Seismic Performance of Friction Isolation Bearings in Major Bridges

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ABSTRACT

Seismic isolation bearings are being used in the seismic retrofit of major bridges to improve their performance. These bearings are typically placed at top of the piers. As a result, the seismic response of the bearing is sometimes much higher than expected in the isolation system. This paper describes the nature of the seismic behavior of isolation bearings in a major bridge subjected to the near-source seismic excitations that is characterized by the energetic, long-duration velocity pulse. Based on the response predicted, the important parameters for performance evaluation are identified for use in the full-scale dynamic testing.

INTRODUCTION

This paper describes the performance evaluation of seismic isolation bearings of the Benicia-Martinez Bridge. To assure the post-earthquake serviceability requirements, frictional-pendulum isolation bearings are used as the primary retrofit strategy. Three sets of ground motion inputs are used to represent the governing near-source earthquake event (Magnitude 6.5 at 3 km from the bridge site). Since this is the first time that the friction pendulum bearing is used in a major bridge, full scale dynamic testing is required. Based on these seismic response predictions, the performance requirements for testing the isolation bearings are established.

EXISTING BRIDGE AND RETROFIT

The Benicia-Martinez Bridge consists of seven 528-foot spans, two 429-foot spans and one 330-foot span. Four separated continuous spans are supported on fixed steel bearings. In between these continuous spans, "drop-in" truss spans are suspended from the cantilever ends of continuous spans. . The weight of a typical superstructure span is 6,000 kips.

The truss spans are supported by reinforced concrete cellular pier shafts. The typical water piers are cellular at the base section, consisting of four in-line reinforced concrete cells (15' by 15' each). The top 40-ft., however, consists of two-split cellular columns spaced 42-ft. center to center. The footings are also of reinforced concrete cellular construction, each with 18 cells. The footings are 25 ft. deep with the top 10 ft. designed to extend above the mean sea level, and are supported by six-foot diameter cast-in steel shell (CISS) piles (eight at Piers 4 and 12, ten at the other piers) which were sunk to bedrock. The thickness of the steel shell is one inch. Sixty inch diameter "sockets" were drilled into the bedrock to anchor the piles. The lower 20-ft. of pile and socket were reinforced as a spiral R.C. column. Figure 1 shows the 3D schematics of a typical water pier. The weight of a typical substructure pier and footing is approximately 12,000 kips.

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Retrofit Strategy

To assure the performance requirement for this lifeline bridge, all truss bearings will be replaced by seismic isolation bearings. The maximum horizontal force transferred by the isolation bearing is only about 500 kips. This will assure the seismic performance of the superstructure truss system. However, the substructure piers are significant dynamic systems that will affect the seismic response of the isolation bearings.

Site Soil Profile

Across the channel, the rock elevations are generally 120 ft below the mean sea level. Above the bedrock overlies the various soil deposit. The mudline elevation varies significantly along the bridge. At Pier 6, the mudline is at -90 ft and the piles are free standing in the water for about 75 ft. At Pier 8, the mudline elevation is at -40 ft and the piles are embedded in the soil for about 80 ft before socket into rock. As a result, these pile group foundations are very flexible with a dominant lateral vibration period of 1.5 second.

SEISMIC HAZARD

Site Specific Seismic Hazard at the project site is dominated by three sources:

Source	Magnitude	Distance (km)	5% ~ 95% Duration (Sec)
San Andreas Fault	8+	48	40
Hayward Fault	7.25	19	20
Green Valley Fault	6.75	3	13

These are seismic events that were selected for the safety evaluation purpose, i.e. the so-called Safety Evaluation Earthquake events, which have an average return period of 1000 to 2000 years.

Near-Source Event

The spectral intensity of the local Green Valley Fault event is much higher than the other distant events. The 3 component rock motion spectra are shown in Figure 2. Due to the close distance, the Green Valley Event ground motions also contain very *energetic velocity pulse* which is characteristic of the near-source event. The rock motion acceleration and velocity time histories are shown in Figure 3. The seismic design of the bridge is strongly affected by this local seismic source.

