Computer-Actuator Response Test of Base Isolated Structure to Two-Directional Earthquake Ground Motion

Matsutaro SEKI, Kouichi SUGIYAMA, Hiraku UCHIDA, Hiroshi OKADA
Obayashi Corporation, Tokyo, Japan

1 INTRODUCTION

Base isolated structure techniques have reached the stage of practical application as a new method of reducing earthquake ground motion. However in order to consider the safety of base isolated structures, the tests which are normally conducted of the effects to one-directional ground motion must be supplemented by tests to acquire a complete understanding of the behavior of such structures when earthquake grounnd motions are inputted from two directions. This is a report of a study of two-directional earthquake ground motion conducted by means of an earthquake response test using a computer-actuator on-line system.(Ref.1)

2 TEST METHOD

This on-line test can simulate the true earthquake response behavior of a large specimen which cannot be tested using a shaking table by making direct use of the actual test results as the restoring force in the equation of motion.(Fig.1)

The analyzed structure is a 5-story reinforced concrete building supported by base isolation devices : laminated natural rubber bearings and PC steel bar dampers.(Fig.2) On the supposition that the superstructure of the analyzed structure is rigid, the analyzed model is taken to be the single-mass shear spring model. The restoring force characteristics model established as the base isolation design is the bi-linear hysteresis model in which the yielding force normalized by the gravity force is 0.08 and the elastic period and the post-yielding period are 1 second and 3 seconds respectively. For this on-line test, the restoring force characteristics of the laminated rubber bearings (14 bearings) is linear, so this characteristics was entered previously in the computer software, and loading was applied only to the 5 PC steel bar dampers. Because 125 of these steel bars were actually used, the steel bar damper restoring force determined by the test and then stored in the computer was multiplied by 25, and the final result was obtained using the so-called simple substructure method of finding the total restoring force of the base isolated devices : adding the hypothetical restoring force of the rubber bearings to this steel bar damper restoring force arrived at through the above process. These relationships are shown in Figure 2.

The specimen of a PC steel bar damper shown in figure 3 is a cantilever-type PC steel bar. The base of the steel bar is fixed in place with a nut, and the loading point is supported by a spherical bearing. As shown in

SMiRT 11 Transactions Vol. K (August 1991) Tokyo, Japan, © 1991

Figure 4, the loading apparatus consists of two electro-hydraulic actuators (stroke : ±37.5 cm) installed at right angles to one another to apply loading horizontally from two directions. When loading is applied from two directions, linear bearings allow the two test beds(steel plate) under the specimen moving horizontally in their respective orthogonal directions.

Two types of test were conducted : a static cyclic loading test and 6 on-line tests. They are shown in Table 1. The static cyclic test specimen was composed of 5 PC steel bar dampers. The input earthquake ground motion was El Centro 1940, and during the one-directional input test, the NS component was used, while for the two-directional test, NS component was used for the X direction and the EW component was the Y direction. The level of the acceleration of both components was matched to the ratio of the original record. The level of the input acceleration for the one-directional test was taken to be 225 gals (velocity : 25 kines), 511 gals (50 kines), and 613 gals (60 kines) for the NS component. For the two-directional input, the acceleration for the X direction was the same as for the one-directional input, while for the Y direction it was the acceleration corresponding to EW component.

When the response was calculated, the natural period of the base isolated structure was long. Therefore the response duration time was taken to be 20 seconds, the integral time interval was taken to be 0.02 seconds, and the numerical integration was done using the central difference method. Also based on the results of previous tests of base isolation devices, the viscous damping is considered to be 2%.

3 SIMULATION ANALYSIS

The restoring force characteristics model used in the design of base isolation device is bi-linear, but the test described in this paper was conducted by applying loading from two directions, so the MSS (Multiple Shear Spring) model,(Ref.2) which takes into account interaction from the orthogonal directions in the single-mass shear spring model. Figure 5 shows the model and its basic properties.

