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SEISMIC BASE ISOLATION OF AN EXISTING BRIDGE AND PIPELINE

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SUMMARY

Elastomeric bearings are used to retrofit 28 supports for a 50-year-old 1010 foot (308 m) long bridge and pipe. The structure is an essential part of The Metropolitan Water District's feeder system to the Los Angeles metropolitan area. Use of the bearings insures that the structure will behave elastically and safely during the controlling maximum expectable event, a magnitude 7.0 earthquake originating on the San Jacinto fault 11 miles (18 km) distant. The bearings were economical and easily installed with minimal shutdown time.

INTRODUCTION

For the past 50 years, a 1010 foot (308 m) long bridge has been supporting a 9'-8" (2.95 m) diameter water pipeline which conveys Colorado River water into the greater Los Angeles area. The bridge and pipeline is owned and operated by The Metropolitan Water District of Southern California, one of the world's largest water agencies. In an average year, it delivers about one-and-a-half-million acre feet (1.9 billion cubic meters) of imported water to Southern California from both the Colorado River through the 242 mile (390 km) long Colorado River Aqueduct and from the 450 mile (725 km) long California Aqueduct. At the terminus of each aqueduct, large storage reservoirs feed Metropolitan's 700 miles (1130 kms) of distribution pipelines. These pipelines range in diameter from about 30 inches (76 cm) to over 15 feet (4.6 m). As a water wholesaler, Metropolitan supplies almost half of the water used by the nearly 13 million people in a six-county, 5200-square-mile (13,500 square-kilometer) area in Southern California. See Figure 1.

In the early 1970's, following the 1971 San Fernando earthquake, Metropolitan began an intensive program to examine its existing system to identify lifeline facilities which might not survive a major earthquake. The Upper Feeder pipeline where it crosses the Santa Ana River was identified as such a facility. This crossing was designed in 1935 and constructed in 1936. The feeder at this location is a 116-inch (295 cm) diameter steel pipeline supported above the river for a length of 1010 feet (308 m), see Figure 2. Its north central portion is supported by three 180 foot (55 m) long steel trusses. The remainder of the crossing is supported by concrete piers spaced at 50 feet (15 m) on center with the steel pipe spanning between them. A pseudo static analysis indicated that both the truss and pipe support pedestals, as well as some truss

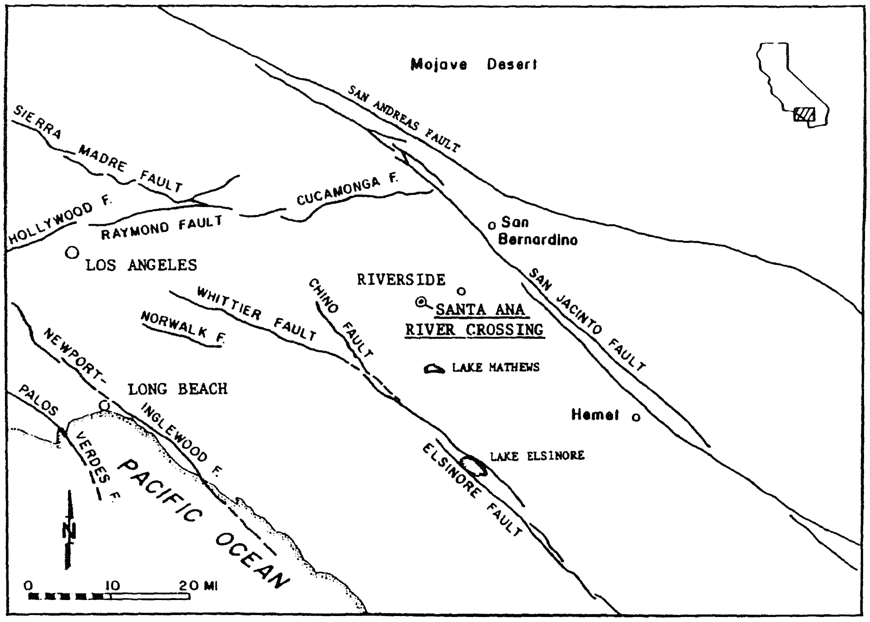

Figure 1. Map showing known active faults in Southern California and location of Santa Ana River Bridge.