SEISMIC RESPONSE CHARACTERISTICS

For major bridge piers, the flexibility of the substructure is very important. The behavior of bearings are characterized by two distinctly different responses as shown in Figure 4:

- The slow-varying response of the isolated superstructure with a period of 3 to 5 seconds; and
- The oscillatory response of the substructure pier with a much shorter period, 1.5 seconds.

The relative displacement and velocity responses of the bearings are strongly influenced by the dynamic behavior of the substructure pier. Because of the massive nature of the pier and foundation, its dynamic response is not affected much by the presence of the isolation bearing and the associated damping. The superstructure and isolation bearings are subjected to a filtered, narrow-band earthquake input that is characterized by a single dominant mode of the substructure with its distinct natural period and amplified response amplitude. Because of this phenomenon, the expected behavior of the bridge seismic isolation bearing is quite different from that expected in the base-isolation bearing for which the seismic ground motion input is typically a wide-band process.

Figure 5 shows the response time histories for bearings at Pier 9. Both relative displacement and relative velocity responses in the two horizontal directions are shown. Further, these displacement responses are transformed into the polar coordinates. Figure 6 shows the relative displacement and the relative velocity responses in the *radial* direction. It is noted that the maximum relative displacement is 46 inches and the peak instantaneous relative velocity is 140 inches/sec. It should be noted that the source of this intense response comes from the dynamic responses of the massive substructures below the bearings. Figure 5 also show the total displacement and total velocity responses at above and below the bearings. It is clearly shown that due to the seismic isolation, the response of the superstructure is relatively mild with a much longer period (3 to 5 sec.). The response of the massive substructure has a dominant period of 1.5 second and the much higher response amplitude that contributes to the higher than expected seismic responses of the bearings.

PERFORMANCE EVALUATION OF ISOLATION BEARINGS

For friction bearings, the seismic performance is affected by the heat generated during the sliding motions and the associated temperature rise which may damage the bearing surface and cause deterioration in its mechanical properties, i.e. friction coefficient (Constantinou et al, 1999). Since bearing of this size has not been used before, careful performance testing is being planned. The important parameters are the *total energy input* to the bearing and the *rate of energy input* during the seismic excitation. The total energy input time history for the Pier 9 bearing is shown in Figure 6. The rate of energy input is the slope of this energy curve and is proportional to the instantaneous velocity.

Theoretically, the controlling parameter is the heat flux at a given point. However, because of the finite size of the slider (the upper portion of the friction bearing with a diameter of 36 inches), the area that is most affected by the friction heating is the center portion of the bearing. Based on our estimation that more than 80% of the total energy input is converted into the heat flux in a small core area at the center. Therefore, the total energy input can be used to gauge the frictional heating of the bearing. In the full scale dynamic testing, it is important that the total energy input to the bearing is simulated and measurements obtained to assess the performance of the bearing.

CONCLUSIONS

Reported herein are interpretations of the response prediction obtained from the global nonlinear seismic analysis. The behavior characteristics of friction isolation bearings in a major bridge structure are carefully described which are unique to major bridges with massive flexible substructures. Further, issues regarding acceptable performance are identified for full-scale dynamic testing.

REFERENCES

Constantinou, M.C., P. Tsopelas, A. Kasalanati, and E. Wolff (1999) Property Modification Factors for Seismic Isolation Bearings, Draft Report for NCEER Highway Project Task 106-F-4.2.1(a), Feb. 19, 1999.

