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# Reconstruction Design for PC Girders Damaged by the Kobe Earthquake

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## Summary

The bridge discussed in this paper has simple composite PC girders supported by six RC T-beam piers and one RC rigid frame pier. It is located in Nada Ward, Kobe and was severely damaged by the Kobe Earthquake. The damage included inclination of the eccentric piers and damage to the end cross beams. To restore the bridge, a girder connection with isolators was used to distribute and reduce inertia force. Specifically, the slab-rubber-hinge girder connection method was developed. Isolators with both lead-rubber bearings (LRB) and sliding rubber bearings (SRB) and restrainers having rubber-sheathed chains were also used. Foundations, piers and girders except the damaged end cross beams were reused with some repair.

## 1. Basic of Structural Framework Design

In the design, focus was placed on developing a girder connection structure and employing omnidirectional seismic isolation to decrease both longtudinal and lateral inertia forces acting on eccentric piers whose reinforcement possibilities were limited (see Fig. 1). The preliminary design was first drawn up by applying the seismic coefficient method and the final, comprehensive design was based on the nonlinear dynamic analysis of the seismic record of the Kobe Earthquake at the Japan Meteorological Agency Kobe station. In addition, to verify the validity of the adopted isolated structures, the cumulative strain energy was calculated by analysis of the entire bridge, obtaining the proportions of seismic energy shared by the foundations, piers and isolation bearings (see Fig. 2).

## 2. Characteristic Structure Components

### 2.1 LRB-SRB Combined Isolation System

Two kinds of bearings, shown in Fig. 3, were applied to the bridge. SRBs were placed under the main girders to support the vertical load, and LRBs were placed in the gaps left under the end cross beams by removing part of their underside to absorb inertia force during an earthquake. This system was applied to the bridge in this paper which made use of thin rubber pad bearings

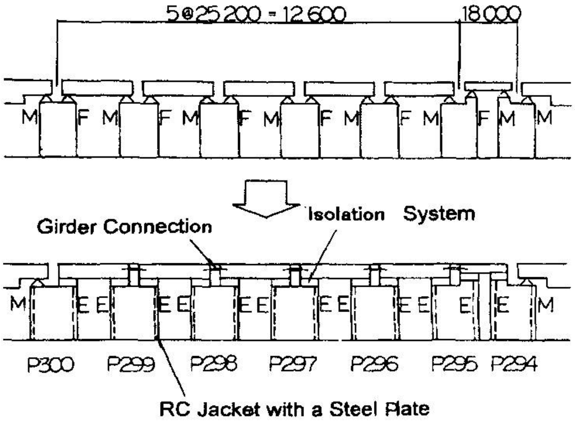


*Fig. 1 Structural Framework*

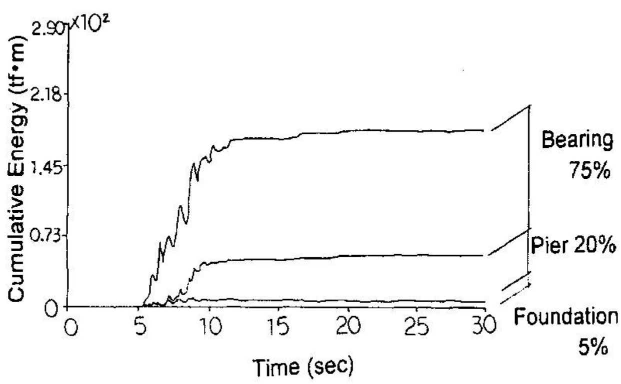


*Fig. 2 Cumulative Strain Energy*

under girders so as to limit the vertical change in that part of the bridge. The following are the main results verified by the performance tests: (1) the horizontal stiffness and damping capacity of LRB depended on the vertical load, but were within the design limit regardless of the small vertical load; (2) there were no significant changes in horizontal stiffness or damping capacity, regardless of the direction of vibration; and (3) the friction coefficient of SRB was approximately 0.1.

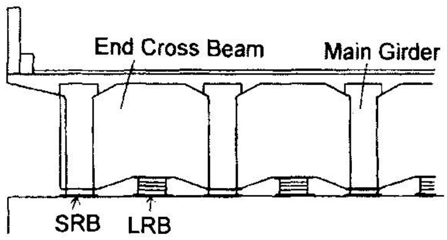


*Fig. 3 LRB-SRB Isolation System*

## 2.2 Connected Girder Structure

The girder connecting sections were designed to satisfy the following conditions: (1) the rotation of the joint section due to live load deflection would not be restricted; and (2) inertia force in the longitudinal direction would be transmitted through the joints. Accordingly, new slab-rubber-hinge designs as shown in **Fig. 4** were adopted. In this method, a rubber functioning like a hinge was placed on the slab and the upper parts of the cross beams were connected by PC wires.

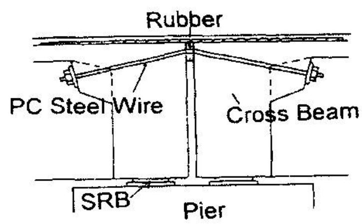


*Fig. 4 Girder Connection*

## 2.3 Restrainers

A restrainer which could work in directions both longitudinal and lateral was required for an omnidirectional isolation system. Rubber-sheathed chains as shown in **Fig. 5** were adopted. Their impact-absorbing properties can also minimize the probability of destruction due to impact. An impact-tension test was conducted to check the impact-absorbing capability with a high-speed tension tester.

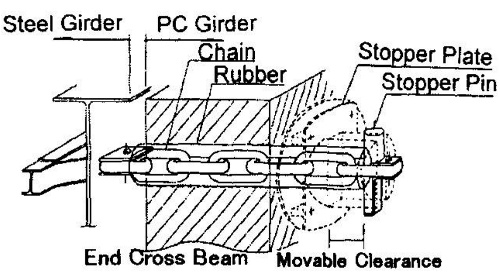


*Fig. 5 Restrainer with Rubber-sheathed Chain*