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A SHAKING TABLE DAMAGE TEST OF ACTUAL SIZE RC FRAME

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ABSTRACT

Shaking table damage tests of actual size three story reinforced concrete frames (one bay x one bay) were carried out. Before the tests, the dynamiccollapse properties of actual size RC columns were investigated, using the shaking table. Two RC frames of three story were tested on the NIED large scale shaking table of one horizontal movement. Two RC frames were designed to make the girders yield prior to the columns. The Kobe JMA NS record of the Hyogo-ken Nanbu Earthquake, and Hachinohe EW record of 1968 Tokachi-oki Earthquake were used in the tests. The failure modes of shaking table tests agreed to the predicted modes. The girders which were normal to excitational direction, sustained the failures at the connections. The maximum story displacement angle was about 1/21 in Kobe JMA excitations.

KEYWORDS

Reinforce Concrete; Shaking Table Test; Damping Ratio;Damage; Earthquake Motion

INTRODUCTION

It is important to study the dynamic failure process of structures, for the aseismic design, the damage judgement of buildings, the evacuation plan, the planning of earthquake disaster mitigation, the retrofit plan. For the purpose, NIED conducted the study of RC structure damages during the strong earthquake as a STA project of joint research with private companies. In the study, the shaking table damage tests of actual size 3 story RC frames, as shown in Photo 1, were conducted two times. At the second test, the test frame was excited by Kobe JMA NS record of the Hyogo-ken Nanbu earthquake.

The RC frame dynamic response studies in which the shaking table tests of small models were used, were already conducted by the group of Sozen, Abe and Okada. EERC in University of California, and BRI in Japan conducted the

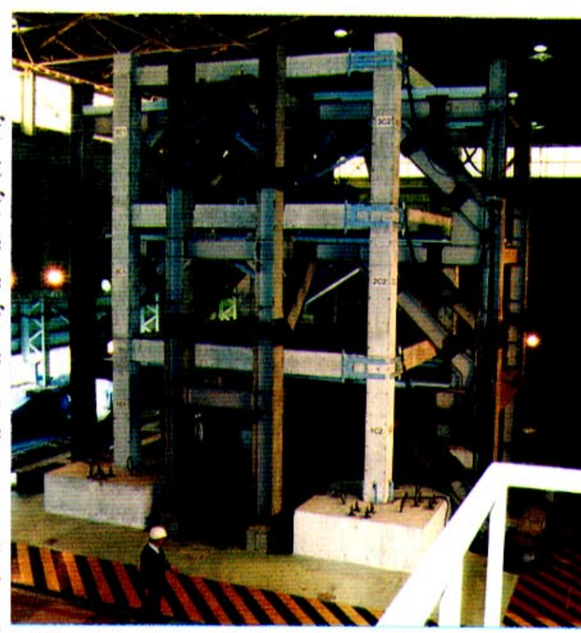

Photo 1. Actual Size Three Story RC Frame

shaking table tests of middle size RC frame models. The shaking table tests of actual size RC structures were carried out in Nuclear Power Engineering Test Center and National Research Center for Disaster Prevention.

The purposes of studies are to make the large deformations and damages in actual size three story RC frames, and to observe the dynamic damage processes . Considering the capacity of NIED Shaking table, the wall structure damage tests should be impossible. Thus, the beam - column frames were investigated.

The research was carried under the promote board, the chairman; Tuneo Okada.

COLLAPSE TESTS OF RC COLUMNS

At the beginning of the study project, two types of test columns were collapsed by the shaking table inertia force. The heights of columns were 2m. The sections were 35cm x 35cm. The Main reinforcements had 8 steel bars of 22mm diameter. The shear reinforcements had the steel bars of 6mm diameter. The shear reinforcement spacings differed in two type of columns. One had the hoop spacing of 10cm, the other had 40cm. The tests devices had a box plan structure of 4 columns. The inertia weight of test device was 103tonf. The shaking table was excited by the same input to the first 3 story test. The collapse patterns of 10cm and 40cm spacing are shown in Photo 2 and 3. Fig. 1 and 2 are the acceleration - story displacement hysteresis loops.

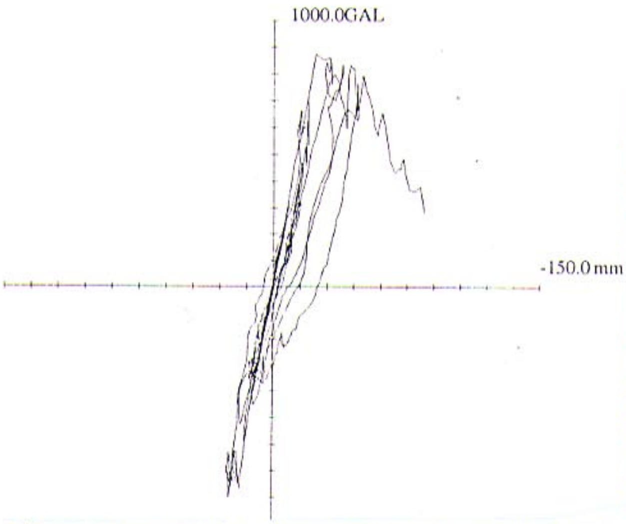

Fig. 1. Hysteresis Loop of Hoop Spacing 10cm.