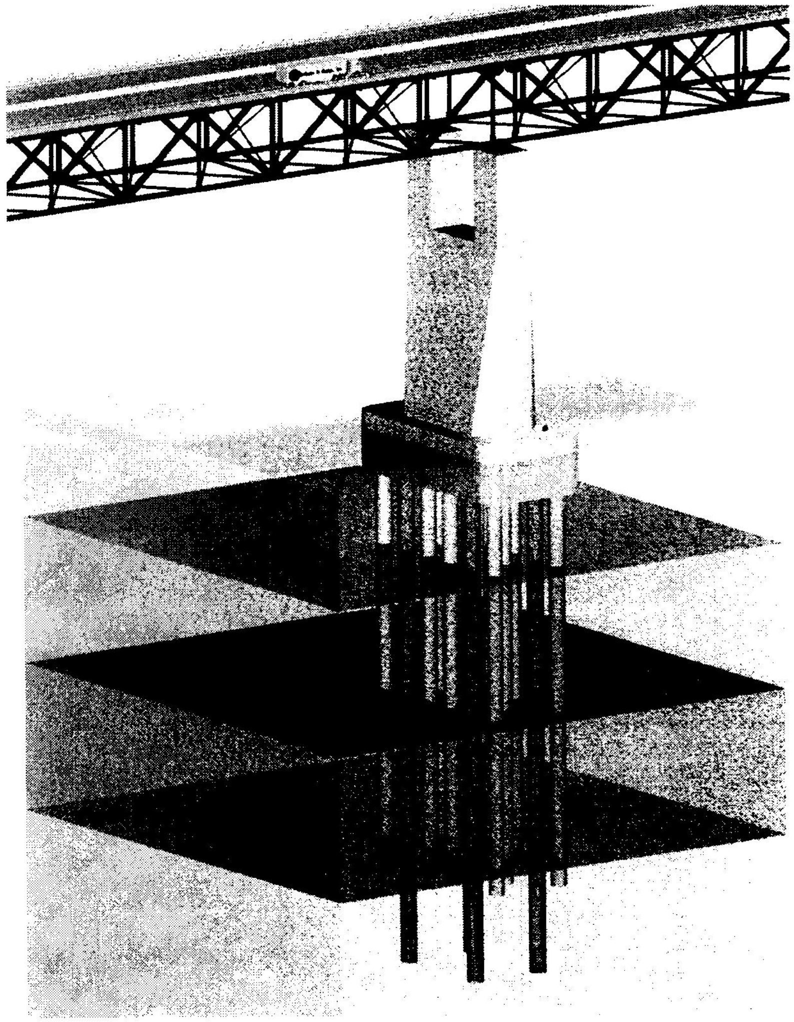


Figure 1 Schematic 3D view of typical pier and pile group foundation

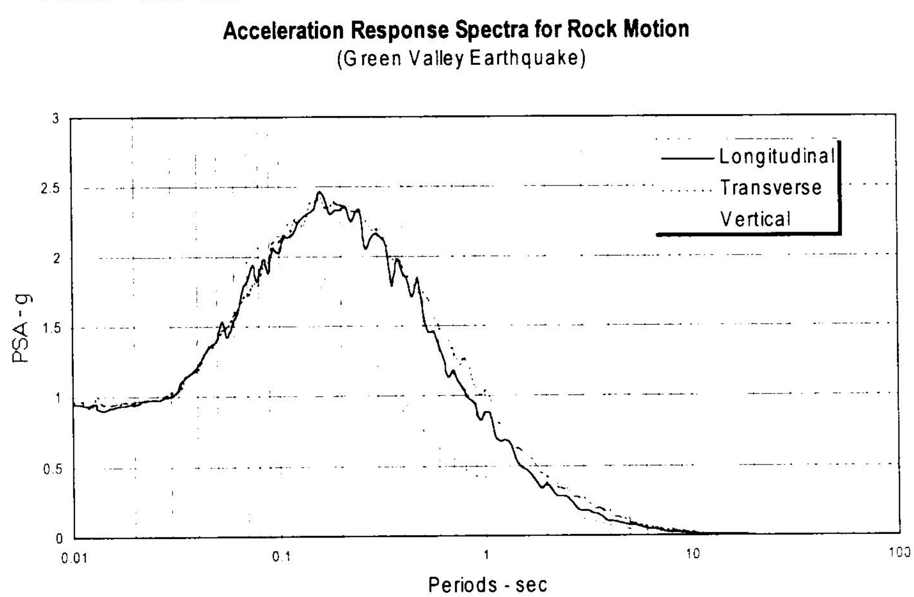


