FVDs. One was a simple 2-dimensional stick model, and the other was a complex 3-dimensional finite element model. Time History analysis were performed using ETABS 6.04, which utilizes the step-by-step linear acceleration method. All FVDs were modeled as discrete link elements in order to study the interaction between the moment frames and the FVDs.

The fundamental period of the building in both directions was 2.2 seconds. FVDs provided approximately 15% of the critical damping at each story. A total of 60 FVD assemblies (bays) with 120 FVD units were distributed throughout the stories. The damping constant for each FVD was 40, 60, and 80 kip second/inch. The design force was 160 kip and 290 kips. The exponential constant was set as a unity, which produced perfect linear viscous behavior.

Cost Analysis

Total structural construction cost, including structural steel, FVDs, metal deck, concrete and foundations was approximately $10.3 million, which equals $23 per square foot. The above figure satisfied the construction cost requirement, which was not to exceed that of a minimum code-conforming building.

In addition, the structure was subjected to the following ground motions:

1. A synthesized time history that matched the UBC Zone 4, S2, response spectra.
2. Recorded time histories from the 1994 Northbridge event.

Using the previously described design procedure, moment frames were redesigned to conform to special steel moment frames of UBC Zone 4. FVDs provided approximately 20% critical damping at each story.

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