"Facilities for Observation and Simulation of Earthquake Motion" and Outline of Studies

by

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1. Introduction

Eighteen years have gone by since ERS started out in 1967. During this time the interest of society in general regarding earthquake engineering has become greatly intensified, and research in this field has shown extreme progress. However, how to evoluate the earthquake resistance of a structure, how to rationally determine the earthquake resistance to be imparted, and further, how to realize these in concerete terms in structures are problems that are not easily dealt with. ERS has been engaged in observations of earthquake motions of ground and bedrock, earthquake observations and vibration experiments of actual structures, earthquake damage estigations, earthquake response analyses, model experiment analyses, dynamic failure experiments of actual structures or models, earthquake resistance evaluations based on these research results, damage predictions, establishment of earthquake countermeasures, etc., for comprehensive research on earthquake engeneering.

In such case, what constitutes a fundamental factor at all times is the ultimate dynamic strength of a structure during earthquakes, and it may be said that efforts have been continued for a long time to explain this strength. The large-sized shaking table completed in 1967 (length 10 m, width 2 m and height 4 m of the sand box, maximum load 170 ton), and the dynamic structure destruction experiment facility which went into operation from 1973 were installed for this purpose, while the "Facilities for Observation and Simulation of Earthquake Motion" described here have the objective of filling in an area which had been a blank in previous research through "Research on Response and Destruction Mechanism of the Ground-structure System due to Natural Earthquakes." These facilities, which were installed at the Chiba Laboratory from 1981 to 1982, serve to indicate the main direction of research activities of the ERS Group. With the completion of these facilities, a new step forward has been taken in research on earthquake resistance of structures, and it is firmly believed that these facilities will contribute to furtherance of research on various problems in earthquake engineering.

2. Outline of Facilities

At these facilities foundation conditions are made similar to cases of actual structures, structural models are fabricated and subjected to damage or failure through natural earthquakes, and detailed studies are carried out. Further, tests are performed using shaking tables or actuators. The results of these all are comprehensively arranged to grasp the failure mechanisms of the models due to earthquake from a dynamic point of view, and to obtain fundamental knowledge about the damage or failures of structures caused by earthquakes.

These facilities, when seen from the aspects of research techniques, may be broadly divided into the two categories of facilities for research by earthquake observations and facilities for reaearch by experiments, and are the following when classified by function:

Facilities for Research by Earthquake Observations

A. Observation system for earthquake ground motions

B. Earthquake response observation system using weak models

B-1. RC-frame weak model

B-2. Steel-frame weak model

B-3. Response observation tower

Facilities for Research by Experiments

C. Two-dimensional shaking table

D. Two-way reaction wall and reaction floor

The facilities from A to D comprise a single coherent system, but of course are still inadequate and the principle is for appropriate facilities to be added to existing facilities as necessary to function together as one. The facilities of C and D are used in common and possess indepenent natures as facilities, while A and B are indivisible from the content of research, and it may be said that the features of these analysis facilities are represented. Therefore, the facilities and research contents will be described together in outline below.

3. Outlines of Facilities and Research Contens

It was during the 1983 fiscal year that roughly all of the facilities had finally come into operation. A number of earthquakes have been experienced during the close to two years since then. However, luckily or not, earthquakes of the scales (nearly VII in MM scale) estimated in the earthquake-resistant design of weak models have not occurred. Details of the facilities and contents of research are available in papers in this bulletin, past issues of Seisan Kenkyu[1),2)], and in the pamphlet[3)] prepared by this research group. Here, outlines of the facilities and contents of the research being conducted will be given from an overall point of view.

A. Observation System for Earthquake Ground Motion

The features of this facility are that 1) earthquake motions input to the weak models are accurately grasped, 2) earthquake motions of ground are grasped in detail by a dense seismometer array, and 3) displacement and strain of the ground and deformations of pipes buried in the ground are measured. At the same time, observations are made at apexes of rough triangular shape having length of one side approximately 110 m including the location of this facility. The dense seismometer array observation system has twenty-nine three-component accelerometers embedded in ground of approximately 21 x 21 m and depth of 40 m, while the underground pipes are one each of a steel pipe and a ductile cast iron pipe 15 cm in diameter and 120 m in length. Observations were started from 1982 and earthquakes of intensities IV and III have been recorded up to now. The synthetic horizontal-direction maximum acceleration obtained at the ground surface was 66 gal, and the maximum strain of ground 15.5×10^{-6}, both having been observed in an earthquake of magnitude 6.0 and epicentral distance of 35 km. That the strain of the ground calculated by the three-dimensional finite element method upon displacements computed from acceleration records shows good agreement with the strain of ground directly observed, that the ground strain waveform corresponds with the velocity and displacement waveform of the ground, and that the ground strain waveform and the axial strain waveforms of the pipelines show good agreement geometrically have been revealed. (Katayama Laboratory)