Figure 2 Rock motions spectra of Green Valley earthquake

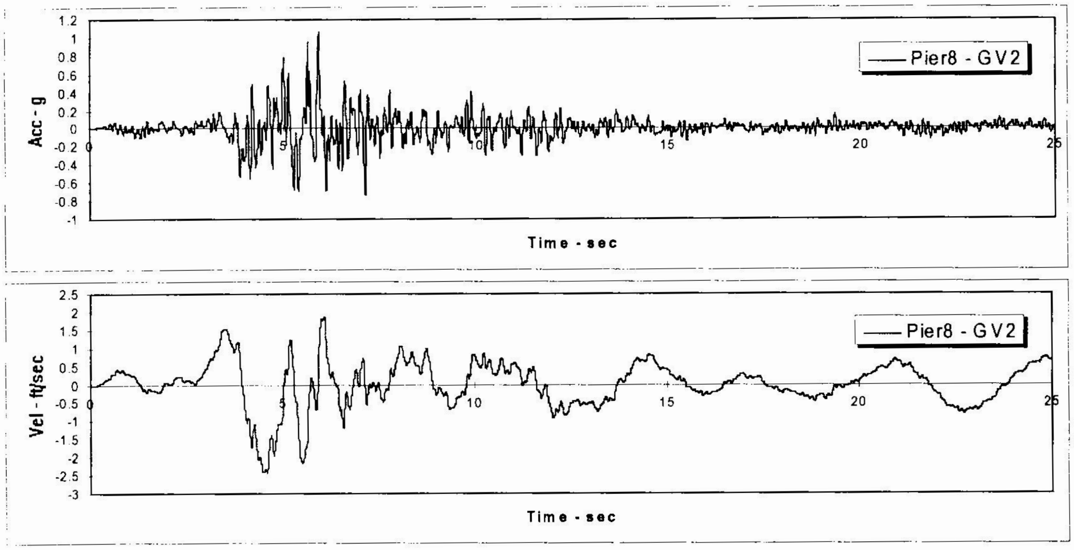


Figure 3 Rock motion acceleration and