4 TEST RESULTS

Photograph 1 shows the two-directional deformation in the PC steel bar dampers. The PC steel bar dampers are almost full-scale size, so it is clear from the photograph that they would function well even if they were deformed more than they were in this case. Figure 6 shows the restoring force characteristics and the orbits of the displacement and load for the one-directional cyclic loading test (DS-11) and the two-directional on-line test (DO-23) conducted at a large input level. Also the results of analysis are shown in the column below.

In the cyclic loading test, the forced displacement was increased gradually, the steel bars were broken at about 20 centimeters, and it was possible to describe the process when there were only laminated rubber bearings supporting the superstructure. The hysteresis loop shows a large energy absorbing shape.

The restoring force characteristics for the X and Y directions in the two-directional on-line test are almost identical in form to that of the one-directional cyclic loading test, but the interaction of the two-directional loading appear as a round shape in the loop. The displacement and the load orbits clearly shows that complex behaviors occur when two-directional test is performed, and that this is dependent upon the earthquake ground motion, but with the El Centro ground motion used in this report, it is almost a perfect circle. Also the analysis can simulate the results of both the one-directional and two-directional tests.

Figure 7 is the time history of response displacement for the two-directional on-line test (DO-23), and the test and the analysis show good correspondence. Figure 8 shows the accumulation process for hysteretic absorbed energy (the area of hysteresis loops). When the X direction component of the one-directional loading test and the two-directional loading test are compared, there are no energy volume differences as great as the maximum response displacement discribed below. Also, the energy absorption volume of the Y direction component in the two-directional loading test is about the same as that of the X direction component.

5 EXAMINATION OF THE TEST RESULTS

Figure 9 shows the spectrum characteristics of the maximum response displacement. With the two-directional loading test, the maximum value of the root mean square value of both the X and the Y direction components are plotted both to serve as a reference and at the same time to indicate the X direction component so it can be compared with the results of the one-directional loading test. This shows that the greater the input acceleration, the more the response displacement increases in a linear form. Also, the X direction component of the two-directional test has an input acceleration of 25 kines, almost the same as it does in the one-directional test, and when it reaches 50 kines or 60 kines, the X directon component becomes almost 30% larger.

Figure 10 shows the total volume of energy absorbed according to the input acceleration. As in Figure 9, it becomes more and more linear in form. Also, the same diagram shows the total absorption energy value up to the moment the steel bar dampers began to break in the one-directional cyclic loading test in figure 6, but it can be seen that the safety margin is more the twice as great as it was in the one-directional on-line test (DO-13).

6 CONCLUSIONS

Using the computer-actuator on-line system, it is now possible to simulate the earthquake response behavior when earthquake ground motion inputted from two directions. Findings obtained includes that when input comes from two directions, 1) the PC steel bar dampers perform well, 2) the response displacement generated by a large earthquake input is greater than it is in the case of one-directional input, 3) it is possible to clearly determine PC steel bar damper energy absorption capacity in quantitative terms, and 4) it is possible to accurately simulate the test results through theoretical analysis.

REFERENCE MATERIALS :

1) Takanashi,K., Okada,T., Seki,M. et al.,(1975), " Non-Linear Earthquake Response Analysis of Structures by a Computer - Actuator On-Line System (Part 1 Detail of the System) ", Transactions of Architectural Institute of Japan, No.229, pp.77-82,(in Japanese).
2) Wada,A. and Kinoshita,M.,(1985)," Elastic Plastic Dynamic 3-Dimensional Response Analysis by using a Multiple Shear Spring Model (Part 1)" Summaries of Technical Papers of Annual Meeting of Architectural Institute of Japan, pp.313-314,(in Japanese).