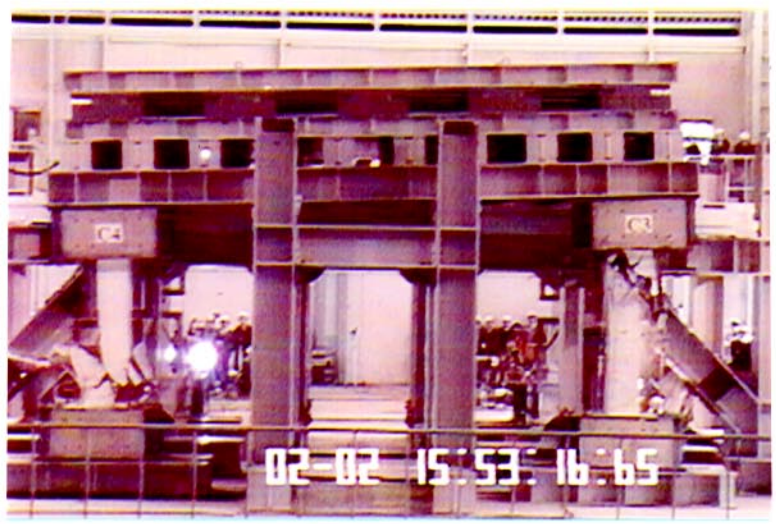

Photo 2. Collapse Pattern Of Hoop Spacing 10cm.

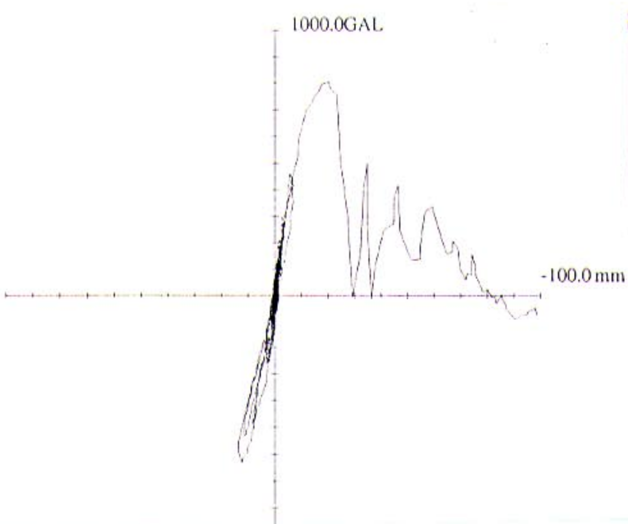

Fig. 2. Hysteresis Loop of Hoop Spacing 40cm.

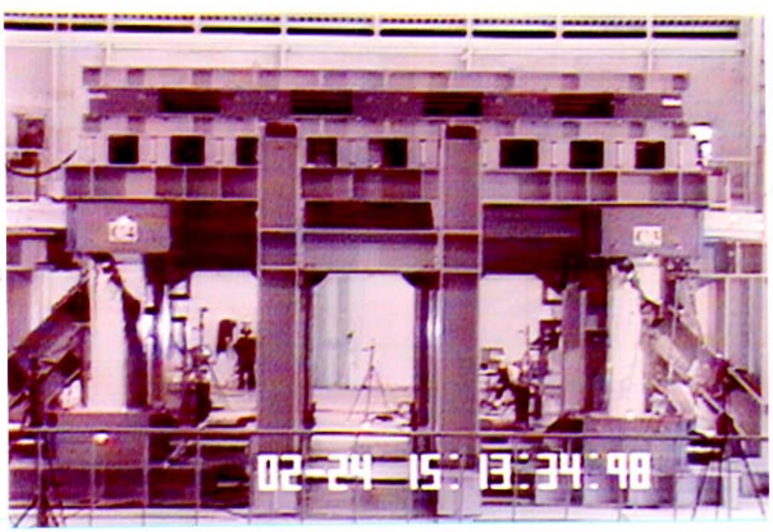

Photo 3. Collapse Pattern Of Hoop Spacing 40cm.

FIRST SHAKING TABLE TEST

Test Frame

The outline and reinforcements of a test frame are shown in Fig.3. The reinforced concrete test frame of three stories has the total height of 10m, the each story height of 3m, the length of 6m in both (x and y) directions, and 4 columns of section 45cm x 45cm. The girders were designed to be weak in comparison with the columns. The x direction was parallel to the excitation axis, and the y direction was normal to the axis. The south and north elevations coincided with the x direction, the east and west elevations coincided with the y direction. The thickness of each floor slab was 15cm. The each slab had a beam in the x direction. The steel blocks which gave the lively loads corresponding to actual buildings, distributed over the slabs. The weights of the third, second, first story were 39.05ton, 37.07ton, 37.28ton respectively.
The date of shaking table damage test was after 39 days from first story concrete casting (compressive strength 316kg/cm^2, before 3 days of the test), after 29 days from second story concrete casting (400kg/cm^2, before 3 days of the test), after 19 days from third story concrete casting (294kg/cm^2, on next day of the test). The tensile strengths of steel bars were about 3.5tonf/cm^2 in small diameter bars like D10, and about 4tons/cm^2 in large diameter bars like D22. In order to mitigate the shock loads of falling frames in the shaking table during damage excitations, a rigid steel frame was fabricated on the table. The weight of the frame was about 80ton.

