Performance Criteria For Bridge Isolation Bearings

A seismic analysis led to the use of isolation bearings for the retrofit of California's Three Mile Slough Bridge

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ISOLATION BEARINGS HAVE OFTEN PROVEN TO BE A COST-EFFECTIVE ALTERNATIVE to more conventional strength-based designs for seismic retrofits. However, engineers today have more than a single isolation solution available from which to choose.

As part of a seismic upgrade program the California Department of Transportation (CALTRANS) set up in response to the Loma Prieta Earthquake, the Parsons Transportation Group performed a seismic analysis and base isolation retrofit design for the Three Mile Slough Bridge, a steel truss vertical lift bridge in Rio Vista, California.

Developing a suitable performance criteria is useful in identifying alternatives with potential to provide effective solutions. With isolation devices, these criteria include energy dissipation in addition to the more usual controls on strength, deflections and stiffness.

The key attraction of isolation bearings to structures in general, and to bridges in particular, is that if used correctly, they have the means to significantly reduce the overall forces and displacements experienced by the structure. This is accomplished by two fairly well understood

Table 1 - Periods of As-Built and Retrofitted Models

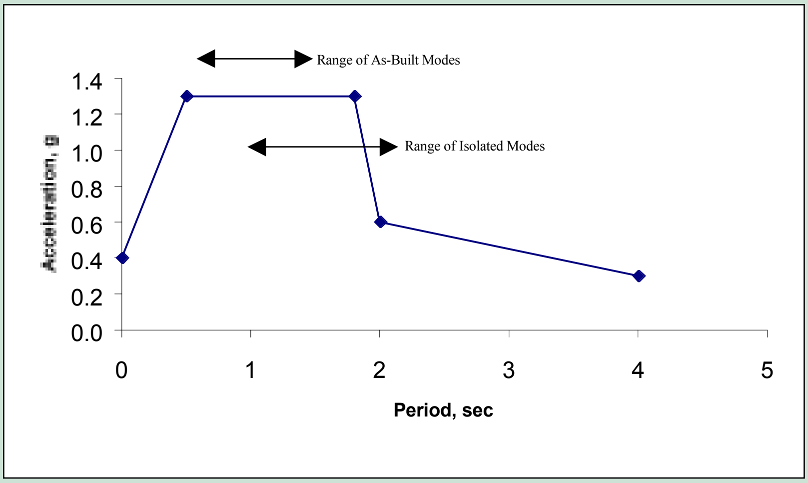
As-built model
Analysis with *FIXED* bearings

MASS PARTICIPATION FACTORS IN PERCENT			
MODE #	Period sec	X % Long.	Y % Vert.
1	1.43	40.5	-
3	1.11	-	66.7
8	0.77	-	9.8
11	0.67	58.0	-
13	0.59	-	19.5

Retrofitted model
Analysis with *ISOLATION* bearings

MASS PARTICIPATION FACTORS IN PERCENT			
MODE #	Period sec	X % Long.	Y % Vert.
1	1.43	40.5	-
3	1.11	-	66.7
8	0.77	-	9.8
11	0.67	58.0	-
13	0.59	-	19.5

Figure 2 - Acceleration Vs. Period for the site



mechanisms. The first is by elongating the period of the structure to the extent that it lies outside the range of the frequency content of the seismic input. This renders the structure more transparent to the seismic event, and therefore less likely to sustain significant damage.

The second mechanism is by introducing additional damping into the structural system; the higher the damping in the system, the higher the reduction in corresponding relative displacements. Today's isolation bearing manufacturers typically can provide the engineer with some control over the amount of damping they require in the bearings.