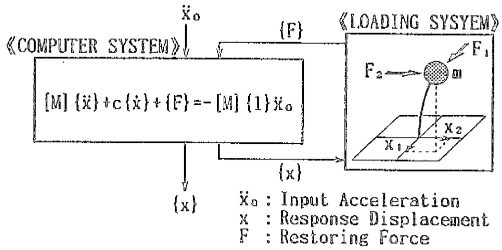


Fig.1 Concept of On-Line Test

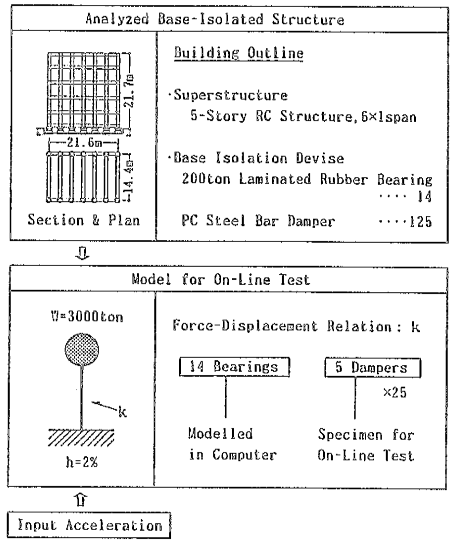


Fig.2 Analyzed Model for On-Line Test

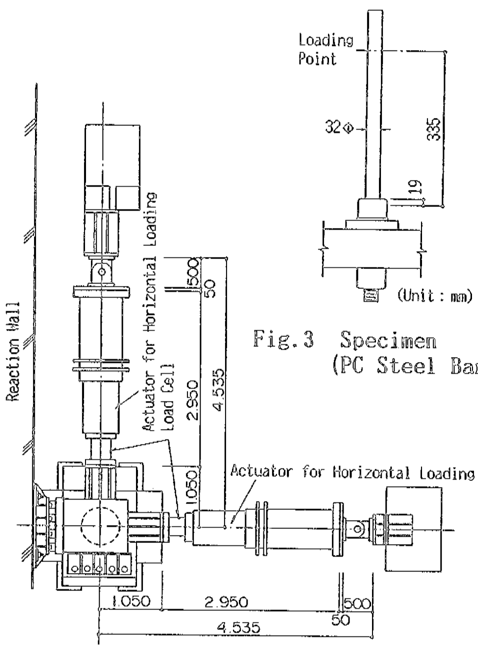


Fig.3 Specimen (PC Steel Bar)

Fig.4 Loading System (Plan View)

Table 1 Input Acceleration (El Centro 1940 NS, EW)

[Unit : gal (kine)]

Specimen	X-Direc. El Centro NS	Y-Direc. El Centro EW
DO-11	255 (25)	——
DO-12	511 (50)	——
DO-13	613 (60)	——
DO-21	255	157
DO-22	511	314
DO-23	613	377

