I-541 RESIDUAL DISPLACEMENTS OF BRIDGES IN EARTHQUAKES

O G. A. MacRae, Member, Public Works Research Institute,
K. Kawashima, Member, Public Works Research Institute.

INTRODUCTION: Large residual displacements and yielding in predominantly one direction has been observed in recent shaking table tests of steel piers with slightly negative bilinear stiffnesses [1]. However, shaking table tests of base isolated bridge models, with positive bilinear stiffnesses showed almost no residual displacement [2]. Residual displacements are undesirable in real structures because of difficulties with straightening them after an earthquake and the possible greater susceptiblity to damage in further earthquakes or aftershocks. An investigation is therefore presently underway at the Public Works Research Institute, Tsukuba, Japan, in order to study the effect of bilinear stiffness on the seismic behaviour of bridges.

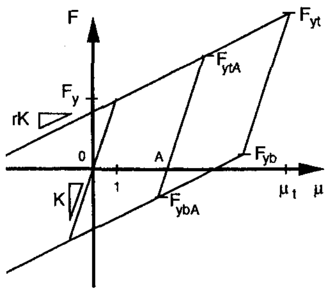

Figure 1. Bilinear Hysteresis Shape

ANALYSES: A computer program was developed to obtain the yield acceleration, displacement and residual ductility of single-degree-of-freedom oscillators (SDOFO's) with different bilinear factors, r, under earthquake ground motions for specified values of target ductility, μ_t. Iteration of yield displacement, d_y, was used until the target ductility was obtained. The residual ductility of an oscillator, μ_r, was defined as the residual displacement, d_r, divided by the yield displacement, d_y. Any elastic displacement which was present at the end of the earthquake record was subtracted in order to obtain the residual displacement at zero force. The maximum possible residual ductility of an oscillator when the negative yield strength corresponding to the maximum displacement, F_{yb}, is less than zero then $\mu_r = (\mu_t - 1)(1 - r)$. When F_{yb} is greater than zero, as shown in Figure 1, then $\mu_r = (1 - r)/r$.

Many earthquake records were used but the trends in the behaviour are able to be shown from the transverse component of the Kaihokubashi record during the Miyagikenoki earthquake (12.6.1978) [3]. Fifty one oscillators were analysed with periods from 0.1 to 3 seconds. Residual ductility versus period is shown for a target ductility, μ_t, of 4 for hysteresis loops with bilinear factors of -0.1, 0.0, 0.1, 0.25, and 0.50 and a damping ratio of 2% in Figure 2. It may be seen that the average residual ductility reduced drastically with increasing bilinear stiffness. In Figure 3 it is shown that the loop with a negative bilinear stiffness sustained less yielding and absorbed relatively less energy.

The hysteresis loops with increasing bilinear stiffnesses had lower residual ductilities because of their greater stability. In Figure 1 it may be seen that a SDOFO oscillating about point "A" will tend to yield at the lower yield force, F_{ybA} before point F_{ytA} causing yielding in the direction toward the zero displacement position. This restoring tendency increases at higher displacements. Conversely, loops with negative bilinear stiffnesses have a destabilizing tendency and larger displacements in one direction are likely to result. The maximum displacement of oscillators with negative bilinear stiffnesses is strongly dependent on the magnitude and number of cycles of yielding which is affected by the length of earthquake record. The maximum velocity of an oscillator subjected to non-forced loading tends to be greatest at zero force. Therefore, after yielding has occurred in one direction the momentum may cause a significant force and possible yielding in the opposite direction depending on the earthquake record and the shape of hysteresis loop.

It should be noted that if the stiffness and bilinear stiffness of a base-isolation device are K_b and r_bK_b respectively and the stiffness of the pier and the foundation system is K_p, then the bilinear stiffness of the whole system, r_s, which controls the seismic response, will have a greater magnitude than the bilinear stiffness of the base isolation device itself, r_b. The system bilinear factor, r_s, is given as $r_s = (1 + K_b/K_p)/(1/r_b + K_b/K_p)$.

SUMMARY: In this paper some analyses carried out with SDOF oscillators with both positive and negative bilinear stiffnesses were described. It was found that oscillators with a positive bilinear stiffnesses had very small residual displacements while those with a negative bilinear stiffness absorbed much less energy and the residual displacements were much larger. This behaviour was consistent with that found from shaking table tests of base-isolated and steel bridge subassemblages respectively. The reasons for this type of behaviour may be understood by considering the *stability* of the hysteresis loop. An inelastic response spectrum design approach which considers only the maximum acceleration is not appropriate to obtain the inelastic response of structure with negative bilinear hysteresis loops in a general earthquake because these loops are unstable and the maximum displacement depends on the length of the earthquake record. Structural systems should, if possible, be designed with a positive bilinear stiffness in order that the residual displacements are small and so that they will not have to be replaced after a moderate-to-strong earthquake.