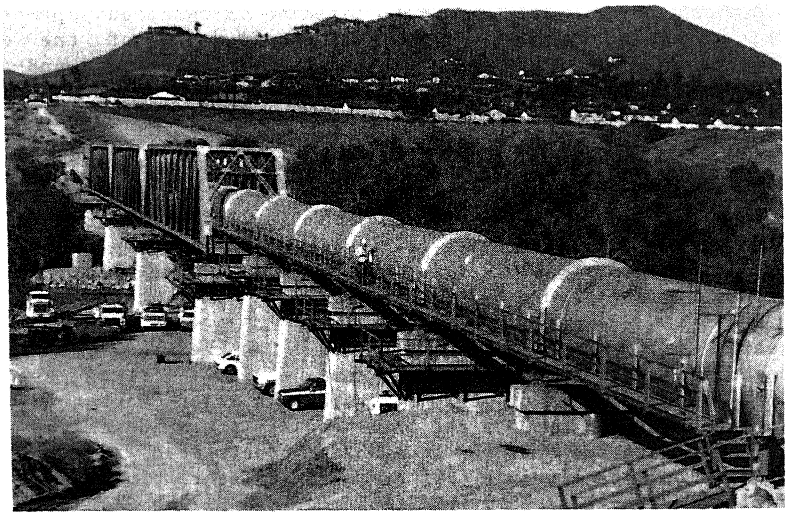

Figure 2. Santa Ana River Crossing looking North

members and connections, could be highly overstressed during a major earthquake. Accordingly, Metropolitan hired the firm of Lindvall, Richter & Associates to perform a seismic stability analysis of the crossing.

RETROFIT ISOLATION BEARINGS

As a result of Lindvall, Richter & Associates' analysis, the Santa Ana River Crossing was retrofitted with elastomeric bearings at all the truss and the pipe piers. These bearings are rectangular blocks of natural ozone-resistant rubber with cylindrical cores of pure lead (see Figure 3). Closely-spaced horizontal sheet-steel laminations (shims), bonded to the rubber during the vulcanization process, provide vertical stiffness to the bearings by inhibiting side bulging. For small lateral loads, the lead provides most of the lateral stiffness and behaves elastically. However, lead is a nearly perfect elastic-plastic material, and under sufficiently large loads, the lead yields and lateral stiffness is provided by the rubber alone.

The selected bearings plan dimensions vary from 12 to 20 inches (30.5 and 50.8 cm) square and their heights are in the 9 to 11.5 inch (23.2 to 29.2 cm) range. The lead cores are 4.5 to 7.0 inches (11.4 to 17.8 cm) in diameter.

The bearings were sized so that the lateral yield force for each bearing is approximately 15% of the vertical load imposed when the pipe is full of water. This is about twice the maximum windload that can be imposed on the structure. The lateral yield displacement for the bearings was set at an average value of 5/8 inch (1.6 cm).

Lateral properties of the bearings were obtained from design guidelines and test data supplied by Computech Engineering Services, Inc., and Dynamic Isolation Systems, Inc.

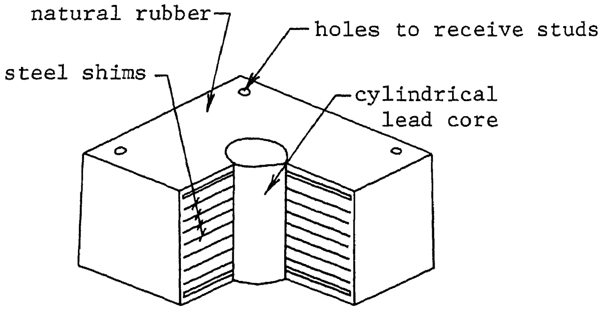

Figure 3. Schematic View of Elastomeric Bearing Lead-Rubber

COMPUTER MODEL

The 1010 foot (308 m) long bridge and pipe with elastomeric bearings was modelled using truss and beam elements with both the SAPV program developed at the University of California, Berkeley, and modified at the University of Southern California, and the ADINA program developed at the Massachusetts Institute of Technology. These programs were used for linear and nonlinear analyses, respectively. In the ADINA supported analysis, the bearings were modelled as kinematic hardening bilinear truss elements in the two horizontal directions and as linear truss elements in the vertical direction.