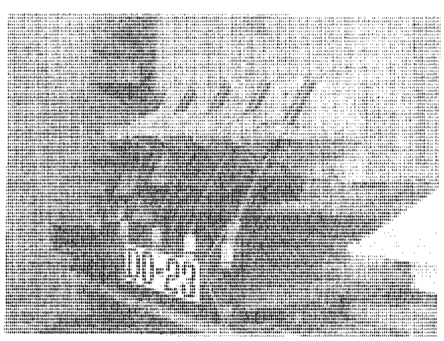


Photo.1 Deformed Steel Bars

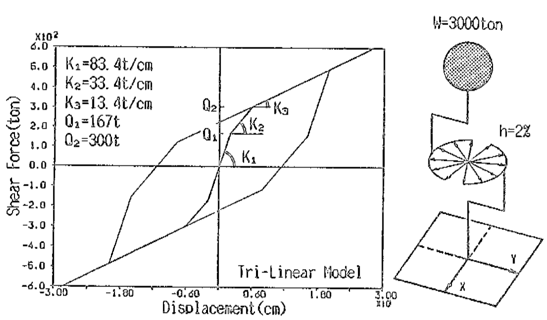


Fig.5 Force-Displacement Relation and Multiple Shear Spring Model for Analysis

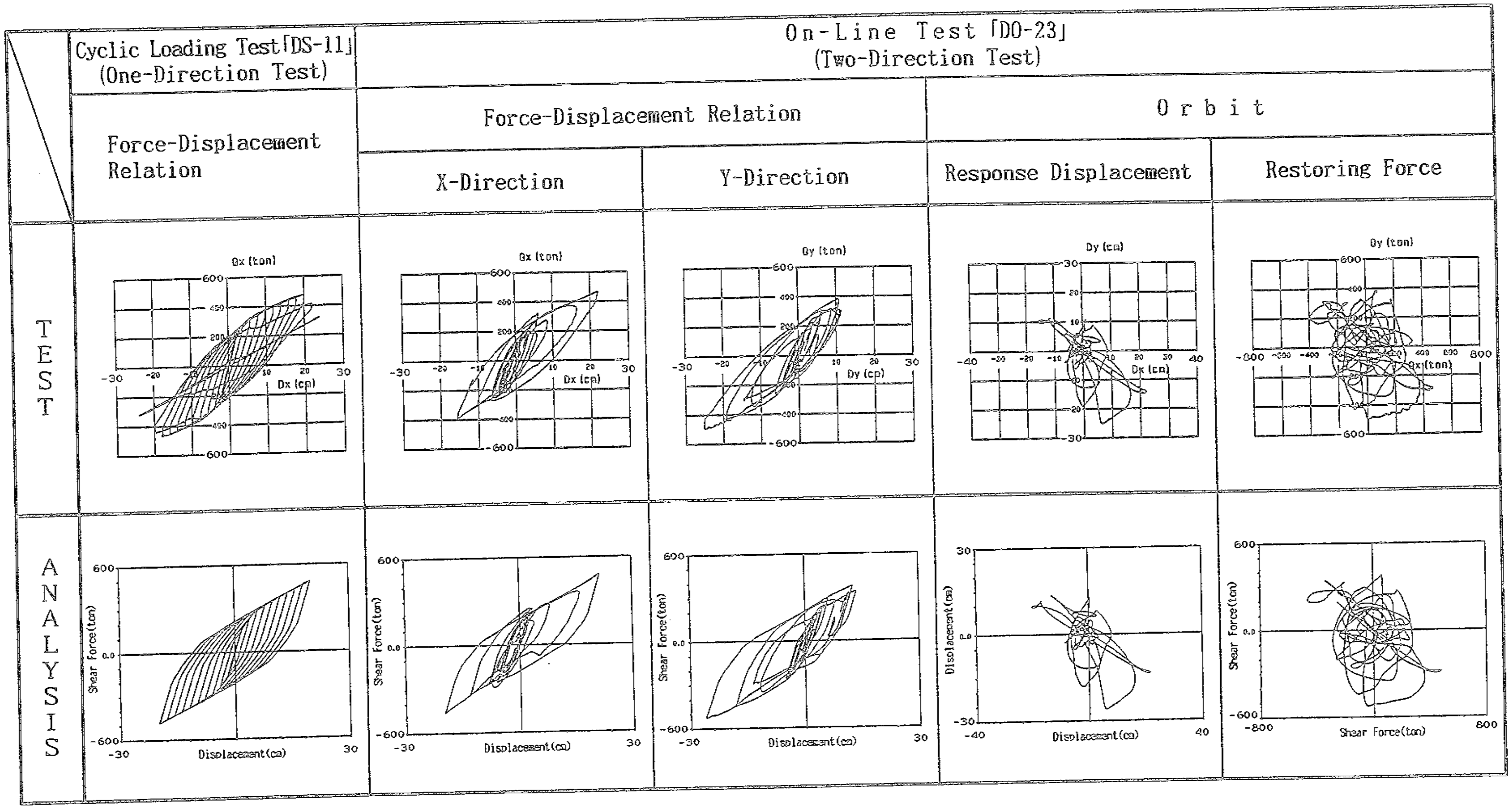
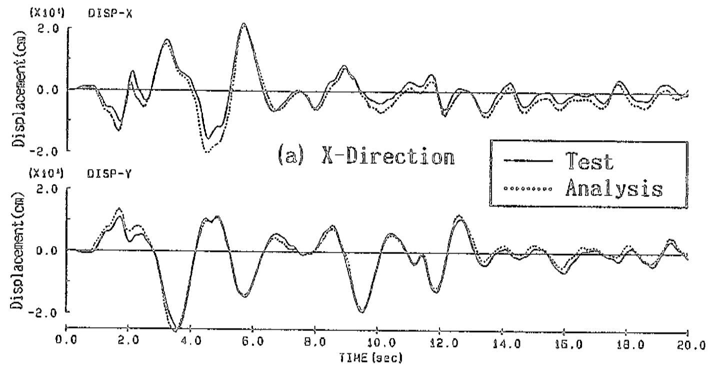
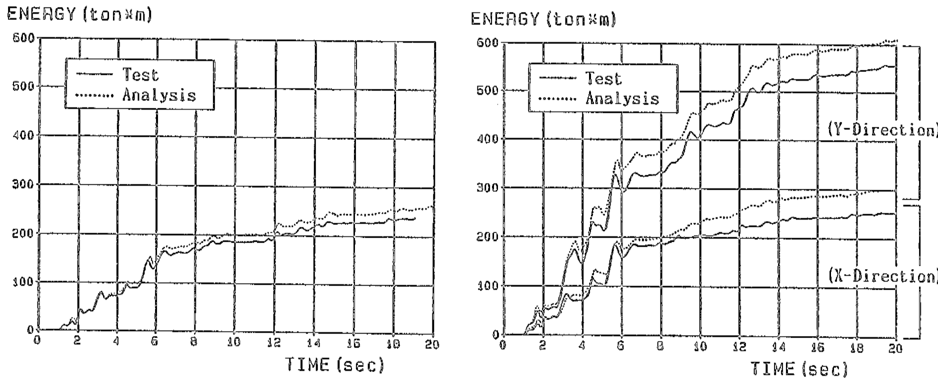