Test Methods

The shaking table was driven by the strong earthquake motion record of 1968 Tokachioki, Hachinohe E-W, which was mode in the use of FFT band pass filter 0.4Hz-50Hz. The real time scale was used. The pulse excitations were used to observe the change of the stiffness and damping The one horizontal dimension shaking table of NIED was used in the test. The dimension of shaking table is 12m by 12m. The table weight is 180ton. The maximum power is 360tons. The deformations of the test frame were measured by potentio meters which were installed in the rigid steel frame. Acceleration and strain responses were measured.

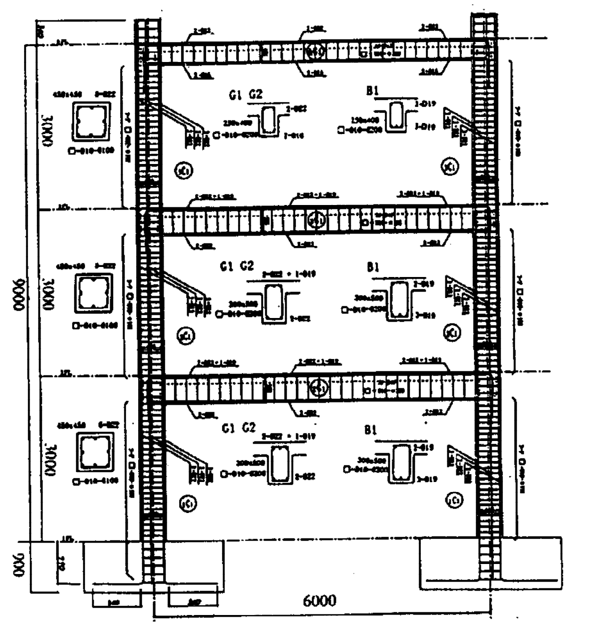

Fig. 3. Steel Bar Distributions of 1st Test Frame

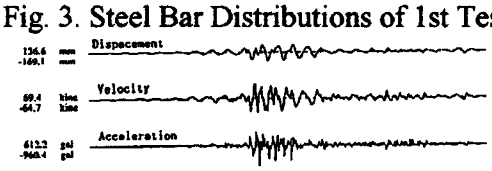

Fig. 4. Hachinohe EW Table Motion

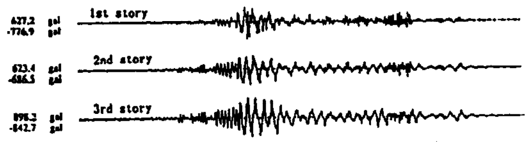

Fig. 5. Acceleration Responses of 1st Test Frame

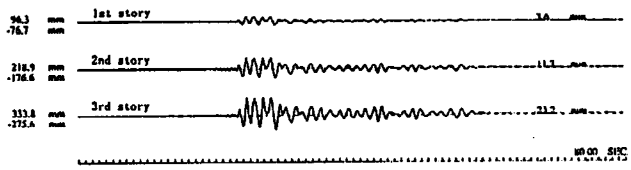

Fig. 6. Relative Displacements of 1st Test Frame

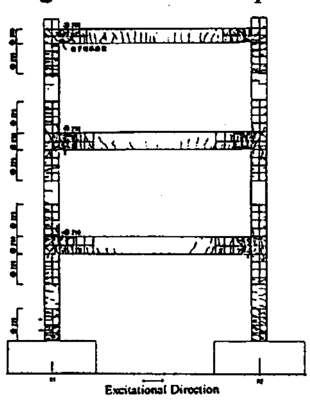

Fig. 7. South Elevation Crack Sketch

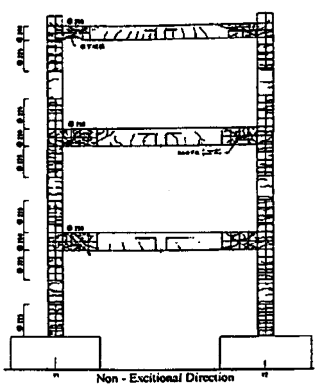

Fig. 8. East Elevation Crack Sketch

Test Results

The table movements of the damage test were 169.1mm in the maximum displacement, 69.4cm/sec in the maximum velocity, and 960gal in maximum acceleration, as shown in Fig.4. Maximum exciting force was 341.4tonf. The acceleration responses of each story were shown in Fig.5. The potentio meter records of each story were 33.3cm in third story, 21.8cm in second story, and 9.6cm in first story, as shown in Fig.6. The displacement offsets after the damage excitation ere about 2.3cm in third story. The x direction girder ends on the connections between columns and girder were cracked and the small crushed concrete separated down from the frame, as shown in Fig.7, and Photo 4,5, because of the weak girder design. The damages of columns, as cracks of column foot in bases, were a little in the comparison with the girders.
Furthermore, the y direction girders were damaged very much, as shown in Fig.8. The reinforcement steel bars in x direction girders yielded very much in every stories. However, in second and third stories, the bars of columns were appeared not to yield or to yield in small plastic ratio less than 2. Thecolumn ends of first story and bases yielded larger than the columns of other stories. The damage modes which were observed in the test, were anticipated in the design processes.
The impulse responses before and after the damage excitation, were shown in Fig.10. The estimated modal characteristics were indicated in Table 1. The natural frequency of the rigid steel frame was estimated to be 10Hz.