B. Earthquake Response Observation System Using Weak Models

Weak structural models which would fail at upper IV or lower V on the JMA scale (about VII on the MM scale) are built at the ground surface and fail or are damaged in a natural earthquake, the processes being measured by strain meters, accelerometers and displacement meters, and also aptically recorded by cameras and video cameras in attempting to clarity the failure mechanisms from a dynamic standpoint. The weak structural models used are of two kind: reinforced concrete and steel structure.

i) Each reinforced concrete model is of rigid frame construction 5 m in height and having 5 stories, each story with four columns 1 m in height and a floor slab 3.5 x 3.5 m. Two models are provided differing in collapse type, one being designed to cause yield hinges in columns and the other in the beams. According to the results of vibration tests, the fundamental vibration periods are 0.35 to 0.36 sec and 0.28 to 0.29sec, respectively. The maximum accelerations observed up to now are 32 gal at the first story and 166 gal at the top floor. Hair cracks thought to be due to bending deformation of upper-story columns have already appeared on the column-yielding type model and the natural frequency has declined. The results obtained in a response analysis case assuming Rayleigh-type damping are that the muximum acceleration occurring in the model agrees approximately with the observed value, but with regard to maximum inter-story displacement the analytical value is on the smaller side. (Okada Laboratory)

ii) Steel models are of two kinds: steel model I (clear height of column 2 m, 3 stories) of rigid frame having a reinforced concrete slab of 5.7 x 5.7 x (thickness) 0.2 m and four H-steel columns for each story, and steel model II (clear height of column 1 m, 3 stories) of composite construction having a reinforced concrete slab of 4.4 x 4.4 x (thickness) 0.3 m and diagonal braces and rigid frame. The former was designed to be amply within the elastic range against earthquake input of maximum acceleration of 80 gal, while the latter is designed for tensile yield and buckling to occur in the diagonal braces. Observations have been carried out since March 1983. The maximum accelerations recorded with model I have been 30.5 gal at the foundation, and 108 gal at the top floor. For model II, earthquake response experiments of a computer-actuator on-line system using actuators are being carried out to investigate yielding of diagonal braces. (Takanashi Laboratory)

iii) Response Observation Tower (Tower Structure Model)
This model has been built to observe the interaction between ground and structure during earthquake, and for the purpose of installing apparatus for optically recording the behaviors and failure conditions of the weak models during earthquake. It is of reinforced concrete construction with 3 stories to a height 10 m above ground and 1 story to a depth 2.5 m underground, having a diameter of 5 m. Accelerometers are installed on the slabs of the individual floors, while 25 direct-pressure type earth pressure gages are installed at the underground portion, thirteen at the bottom slab and twelve at side walls. Observations were started from August 1983, while excitation experiments were carried out at the time of completion of the underground portion and after completion of the whole. It has been

disclosed by acceleration and earth pressure records that the tower shows rocking vibration during earthquake. Optical recording apparatus comprise cameras and video cameras which are installed on the second floor. These are set so that they will be automatically activated when a given acceleration level is exceeded. Further, a three-dimensional earthquake-isolation device is installed on the third floor. (Hangai, Katayama,and Tatsuoka Laboratories)

C. Two-dimensional Shaking Table

This shaking table is capable of vibrating independently with any waveform simultaneously in the two directions of horizontal and vertical, and is driven by an electro-hydraulic servo system. The principal specifications are as follows:

Table dimensions:	3.0 x 3.0 m
Maximum load:	7.0 ton
Maximum amplitude:	Horizontal ±150 mm
	Vertical ±60 mm
Maximum acceleration:	Horizontal ±3G (no load)
	±2G (7-ton load)
	Vertical ±1.5G (no load)
	±1.1G (7-ton Load)
Frequency range:	0 to 50 Hz
Controlled variables:	Acceleration, velocity, displacement

This shaking table is of medium scale, but has considerable exciting power and is being used for studies of response characteristics of the three-dimensional earthquake-isolation device, sloshing of water tanks, vibration failure experiments of three-dimensional fill dam models, vibration failure experiments of slopes, stability of operation of equipment by people during strong earthquakes, etc. The outlines of two of these studies are given below.

i) The three-dimensional earthquake-isolation device has been developed and is being studied to secure stability during earthquake of precision equipment. This device is of a construction to prevent rotation and rocking through independent straight-line motions in three directions, vertical and horizontal. Viscous damping and frictional damping are used in combination for absorption of vibration. The test device has been installed on the third floor of the previously-mentioned response observation tower and responses to actual earthquakes are being observed. According to the observation results, reductions to one-fourth to one-fifth in horizontal directions and to about 60 percent in the vertical direction have been recognized. (Fujita Laboratory)

ii) In vibration failure tests on three-dimensional fill dams, attention has been paid especially to the influence of excitation in the vertical direction on slope failure of fill dams. Sand models constructed on original ground simulating the foundation of a dam were vibrated in one direction or two directions and the failure conditions were investigated. As a result, it was found that the influence of cohesion on failure properties is great, that the effect on failure of excitation in the vertical direction is roughly one-half compared with excitation in the horizontal direction, and that even though there is a phase differential in excitations in two directions of horizontal and vertical, the effect on failure is small. (Tamura Laboratory)