velocity time histories

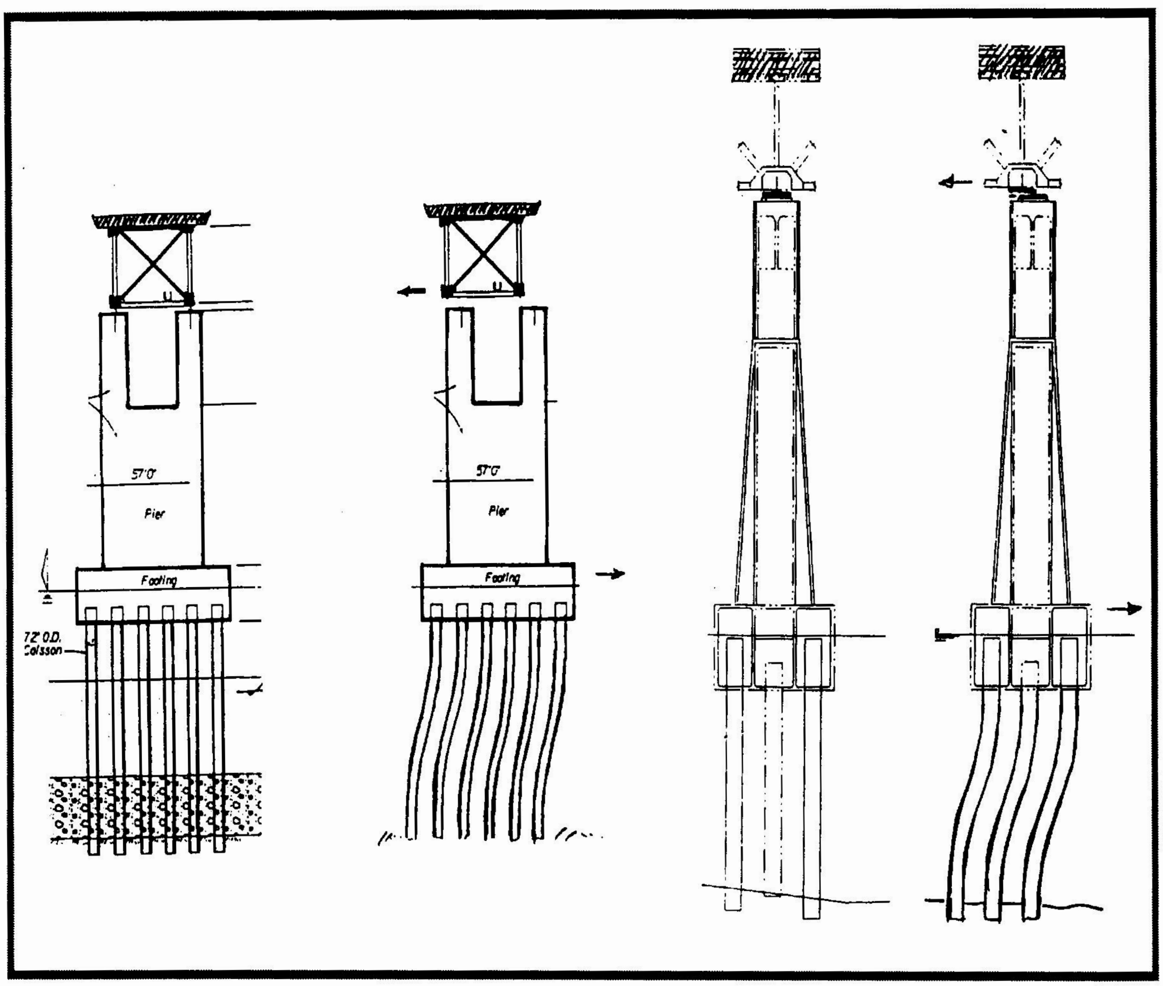
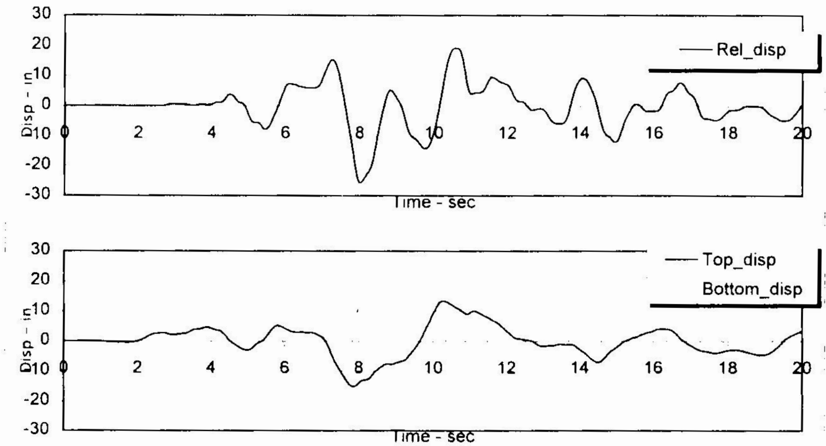
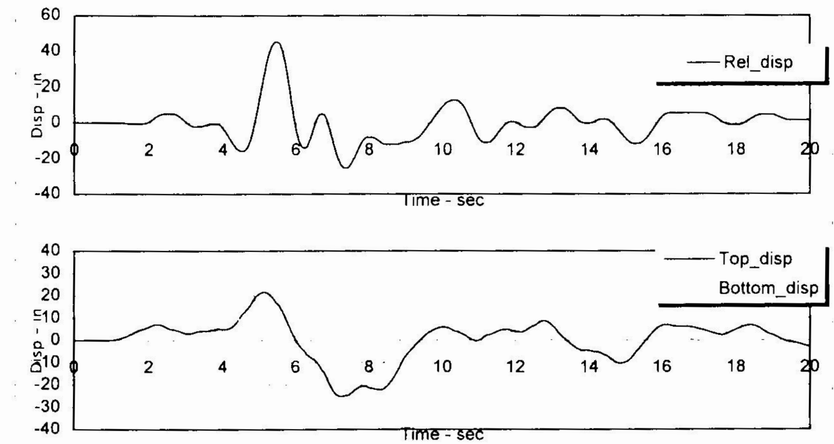