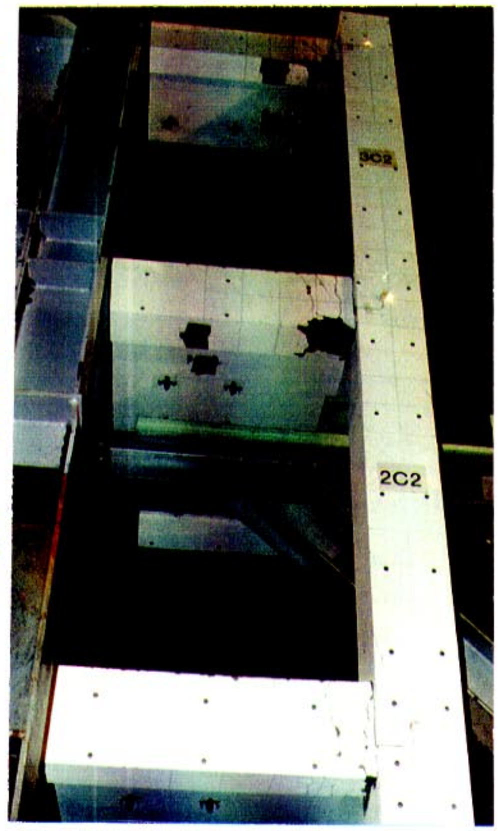

Photo 4. Damaged 1st Test

Discussions

The inertia force - story displacement hysteresis loops are shown in Fig.9. The inertia forces were calculated by the acceleration X the story mass. The simulation data were given by the Computer code RESP-F of plane frame elasto - plasto dynamic analysis. The Calculated natural frequencies, using material test data, were described in Table 1. Simulation hysteresis loops are seen to agree with test results, well. However, the displacement values were a little different from test results. The more study will be necessary.

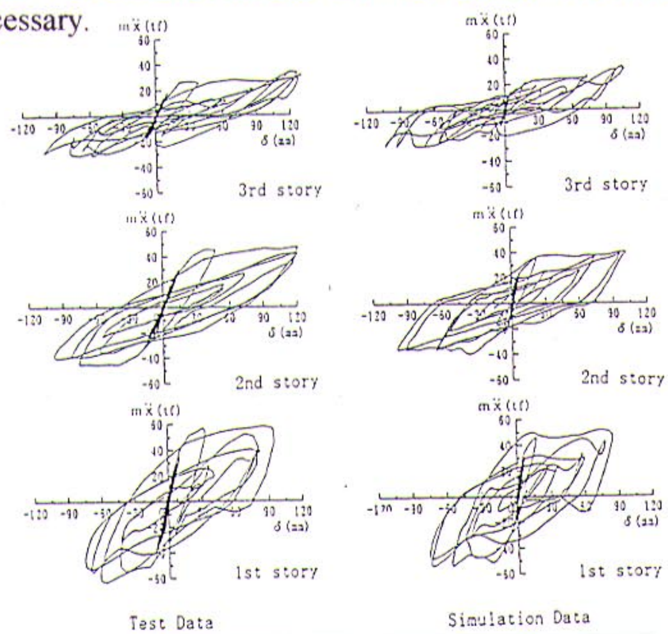

Fig. 9 .Hysteresis Comparisons of Test and Simulation


Photo 5. Damaed Girders of 1st RC Frame

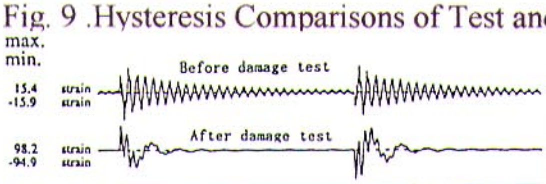

Fig. 10. Impulse Responses of 1st RC

Table 1 Measured Modal Characteristics of 1st RC Test Frame

	1st Mode		2nd Mode		3rd Mode	
	Frequency	Damping	Frequency	Damping	Frequency	Damping
Before Damage	3.0Hz (3.3Hz)	1.3% - 2.0%	9.7Hz (10.1Hz)	2.0% - 3.7%	18.7Hz (20.2Hz)	2.5% - 5.2%
After Damage	0.85Hz	15%	3.7Hz	3% - 6%	8.5Hz	3% - 6%

( ) : Simulation

SECOND SHAKING TABLE TEST

Test Frame

The most of test frame details were as same as first test frame, except the reinforcements of girders and beams, and the distributions of steel blocks. The section of third story beam was 35cm width by 30cm height. The up side reinforcements of the beam were 3-D16 in the end and center parts, and the lower side reinforcements were 2-D16 in the end part, 4-D22 in the center part. The section of second and first story beam was 30cm width by 35cm height. The up side reinforcements of the beam were 2-D16 in the end and center parts, and the lower side reinforcements were 2-D16 in the end part, 3-D19 in the center part. The y direction girders were made strong by the web reinforcements 2-D16 and straps D-13 with the spacing of 10cm. The lower side reinforcements of third story girders were 2-D13 and 2-D10. The change had been done in order to increase the torsional strengths of girders.

