Westside Pavilion

Seismic Retrofit for a Pre-Northridge Moment Frame Building

By Bill Williams, P.E., S.E. and Arvind Nerurkar, P.E., S.E.

The 1994 Northridge Earthquake was among the costliest seismic disasters in North American history. A sizable portion of the economic loss resulted from inadequate moment-resisting steel frame detailing. The pre-Northridge connection, previously thought to be very ductile, was found in many cases to be prone to fracture. The problems discovered in pre-Northridge connections have led to great improvements in the construction of moment-resisting steel frame buildings designed and built since the event. However, many steel frame buildings built before the January 1994 quake still exist with these connections. Because connection damage was often discovered in buildings with little or no apparent architectural damage, many of these existing buildings may already be weakened.

It is because of this risk to life, safety and property that a major retail company and owner of a broad range of retail buildings embarked on an investigation into the structural adequacy of their building inventory to resist seismic events. During this investigation, their building at the Westlake Pavilion in Los Angeles, California was determined to present a substantial risk to public safety and economic loss.

Originally built in 1984, the three story structure relies on a moment resisting steel frame for the lateral-load resisting seismic system to maximize usable floor space. As was common at the time, the system used multiple interior lines of moment frames, each with multiple bays. The beams were typically 27-inch deep sections supported on W14 columns. With brick cladding and parking on the roof, the store was particularly heavy for a three story building.

The structural engineer was engaged by the owner to evaluate the original structure for significant deficiencies using the procedures in ASCE 31, *Seismic Evaluation of Existing Buildings*. This standard provides an array of "broad brush" tools to quickly evaluate existing buildings. As is commonly the case with moment-resisting steel frame buildings designed to older codes, the primary issue discovered was excessive drift under a modern design level event, in this case almost twice the code-allowable drift of 2 percent of the story height. At this drift level, a majority of the pre-Northridge connections would be expected to fail during the seismic event. Ultimately, a structural report was issued to the owner listing an increased risk to the safety of the occupants and to the profitable operation of the store.

Decisions

As part of their effort to improve the safety and longevity of their stores, the building owner immediately made the decision to retrofit the building. The owner had two major requirements: First, the system should be as cost effective as possible, and second, the installation of the system should be as minimally invasive as possible. The second requirement is critical in retail buildings where usable floor area directly equates to sales and profitable operation. Passive viscous dampers were selected as the ideal retrofit system to achieve the owner's goals in the most cost-effective and least disruptive way.

Retrofit

Of all of the structural systems available to reduce building drift, passive viscous dampers were selected by the structural engineer for their unique ability to reduce inter-story drift without significantly increasing the lateral stiffness of the system. Maintaining the original flexibility of the system avoids a dramatic increase in base shear and

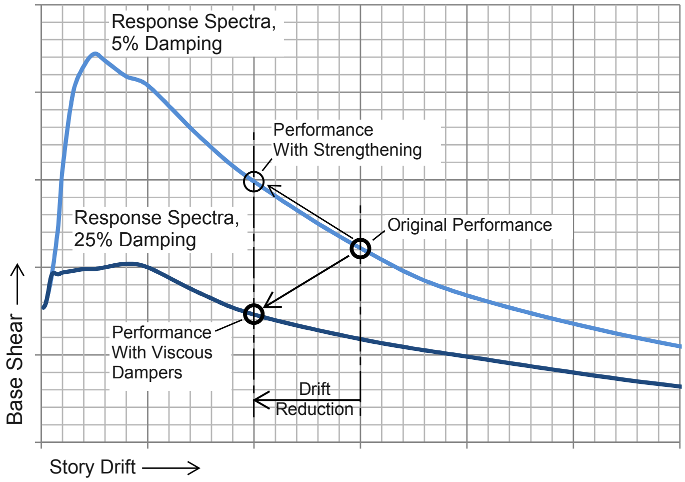

Figure 1: Retrofit performance comparison. Note that while both damping and strengthening reduce drift, only damping reduces drift while simultaneously reducing base shear.