Fig.6 Test and Analytical Results



(b) Y-Direction

Fig.7 Time History of Response Displacement(DO-23)



(a) One-Direction Test(DO-13)

(b) Two-Direction Test(DO-23)

Fig.8 Time History of Cumulative Hysteretic Energy

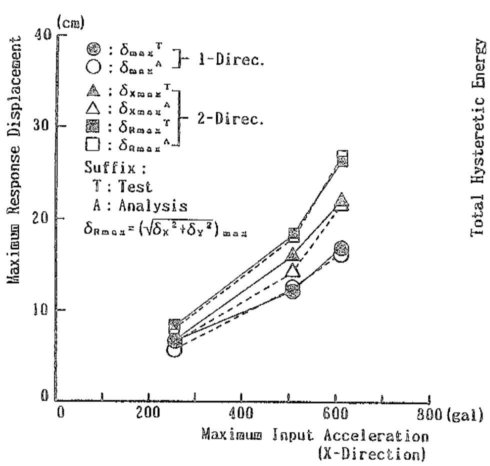


Fig.9 Maximum Input Acceleration (X-Direction) vs. Maximum Response Displacement

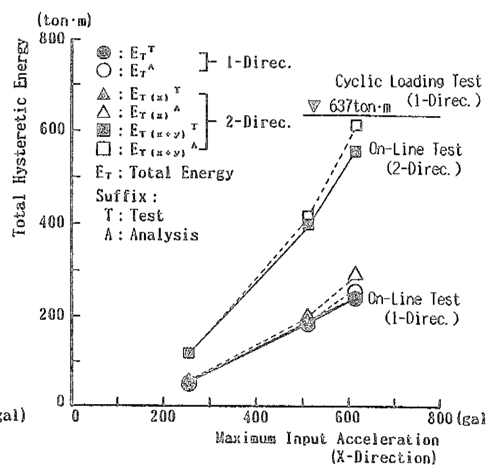


Fig.10 Maximum Input Acceleration (X-Direction) vs. Total Hysteretic Energy