The steel blocks were distributed to make the torsional vibrations in the test frame. The steel block positions were near the edges line of south side in each story, as shown in Fig.11. The weight of each story were as same as the first test. The distance between gravity centers and rigidity centers of each story was about 0.9m.

Test Methods

The test schedule of the second test frame was, that the Hachinohe E-W was used in the first excitation so as to compare the results with the first test, and Kobe JMA NS record of the Hyogo-ken Nanbu Earthquake was used in the next excitations. Assuming the after-shocks of, etc., the excitations of Kobe JMA NS were conducted three times. The shaking table input of Kobe JMA NS record of the Hyogo-ken Nanbu Earthquake was obtained, as follows.

In the case of shaking table simulations of earthquake motions, the time histories of the simulated earthquake motions must be kept in the limit performances of shaking tables. The most of strong earthquake motion would be recorded in accelerations. Thus, The integrals of accelerations have to be executed two times so as to get the displacements. Usually, the displacement time histories which were taken by the integrals, would diverge. Therefore, high pass filter would be used for cutting the long period components of source waves and getting the converged displacement time histories. FFT and digital filters would be applied for the purpose. However, in principle, the filter must not be used, because the filter would deform the original waves in excess.

The integrals of Kobe JMA NS acceleration gives a divergent displacement as same as other

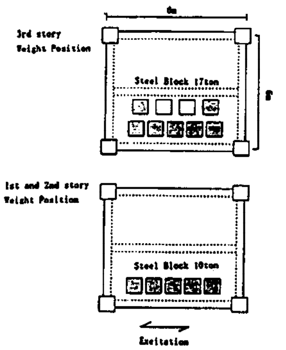

Fig. 11. Weight Blocks of 2nd Frame

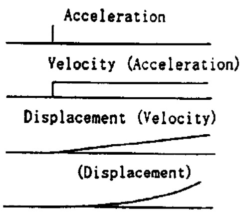

Fig. 12 Outline of Integration

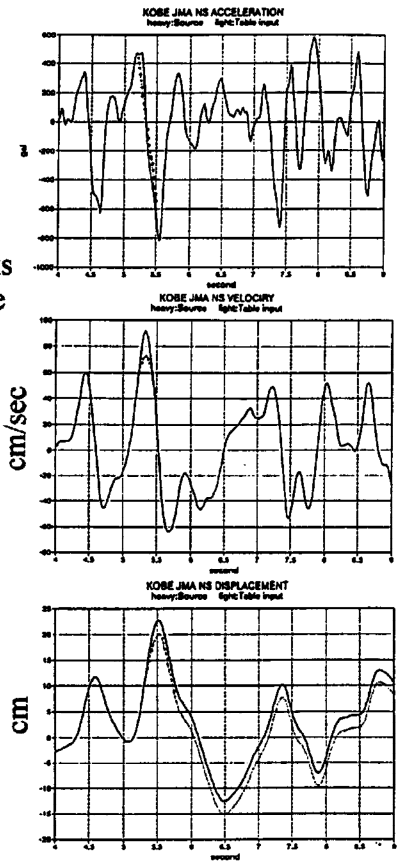

Fig. 15. Explain of Table Input

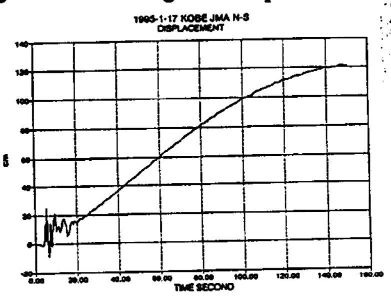

Fig. 13.. Integrated Disp. of Sourrce Accel.

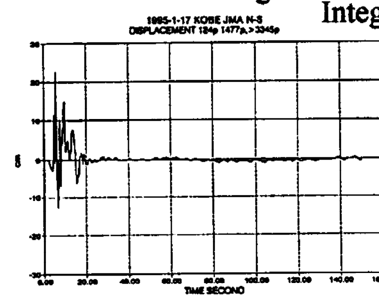

Fig. 14. Integrated Disp. of Corrected Accel.

acceleration records, as shown in Fig.13. However, the divergent portion of the integrated displacement looks to consist of the linear of quadratic curves. If the displacement would increase linear or quadratic, the velocity would make a zero shift or a linear curve, which will correspond to an impulse or an shift in the acceleration, as shown in Fig.12. The values of impulses and shifts are estimated from the gradients of divergent parts. The impulse and shift may be found as electric noises. Also, the impulse and shift may be given by the shock noise of drop stone and the inclines of base mats. The convergent displacements are obtained by adding the same opposite values of impulses or shifts at the corresponding time positions in acceleration records. The integrated displacements are to leave the offsets. The displacement offsets are to be natural. The displacement time history of Fig.14 was obtained by the presented methods. The offsets of displacement are found in EW and UD components, not in NS component.