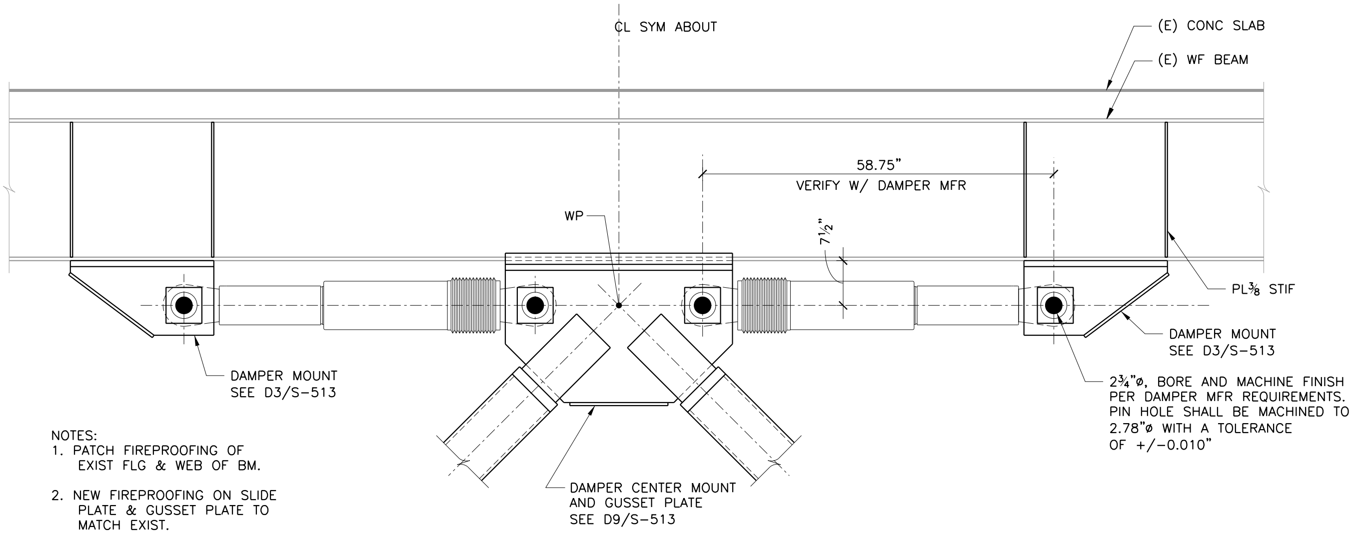

Figure 2: Typical damper installation.

the associated structural demands encountered in strengthening systems (*Figure 1*). This ability is critical, for projects of this type, to avoid extensive foundation upgrades. Foundation upgrades would have been prohibitively expensive and severely disruptive to the operation of the store.

The problems with adding lateral stiffness stem from the low stiffness of the original building and its associated long fundamental period of approximately 1.7 seconds. This period is well beyond the peak spectral response period of 0.3 seconds and correlates with design accelerations much lower than would be the case with a stiffer building. This means that any solution to lower the drift of the building by adding stiffness would lead to larger lateral loads, potentially by as much as a factor of 2.5. This increase in load effectively ruled out a traditional braced frame or shear wall retrofit, primarily due to the inability of the existing foundations to carry the additional load.

Viscous dampers, on the other hand, reduce drift through energy dissipation instead of through added stiffness. This allows the continued safe use of the existing moment frames and limits the required retrofit to economical levels.

This drift reduction strategy, however, requires a drift target substantially lower than current code requirements for new buildings. This lower building drift must be achieved to ensure the performance of the pre-Northridge MRSF connections. Prior to the Northridge event, MRSF connections were simple and primarily prescribed by code. The standard of care at the time for both structural engineers and contractors did not require the design, detailing and fabrication techniques necessary to ensure adequate ductility and performance of the connections. Modern codes for special moment-resisting frames require connections be tested and shown to be able to achieve an interstory drift angle of 0.04 radians. Pre-Northridge connections are typically only able to achieve an interstory drift angle of 0.005 to 0.015 radians, depending on beam depth. Based on this a target drift of 1.35 percent was calculated using the provisions in FEMA 351 *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*.