The model incorporated a high degree of sophistication. Each member of the three central trusses was represented with truss elements, and where stability or secondary bending effects were important, beams were used to model individual members.

A cylindrical Vierendeel truss skin of beam elements was used to model the 9′-8" (2.95 m) inside diameter pipe. This cylindrical skin was internally supported by a centralized line of axial beams with radial spokes at the element termini. Shear and flexural behavior of the pipe was represented by the Vierendeel truss skin for which the axial area of longitudinal elements was suppressed. Inertia and shear area properties of these skin elements were selected to match the theoretically calculated bending and distortion behavior of the monolithic pipe. Longitudinal area was entirely represented by the centralized axial beams. As such, the expansion joint in the pipe near the crossing′s midspan was conveniently modelled by deleting one of the centralized axial beams.

The complete model consisted of 1219 spatially distributed nodes having 4584 degrees of freedom and a half band width of 119. The total number of elements was 2851 of which 1030 were of the truss type and 1821 were beam elements. Twenty-eight elastomeric bearings were used to support the crossing; consequently, 56 of the truss elements were modelled as bilinear elements, two for each horizontal direction for each bearing.

The full pipe has a distributed weight of 5.69 kips per linear foot (klf) (83.0 kn/m), 4.58 klf (66.8 kn/m) due to the water in the pipe, and 1.11 klf (16.2 kn/m) due to the pipe itself. The average distributed weight of the 180 foot (55 m) span trusses is 1.31 klf (19.1 kn/m). Consequently, the total distributed weight of the structure in the full-pipe condition is 7.00 klf (102.1 kn/m) in the three 180 foot (55 m) long truss spans and 5.69 klf (83.0 kn/m) in the pipe only portions. Water accounts for 72% of the total weight of the bridge and full pipe structure.

LOADING CONDITIONS

The bridge was analyzed for gravity, earthquake, thermal, hydraulic, and wind loads. Because of both the inertial effects of water in the pipe and the proximity of major faults, wind loads are subordinate to the earthquake loads. Hydraulic loads, which arise from a static head of 464 feet (141 m) produce a hoop tension on the pipe equal to 37% of its yield value.

The thermal load condition gives rise to rather complex behavior. The 9′-8" (2.95 m) inside diameter pipe is fixed along its axis at the abutments at the north and south ends of the bridge and is separated near midspan by a flexible expansion joint. Further, each truss is fixed along its axis to one of its supporting piers. For gravity loads, the pipe is supported by each truss using vertical rocker supports. Hinged lateral ties connect the pipe and truss laterally. These vertical and lateral supports, spaced at 36 feet (11 m) on center, permit differential thermally-induced longitudinal motions of the pipe and each truss.

EARTHQUAKE GROUND MOTIONS

Seismicity at the Santa Ana River Crossing is dominated by the San Andreas and San Jacinto faults, see Figure 1. The San Andreas fault is capable of producing the greater magnitude event. However, the proximity of the San Jacinto trace to the site, 11 miles (18 km) versus 17 miles (27 km) for the San Andreas, and the recency of significant activity along this fault, imply that the San Jacinto fault is dominant.

A maximum expectable earthquake on the San Jacinto fault is defined as a Richter Magnitude 7.0 event. The peak ground acceleration at the Santa Ana River Crossing for this event is 0.35g and the duration of strong ground shaking is approximately 20 seconds. Satisfactory response for this event implies that the pipe and trusses respond elastically and that the bearings maintain a stability factor of safety of at least two.

A maximum credible event on the San Jacinto fault would have a Richter Magnitude of 7.5. This event would produce a peak ground acceleration of 0.40g at the bridge with a strong shaking duration of 30 seconds. For this event, the bridge and pipe structure was permitted to sustain some damage, but it must remain in service with no risk of collapse.