Kobe JMA records are understood to be about 820gal, 90cm/sec and 36cm p-p in NS component, and about 613gal, 75cm/sec and 30cm p-p in EW component. The response spectra indicates that the NS component would be destructive. The one horizontal direction shaking table of NIED has maximum velocity of 75cm/sec and maximum displacement of 46cm p-p. The NIED shaking table can't reproduce the maximum velocity of Kobe JMA NS component. In Kobe JMA NS component, the position which is over 75cm/sec, is only one and shorter than 0.3 seconds. If the only velocity peak of 92cm/sec would be reduced under 75cm/sec, the less deformed shaking table input will be obtained. Thus, the modification of acceleration records shown in Fig.15, was attempted. Fortunately, the shaking table input which has the same maximum acceleration and similar displacement and maximum velocity of 72cm/sec was obtained. The input wave modification of the methods shows that the response spectra of original and modified accelerations are almost same. The differences are less than 5%, as shown in Fig.16 and 17.

Test Results

At the first large amplitude excitation of Hachinohe E-W, the reinforcement steel bars of the test frame were measured to yield, and small cracks were observed around the connections. From second excitation, the Kobe JMA NS record was applied. The potentio meter displacement records of total excitations in the x-direction, are shown in Fig.18. The maximum response 47cm of an excitation was the record of first Kobe

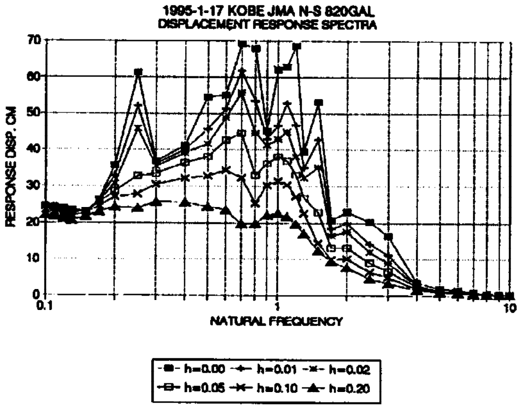

Fig. 16. Response Spectra of Source.

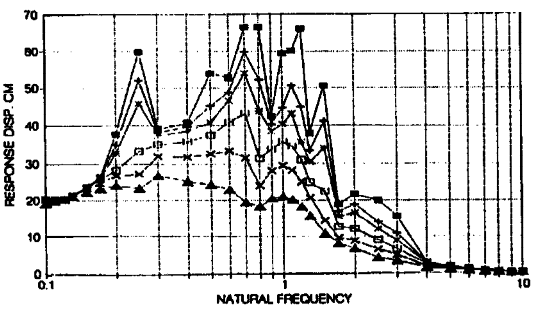

Fig. 17. Response Spectra of Correct.

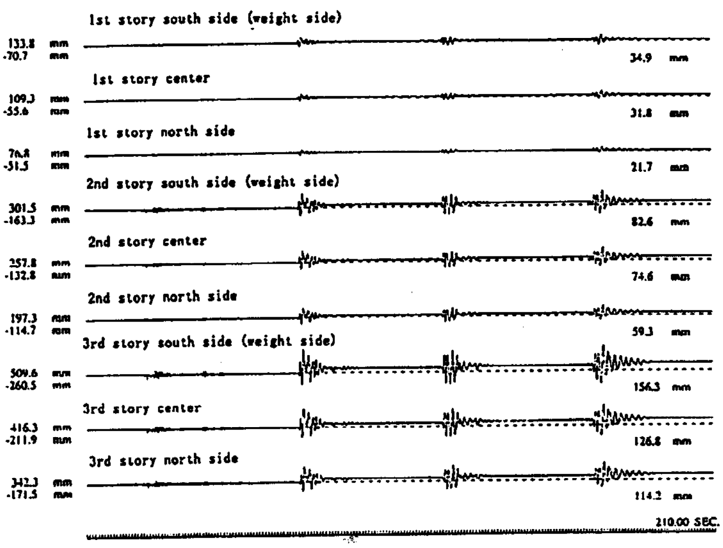

Fig. 18 2nd RC Frame Relative Displacements from Support Frame.

JMA NS at the steel block side, and left the offset 8.4cm. In next two excitations of Kobe JMA NS, the same amplitude inputs were adopted. The apparent natural frequencies went down by the reduction of stiffness, and shifted from the peak frequencies of response spectra, as a result, the response values decreases in 70% - 80%. By these excitations, the displacement offsets increased in the same direction. And at the end of test, the third story offset resulted in about 15cm on the steel block side, in about 11cm on the opposite side. The failure occurred in the x-direction girders near the connections, as same as the first test frame. Photo 6, 7, 8, 9 and 10 are the damage extentions of 3rd story girder connection at the first excitation of Kobe JMA NS, which corresponds to time points of Fig.19. The torsion damage of y-direction girders were small in comparison with the first test. The inertia force - story displacement hysteresis loops are shown in Fig.20. The changes of impulse responses are shown in Fig.21. The modal characteristics are described in Table 2.