D. Two-Way Reaction Wall and ReactionFloor

The reaction wall set in an L-shape facilitates application of load simultaneously from two directions. The feature of this wall is that the two surfaces, outer and inner, can be used, and it is possible for experiments to be made on a specimen on the test floor at the inside and on a specimen on the ground in the outside.

There are five electro-hydraulic servo mechanism actuators provided and it is possoble for various loading tests and earthquake response experiments to be made by a computer-actuator on-line system. The outline specifications of an actuator are as given below.

Maximum load:	Tensile 15 ton
	Compressive 20 ton
Maximum stroke:	$\pm$30 cm
Frequency range:	0 to 1 Hz
Controlled variables:	Load, stroke

Failure tests of weak models were performed using this facility.

4. Outline of Other Research Activities

The research activities of ERS have been described in outline centering on the "Facilities for Observation and Simulation of Earthquake Motion," but there is much other research also being done. Besides model experiments of ground, slopes, bridge pier foundations, bridge piers, fill dams, etc. by large shaking table (Tamura and Katayama Laboratories), and research on dynamic strengths of reinforced concrete structures, steel frame structures, shell structures, high-pressure steel pipes with dynamic structure destruction experiment facility (Okada, Takanasi, Shibata, and Hangai Laboratories), earthquake observations are being carried out on a chemical plant model. This is mainly for study of the earthquake response characteristics of water tanks, and observations have been made since 1973. The models at present are the trio of two thin-wall circular steel water tanks (volumes 20 m^3 and 54 m^3, respectively) and a box-shaped tank (volume 60 m^3) made of prefabricated FRP panels, fluctuation of responses, the input-response magnification and characteristics of sloshing are being studied. The maximum acceleration of the foundation observed up to now is 90.2 gal. Partial buckling has been seen in one of the water tanks (Shibata Laboratory). Further, research is being conducted on soil testing methods, dynamic stabilities of various soil materials, and the reinforcing effects on soil embankments and slopes by nonwoven fabric in connection with stability of ground during earthquake and earthquake-resisting strength of soil structures (Tatsuoka Laboratory). Various studies are also being made using a small-size shaking table, but explanations of these will be omitted here.

Finally, the research topics on which ERS members have worked, if ventured to be classified, are as shown below although of course there are items which are related to a plural number of topics.

- Earthquake Motion-Related Topics
  - Earthquake motion observation, statistical analyses of records for various types of ground
  - Extrema analyses of earthquake responses of structures
  - Design earthquake motion, earthquake risk analysis
- Earthquake Observations and Vibration Experiments of Structures
  - Actual structures (dam, tunnel, building, bridge, pipeline)
  - Models (storage tank model, chemical plant model)
- Experimental Research by Model
  - Dynamic characteristics of dams, underground structures, pipelines,

piles, rigid foundations, earthquake-isolation devices
Failure properties of fill dams, slopes, reinforced concrete buildings, steel frame structures, pedestrian overbridges, shells, etc.

Topics Related to Properties of Soil
Soil testing methods, dynamic characteristics of soil, stability of soil embankments

Studies by Analytical Techniques
Development of "rigid body-spring model" and analyses of static and dynamic stabilities thereby
Propagation of tsunami
Dynamic stability of shell structure

Earthquake Damage Surveys
Koyna Earthquake (India, 1967), 1968 Tokachi-oki Earthquake, San Fernando Earthquake (U.S.A.,1971), 1974 Izu Hanto-oki Earthquake, 1978 Izu-Oshima Kinkai Earthquake, 1978 Miyagiken-oki Earthquake, 1983 Nihonkai Chubu Earthquake, 1984 Nagano-ken Seibu Earthquake, etc.
Reconnaissances of Haicheng Earthquake (China, 1975) and Tangshan Earthquake (China, 1976) sites in 1981.

Earthquake Damage Analysis
Analyses of earthquake damage including old earthquakes, spreading of fire, evacuation processes

Evaluation of Earthquake Resistances of Actual Structures and Reinforcement and Repairs
Evaluation of seismic performance of reinforced concrete buildings, and steel frame buildings, and countermeasures
Earthquake resistances of functions of lifelines

References

1) "SEISAN-KENKYU", Vol.35, No. 9, 1983
2) "SEISAN-KENKYU", Vol.36, No. 9, 1984
3) "Facilities for Observation and Simulation of Earthquake Motion", Pumphlet issued by ERS, 1983