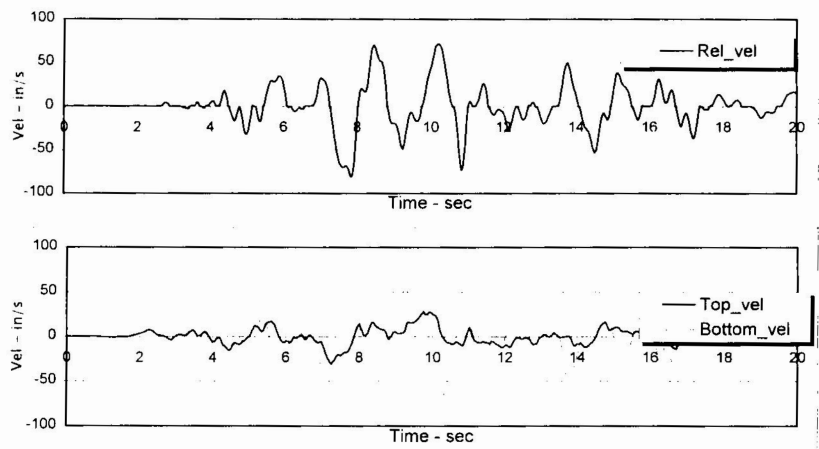
Figure 4 Dynamic behavior of isolation bearings at typical pier



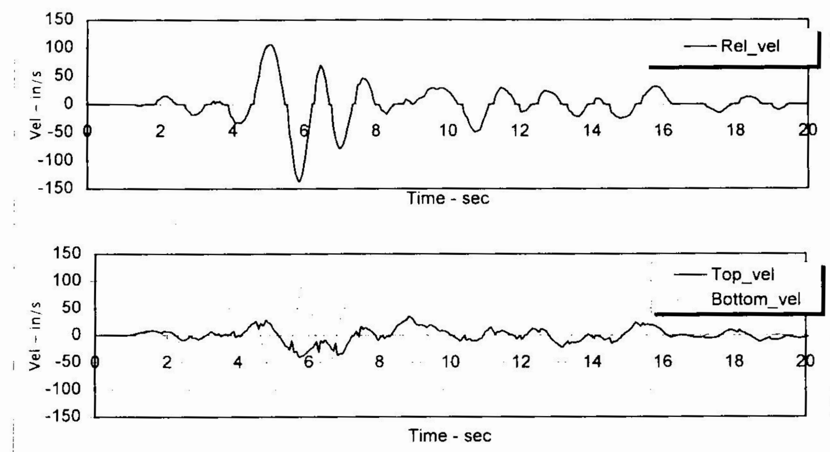
(a) Displacement (Longitudinal)



(a) Displacement (Transverse)



(b) Velocity (Longitudinal)



(b) Velocity (Transverse)

Figure 5 Relative displacement and velocity time histories across the FPS bearings and absolute displacement and velocity at above and below the FPS bearings at Pier 9