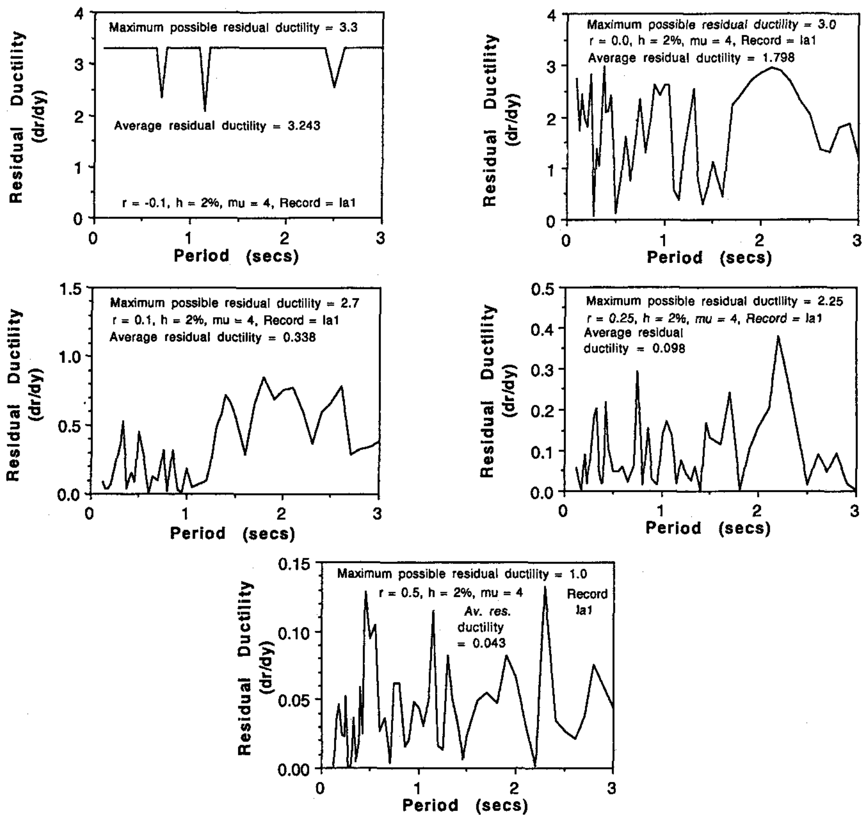

Figure 2. Residual Displacements of Oscillators with a Ductility of 4 Subject to Kaihoku record

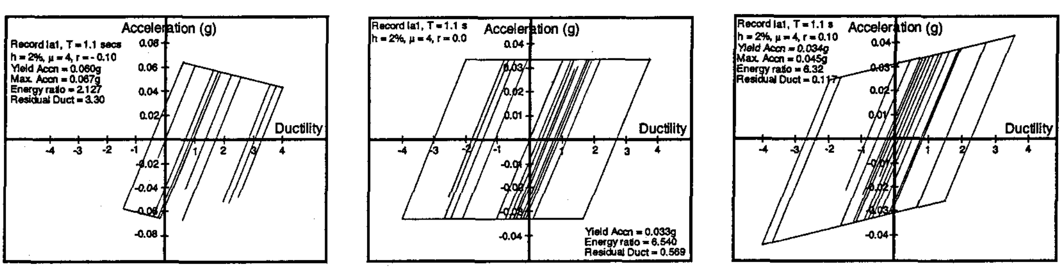

Figure 3. Hysteresis Loops of Oscillators with Bilinear Stiffnesses of -0.1, 0.0, and 0.1.

REFERENCES:

1) Kawashima K., MacRae G. A. and Hasegawa K., "The Strength and Ductility of Steel Bridge Piers Based on Loading Tests", Public Works Research Institute Report, Ministry of Construction, 1991.

2) Kawashima K., et al. "Development of Base-Isolated Structural Systems for Road Bridges", Cooperative Research Report (Pt. 1), No. 44, March 1990.

3) Kawashima K., and Aizawa K. and Takabashi K., "Attenuation of Peak Ground Motions and Absolute Acceleration Response Spectra", Report of The Public Works Research Institute, Ministry of Construction, Vol. 166, Sept 1985.