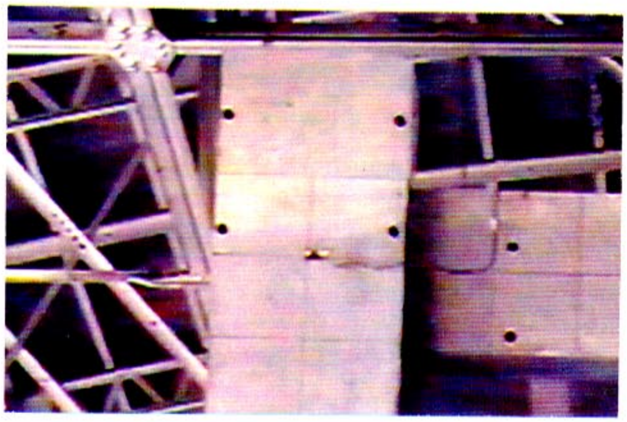

Photo 6. Deformation of 3rd Story at Time Point B of Fig. 19.

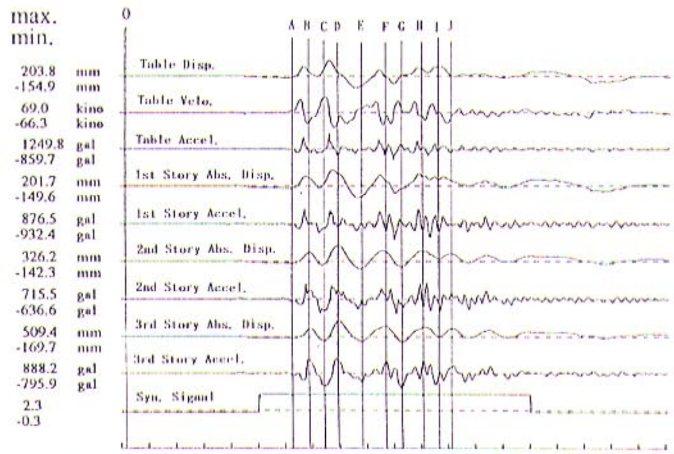

Fig. 19. 1st Kobe JMA NS Excitation Time Histories

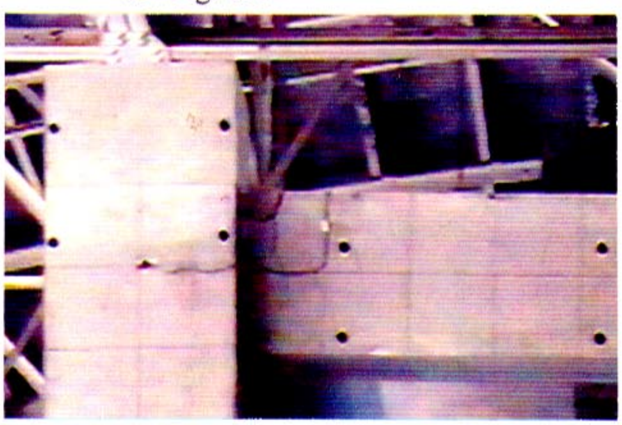

Photo 7. Deformation of 3rd Story at Time Point C of Fig. 19.

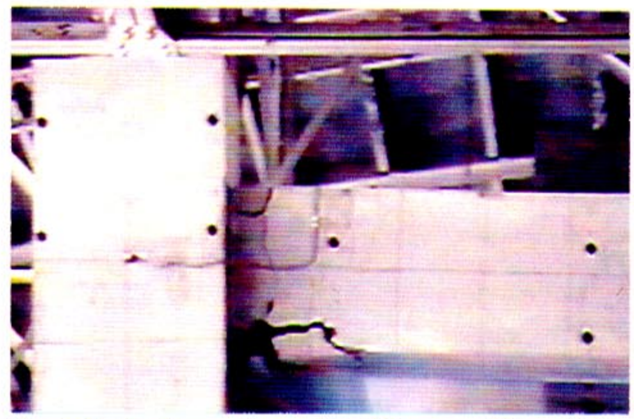

Photo 9. Deformation of 3rd Story at Time Point G of Fig. 19.

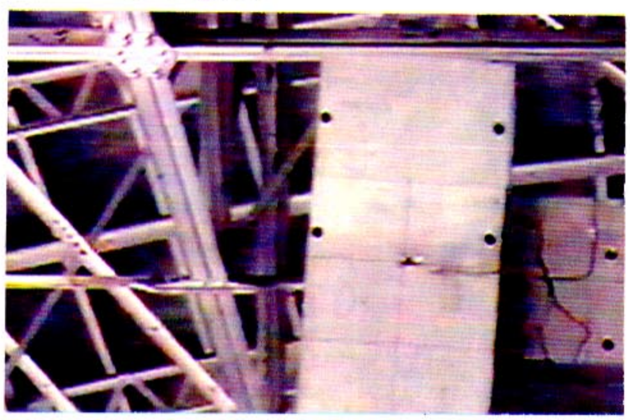

Photo 8. Deformation of 3rd Story at Time Point D of Fig. 19.