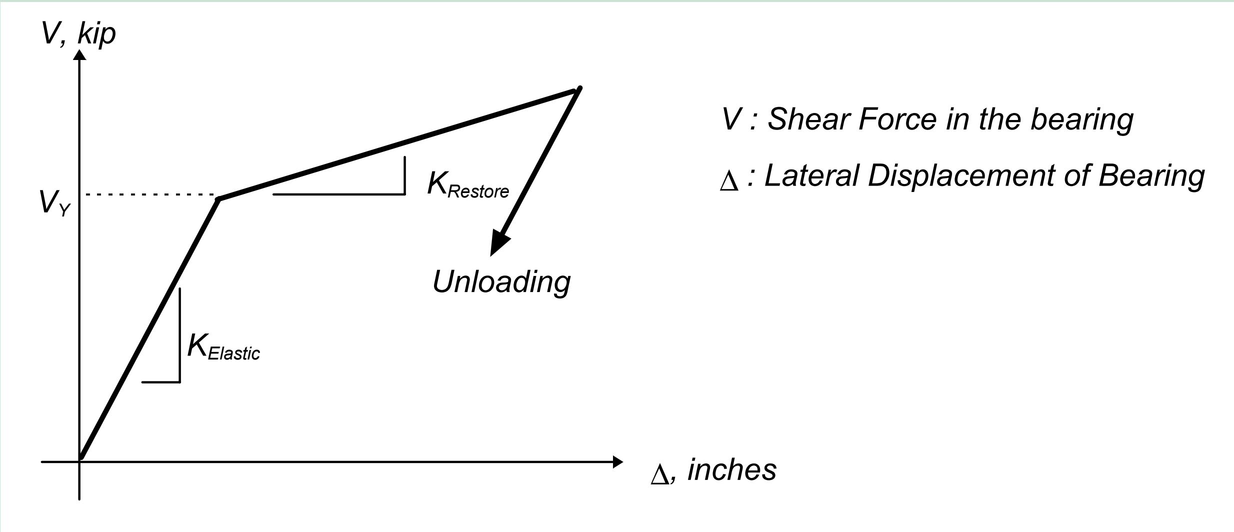
A preliminary response spectrum analysis was conducted and the piers and tower superstructure components were deemed to be the major vulnerabilities under seismic loading. For the piers, the primary reason for the deficiency was because of inadequate development of reinforcement at the connections to ensure flexural continuity, in addition to insufficient confinement at the column-to-footing connections. A simple pushover-type analysis was conducted on the as-built structure and computed demand displacements exceeded displacement capacities.

For the tower components, the presence of the large concentrated masses, the counterweights, at the very top of the tower induced large forces in members in and around the tower framing. The force levels in these members far exceeded reasonable ductility expectations in flexure. There were also several members that either buckled or fractured and connections that were unable to transfer demand forces.

The original retrofit concept considered was conventional, in that it consisted of the use of more traditional methods of strengthening deficient structural components in addition to increasing their ductility. Preliminary concepts included the addition of supplemental piers (foundation retrofit) and significant superstructure strengthening by building up sections, adding bracing and reconstructing connections. The wide-ranging extent of the work needed for the conventional retrofit combined with the determination that soil liquefaction around the piers was not likely, led to the consideration of seismic isolation of the superstructure as a retrofit solution.

There were very specific reasons for the consideration of I/D devices on this project. From the results of the preliminary analy-

Figure 3 - Force Displacement for typical bearing



ses, it was very clear that the bulk of the deficiencies were concentrated at the piers and in and around the tower framing. Any effective retrofit concept would have to satisfy two criteria. The first was to protect the piers through force redistribution to the abutments. From prior evaluation, it was apparent that the piers were deficient, and would be costly to retrofit due to underwater conditions and the necessity to construct cofferdams. The abutments, on the other hand, were more accessible and significantly less expensive to retrofit. By using I/D devices to distribute more force to the abutments, we could relieve the piers of a portion of their demands.

The second was to protect the towers by period shifting. Preliminary analysis found that fundamental frequencies of the towers were close relative to the dominant frequency content of the seismic input. By shifting the period of the tower, we could significantly reduce counterweight accelerations and tower member forces. A summary of the preliminary "eigenvalue" analysis results is shown in Table 1 for both the as-built and the retrofitted conditions. Studying the dominant periods of the structure and the acceleration response spectrum shown in Figure 2, illustrates that shifting the period to the right, off the 1.3g plateau, would reduce demands.