Ground motions were constructed to represent both maximum expectable and maximum credible events at the Santa Ana River Crossing due to fault rupture on the San Jacinto fault. These motions were synthesized from the Taft Lincoln School records obtained during the 1952 Kern County earthquake. The modified records have response spectra which compare well with those obtained during both the 1971 San Fernando and the 1979 Imperial Valley earthquakes. Three uncorrelated components, two horizontal and one vertical, were constructed to represent both the maximum expectable and maximum credible events.

The Santa Ana River Crossing's length of 1010 feet (308 m) suggested separation of seismic wave arrival times at different points along the bridge. However, the orientation of the bridge relative to the fault trace indicated that seismic waves would arrive nearly broadside to the bridge, with arrival times at the south abutment delayed only 0.126 second relative to north abutment arrivals. In comparing this value to the linearized fundamental period for the structure, in the 1.0 to 1.5 second range, it was concluded that arrival time differences were negligible.

DYNAMIC ANALYSIS

The computer program ADENA was used to analyze the Santa Ana River Crossing with elastomeric bearings for the prescribed earthquake motions. A step-by-step Newmark integration procedure was deployed in the analysis with constant average accelerations in each 0.02 second time-step interval. Viscous energy dissipation was introduced by using mass proportional damping. The proportionality constant for the damping matrix was selected so that modal damping close to 5% of critical was realized throughout the linearized period range of interest. This damping value of 5% is appropriate for most steel structures subject to strong ground shaking.

The maximum expectable earthquake produced wholly satisfactory response for the Santa Ana River Crossing bridge and pipe. Only the elastomeric bearings experienced yielding thereby limiting the extreme lateral force experienced by the supported structure to less than 20% of its weight. In contrast, for the pre-retrofit condition, the potential lateral force was equal to the structure's full weight, which could have resulted in significant failures or even collapse of the bridge. Further, it was determined that the maximum credible earthquake response would be satisfactory since this event's demands exceed those for the maximum expectable earthquake by only 10%.

Two factors gave rise to the much-improved seismic response of the retrofitted bridge and pipe. The use of soft, yielding lateral supports shifted the fundamental period for the structure from about 0.6 second prior to retrofit to a value in the 1.0 to 1.5 second range after retrofit. This produced a reduction in spectral accelerations or lateral force levels. Secondly, and more important, the hysteretic behavior of the bearings, increased the rate of energy dissipation to a value equal to that for a 40% damped oscillator.

Earthquake lateral-force demands were scaled by a factor of one-fifth and extreme displacements were modestly reduced. Most of the earthquake induced displacements were manifested in the bearings themselves with the supported bridge and pipe structure moving much as a single lobe for a 1010 foot (308 m) long beam.

CONCLUSIONS

Implementation of the retrofit design for the Santa Ana River crossing has been undertaken. The original support pedestals have been replaced by elastomeric lead-rubber bearings, see Figure 4.

In order to prevent accidental distortion of the bearings in the longitudinal direction due to creep and rocker induced loads along the pipe axis, retrofit stops have been provided to inhibit such behavior. These stops do not affect the lateral response of the bearings.

The new retrofitted Santa Ana River Crossing is now protected and the risk of significant damage arising from a major earthquake on any of the nearby faults has been mitigated.

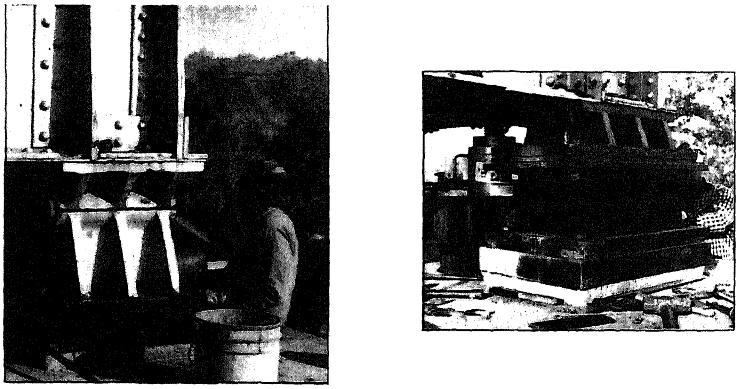

Figure 4. (left) Original support pedestals
(right) Lead-rubber isolation bearing