Analysis and design was performed using ASCE 41 *Seismic Rehabilitation of Existing Buildings*. Based on the analysis, a retrofit design was produced consisting of the installation of 32 viscous dampers on two of the three stories. Each damper was selected and fabricated to deliver 220 kips of damping force at peak velocity. With the added damping, the interstory drift is anticipated to be reduced to design target levels, and the demand on the existing pre-Northridge connections would fall well within acceptable levels.

Construction

Many different damper configurations have been used on retrofit projects successfully, each with its own benefits and drawbacks. Horizontal installation (*Figure 2*) was chosen for this project for its simplicity and to maximize the efficiency of the dampers and lower the damping forces required in the system. The dampers were mounted in pairs in a horizontal position and supported with chevron braced frames. Upper damper mounts were detailed to slide against the beam above using Teflon bearing plates to minimize friction. Existing beams above the dampers were reinforced to support the moments and axial loads generated by the damper mounts. Due to the limited space available while working in an operational building, many of the new beams, columns, and braces had to be delivered in two pieces and spliced together in the field.

Installation was complicated by an architectural feature of the original building; perimeter beam lines were set into the building several feet and did not line up with the existing perimeter columns. Because the dampers could not be installed on the interior bays of the building due to the open space requirements of the owner, all of the dampers were installed at the perimeter. To accomplish this, new columns were installed in line with the perimeter beams to resist the vertical damper forces to the existing foundation.

The effective installation of the dampers required a significant upgrade to the beams and connections in the collector system. ASCE 41 requires that all of the elements in the damper load path be designed to remain elastic during the design events. The existing connections were single row bolted shear tabs and did not have sufficient capacity to resist the loads from the dampers. In order to upgrade them, tie plates were welded to the beam web and supporting column or beam (*Figure*

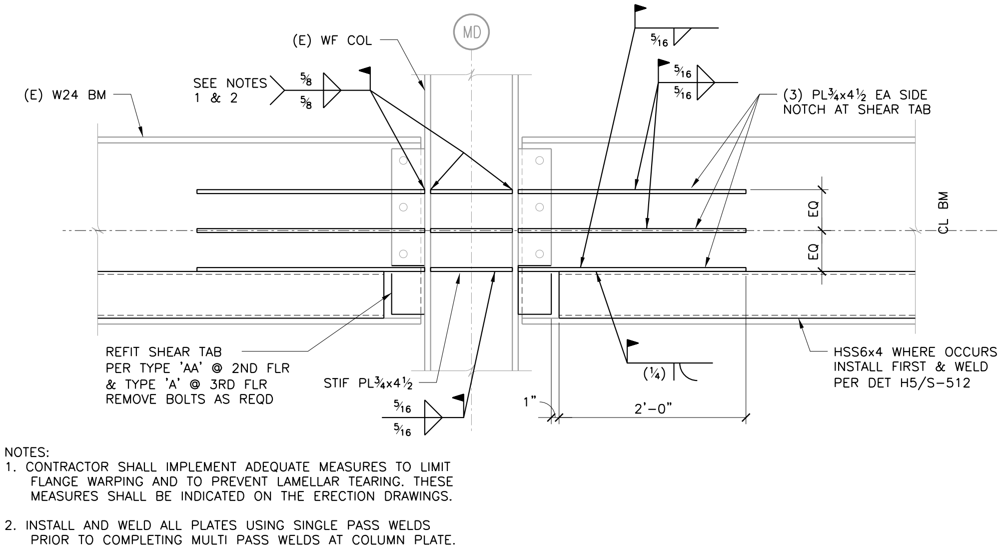

Figure 3: Typical drag retrofit connection.

3). These tie plates were designed to carry the entire collector design load, leaving the original connection to resist shear. These tie plates were located as close to the centerline of the beam as possible to minimize the potential effects of added rotational restraint. The collector beams were also refitted with added plate, tee, and HSS sections to improve their compressive capacity. Because the dampers were installed on the perimeter of the building, in some locations the existing diaphragm was not capable of transferring the load between the dampers and the existing drag system on the interior column lines. In several locations, HSS bracing was installed to transfer these loads directly.