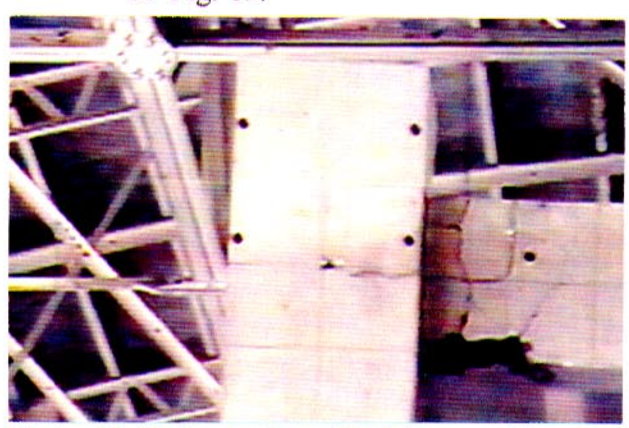

Photo 10. Deformation of 3rd Story at Time Point H of Fig. 19.

Discussions

The predicted responses of the second test frame are shown in Fig.22. The predicted maximum displacement was 38cm at the steel block side of the third story, and the offset was 15cm. The frame torsional responses which were assumed a little in the design, were observed very much in the test. The response calculations to the original Kobe JMA NS record, were diverged.

CONCLUSION

It was examined that the structures which were designed to make the girders yield before the columns, were very strong, and it would be difficult for the structures to collapse down.
The dampings increased with the progress of damages. The torsional structures gave the small damping in comparison with the general structures in the large deformation areas.
The damage of y-direction (normal to excitation direction) girders were examined.

The damages of Hobe earthquake were estimated to occur in 2 or 3 peak waves.

ACKNOWLEDGMENT

The strong earthquake motion data were provided by the efforts of Mr. Fujio Kusano; the member of Japan Meteorological Agency, Dr. Hisanobu Akagi; The member of NTT Facilities, Mr. Makoto Miyamoto; the member of NIED. The authors wish to express the appreciations to them.
The author appreciates the analysis advices of Professor Heki Shibata, Yokohama National University.

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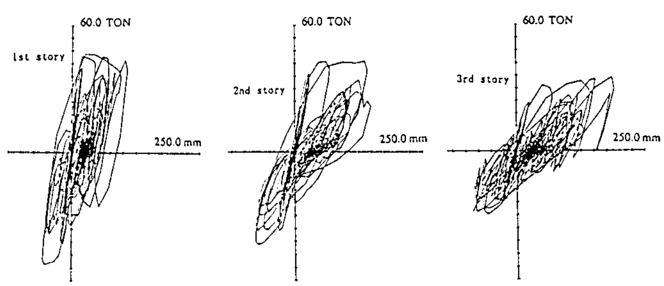

Fig. 20 Hysteresis Roops of 2nd Frame

Table 2 Rough Modal Estimation of 2nd RC Test Frame

	1st Mode		2nd Mode		3rd Mode	
	Frequency	Damping	Frequency	Damping	Frequncy	Damping
No Damage	2.55Hz	1.60%	8.49Hz	2.12%	15.2Hz	3.57%
After Hachinohe	1.65Hz	6% - 12%	6.1Hz	2.5%-5%	13Hz	3%-6%
After 1st Kobe	0.98Hz	12%	4Hz	2% -3%	9.2Hz	3%
After 2nd Kobe	0.86Hz	11% - 14%	3.5Hz	2%-3.5%	8Hz	2.5%-3%

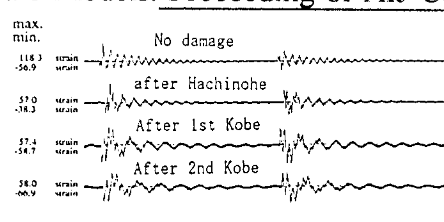

Fig. 21 Impulse Responses of 2nd Frame

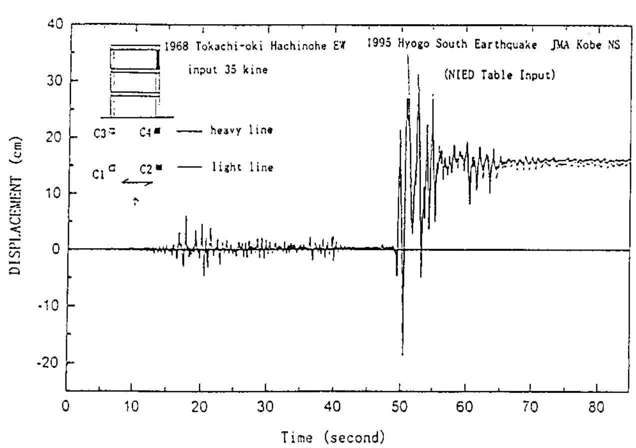

Fig. 22 Calculated Response Prediction