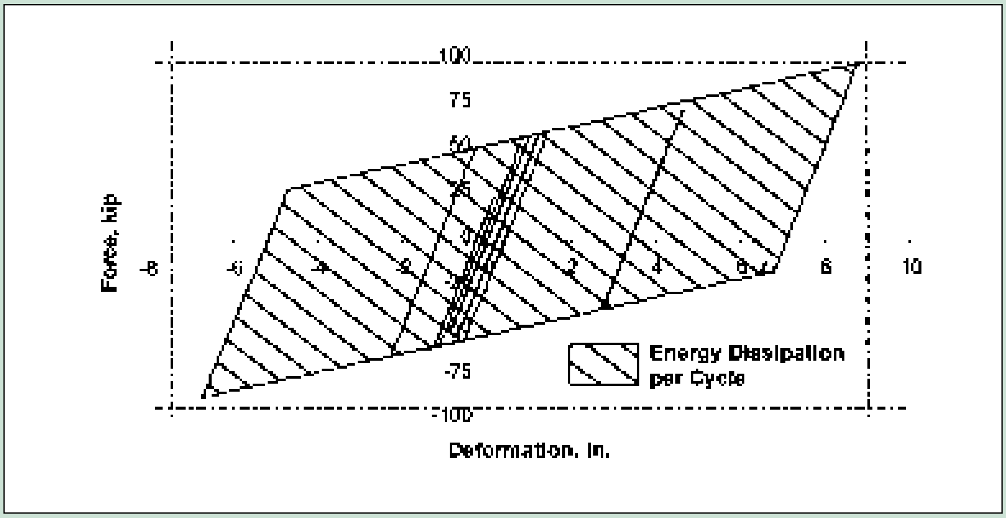
In deciding on performance criteria for this project several factors had to be taken into consideration. First and foremost was obtaining some measure of the level of isolating that had occurred. It was clear that using isolation bearings provided a period shift and therefore a reduction in forces.

The next quantification that was deemed necessary was getting a sense of the response of the isolated structure under nonseismic service loads. Because this was a moveable bridge, maintaining mechanical tolerances was key to the successful lifting operations of the bridge. In this case, the design criteria for service load stiffness were such that displacements were to be limited to pre-retrofitted levels. Because the as-built structure had fixed bearings, this mandated that lock-up devices be installed to stiffen the structure under services loads. These devices were designed to break off under higher seismic loads. For the higher seismic loads, accommodation had to be made for the increased displacement both at the piers and at the abutments. "Break-off" devices were installed to allow for the displacements resulting from isolation.

With respect to criteria on force, the limitation was based primarily upon support distribution. Because of the deficiencies of the piers, it was important that they remained elastic under seismic loads. The rationale behind limiting the forces in the bearings was essentially an effort to control the forces transferred to the piers. These forces depended on the strength of the piers that each bearing rested upon.

Finally, there was criteria pertaining to the damping in the system. The measure of equivalent damping was obtained from the Energy Dissipation per cycle (EDC) of loading, as seen in Figure 4. The controls here were twofold. In the first case, there was a minimum amount of EDC that had to be expended by all the I/D devices during the seismic event. In addition, no more than 5 to 10 percent was allowed to be dissipated at any one bearing. As a final check, a minimum value of the equivalent damping

Figure 4 - EDC Computation for a typical bearing



ratio (ζ_{eq}) of 10 percent was required for each I/D device. The first constraint on the system of I/D devices was set in an effort to stipulate a minimum amount of energy needed to be extracted from the system by the devices. Extensive studies were carried out to arrive at a minimum system-wide EDC expended that would make the retrofit effective. Individual I/D device minimums were set to control the energy distribution to any one device. Concentration of EDC at any one location could increase the risk of damage to the piers at that location.

For the final criteria on equivalent damping ratio, ζ_{eq}, was computed as follows :

$$\zeta_{eq} = \frac{EDC}{4\pi A_e}$$

where :
EDC is computed as the shaded area and,

$$A_e = \frac{1}{2} V_i \Delta_i$$

i.e., the elastic strain energy stored in an equivalent linear elastic system.

V_i = force during seismic event

Δ_i = displacement during seismic event

Lateral force versus lateral displacement traces are shown in Figure 4 at the isolation device locations. These plots showed extensive non-elastic behavior indicating that isolation had occurred. A simple algorithm was set up to compute the area under the $V - \Delta$ curve and the EDC computed.

These plots were generated for every bearing for each I/D system proposed, and EDCs and damping ratios calculated to ensure that each system could satisfy all the criteria.

By carefully developing criteria such as those performed on the Three Mile Slough Bridge, Parsons was able to come up with an effective, economical solution that provided several more years of safe and reliable service for the bridge.

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