At several locations, the uplift from the dampers was enough to overcome the dead load ballast in the existing column. This presented the challenge of adding uplift capacity to a pile cap system designed for gravity-loads only. The solution was to add deep micropile anchors on either side of the pile cap. The column loads were delivered to the micropiles using sloped anchor rods stabilized by a compressive strut through the existing pile cap.

Steel had to be moved and installed by hand due to the limited space and access in the operational building (*Figure 4*). In many cases, the welding involved had to be performed in extremely tight quarters. Often, details were reworked on the fly by the structural engineer in order to allow the contractor to complete the work. These collector retrofits, and the difficulty in building them, represented the vast majority of the complexity in the construction of the retrofit.

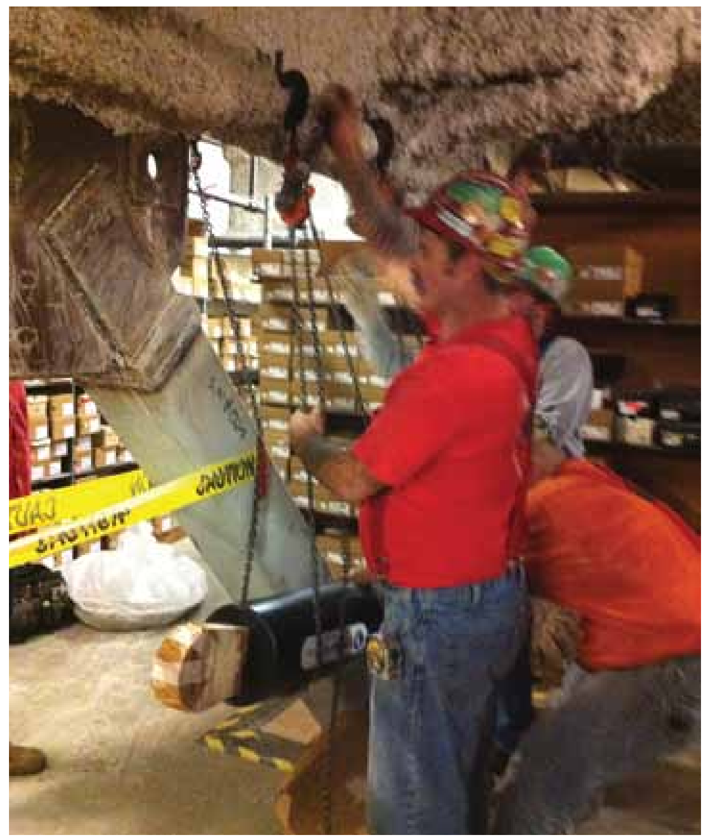

Figure 4: Installation of the viscous dampers by hand. Each damper weighs 500 pounds.

Conclusion

Through the use of viscous dampers, the owner was able to extend the life of a profitable store for years to come. The retrofit successfully satisfied the owner's requirement to retrofit the building cost effectively and with minimal impact to the operation of the store. With the unique ability to lower both seismic drift and force demands, viscous dampers are an ideal system to retrofit existing pre-Northridge moment frame buildings. This and similar systems provide an economic method to extend the useful life and significantly improve the safety of these buildings throughout the region.▪

Bill Williams, P.E., S.E. is a Senior Engineer at Coffman Engineers. He can be reached at ***Williams@Coffman.com****.*

Arvind Nerurkar, P.E., S.E. is a Principal at Coffman Engineers. He can be reached at ***Nerurkar@Coffman.com****.*

Project Team

Structural Engineer of Record: Coffman Engineers, Seattle, WA
Owner: Nordstrom Inc., Seattle, WA
Architect of Record: Callison, Seattle, WA
General Contractor: Pacific National Group, Los Angeles, CA
Viscous Damper Manufacturer: Taylor Devices, North Tonawanda, NY
Steel Fabricator and Erector: Riverton Steel Construction, South Gate, CA
Software: ETABS Nonlinear V9