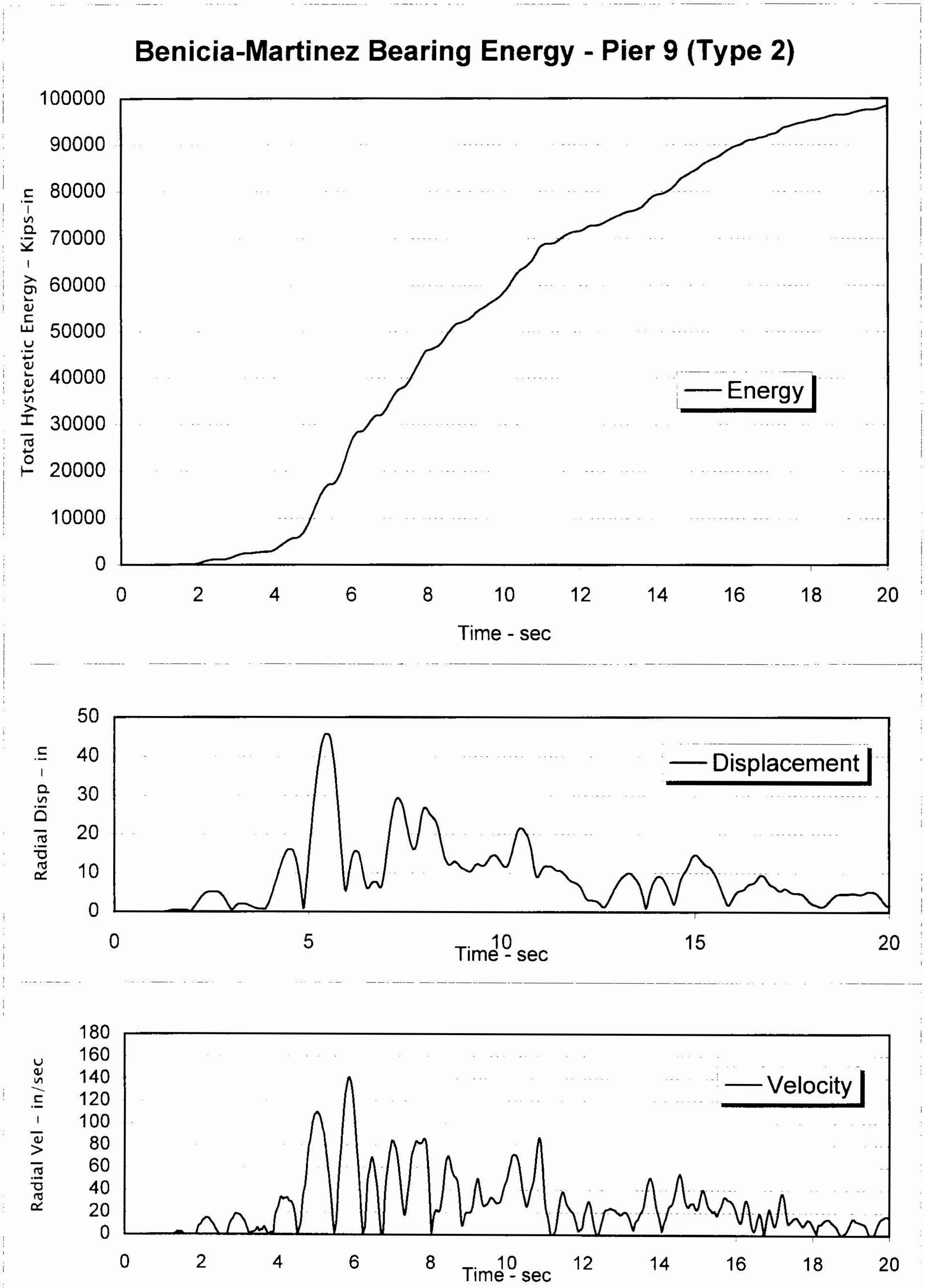


Figure 6 Energy time history and corresponding relative radial displacement and velocity time histories at Pier 9 (Ground motion set #2)