PROJECT ON 3-D FULL-SCALE EARTHQUAKE TESTING FACILITY (THE FOURTH REPORT)

by

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ABSTRACT

Considering the lessons learnt from Hanshin-Awaji Earthquake, NIED plan to construct "E-Defense", which will be possible to test real-sized structures to collapse and thus will facilitate to calibrate and validate our earthquake resistant design capabilities. The basic performance of E-Defense are maximum lording capacity 1,200 tons, maximum velocity 200 cm/s and maximum displacement +/- 1 m for horizontal excitation and maximum velocity 70 cm/s, maximum displacement +/- 50 cm for vertical excitation to realize destructive ground motion. The construction work of E-Defense has been begun at early 2000, and will be completed at the beginning of 2005. We are conducting the construction works of the facility at the Miki-city, and the manufacturing of actuators, oil-pressure supply system and other major parts of shaking table by MHI. E-Defense is the very large scale and high performance testing facility in the world. E-Defense should be operated the international common use. For the international collaboration and the dissemination of research results, E-Defense Network ("ED-Net") will also construct until the completion of "E-Defense". However, concerning the utilization of E-Defense, there are many subjects, which NIED should make clear before the operation of the facility becomes possible. In order to solve these subjects, NIED investigates actively the practical research themes for using E-Defense, which are the test and analysis of reinforced concrete structures, soil-pile-structure systems and conventional wooden structures. We hope that E-Defense and ED-Net will be situated to one of the cooperative research organization for the earthquake disaster mitigation in the world.

KEY WORDS:

Failure mechanism of structures
Full Scale Testing
International Common Use
3-D Shaking Table
Network of Earthquake Research

1. INTRODUCTION

The Hanshin-Awaji Earthquake (Hyogoken-Nanbu Earthquake, January 17, 1995) clearly demonstrated that the occurrence of very strong ground motion in the area near to the seismic fault is capable of causing severe structural damage beyond general estimation. The destructive earthquake occurred in the worldwide in the recent years, such as Northridge earthquake (1994), Umbria-Marche earthquake (1997), Kocaeli earthquake (1999), Ji-ji earthquake (1999), El Salvador earthquake (2000), Gujarat earthquake (2001) and so on.

In order to reduce the hazards associated with large earthquakes, it is essential to improve the reliability of earthquake resistance estimations and

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reinforcement methods in the construction of urban and major structures. For this purpose, failure mechanisms and collapse processes of various kinds of full-scale structures must be investigated. Many types of experimental apparatus have been used for such investigations, and some of them have as large a size as possible to alleviate any difficulties arising from limitation of the model. Considering the lessons learnt from recent earthquake disasters, the National Research Institute for Earth Science and Disaster Prevention (NIED) planned to build a new three-dimensional, full-scale, earthquake testing facility, which can carry large-size soil and structure models and reproduce the processes of structural failure. This facility is expected to become a powerful tool for international collaboration in earthquake engineering research. It also requires international cooperation to successfully complete the facility and to use it effectively for engineering purposes.

Following the technical developments and surveys in earthquake engineering and related fields, the NIED began the design and construction of this new facility in the Japanese fiscal year of 1998.

We already reported three times for the Joint Meeting of Wind and Seismic Effects, UJNR. This paper is the progress report of our construction project of E-Defense and the research projects for using E-Defense.

2. E-DEFENSE (3-D FULL-SCALE EARTHQUAKE TESTING FACILITY)

Based on the lessons learnt from Hanshin-Awaji earthquake, the Minister of State for Science and Technology was inquired to the Council for Aeronautics, Electronics and Other Advanced Technology, which is the one inquire organization of the Minister, for the discussion of the effective arrangement of research bases for earthquake disaster mitigation at March 29,1996. The Council was reported to the Minister at September 3, 1997.

The report was clearly pointed out the arrangement of large-scale three-dimensional earthquake simulator facility as the core facility of research bases for earthquake disaster mitigation.

NIED initiated the project on the large-scale three-dimensional earthquake simulator facility just after the occurrence of Hanshin-Awaji earthquake. The research and development for core technology for this facility (E-Defense) was started on 1995. The fundamental concepts of this project based on the report by the council. The E-Defense constructs as the core facility of the research bases for earthquake disaster mitigation.

The importance of promoting the strengthening and rationalization of earthquake-proof structural design is just one of the lessons from Hanshin-Awaji earthquake. Because earthquake vibrations involve three-dimensional movement, it is necessary to set up a three-dimensional earthquake simulator facility to accurately reproduce earthquake motions. To perform tests on real-size objects or large-scale models of test structures and foundations, it is desirable to have the large-scale three-dimensional shaking table. If large-scale 3-dimensional shaking table is available, tests could be performed to shed new light on the mechanism of dynamic failure using real-size structures. If a stage reached whereby design based on such discovery can be performed, this will contribute immensely to reducing earthquake disaster.

The main specification of E-Defense is shown in Table 1. The actuator performance for horizontal and vertical axes is shown in Fig. 1.

Table 1. Main Specification of E-Defense

Payload	12MN(1200tonf)	
Size	20m×15m	
Driving Type	Accumulator Charge Electro-Hydraulic Servo Control	
Shaking Direction	X･Y - Horizontal	Z-Vertical
Maximum Acceleration (at Maximum Loading)	>900cm/s^2	>1,500cm/s^2
Maximum Velocity	200cm/s	70cm/s
Maximum Displacement	±100cm	±50cm
Maximum Allowable Moment	Overturning Momnet	Yawing Moment
	150MN･m	40MN･m

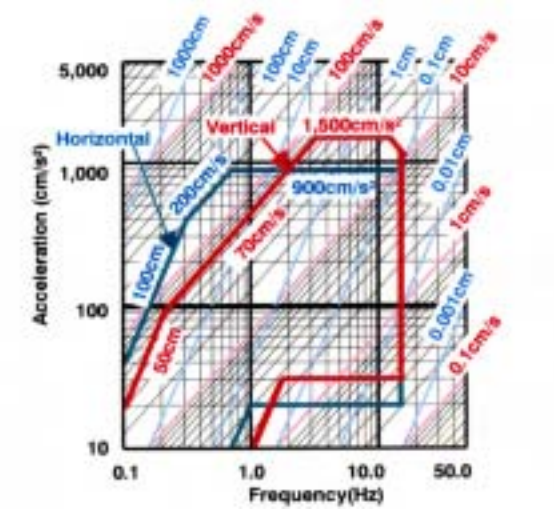

Fig. 1. Limit Performance of E-Defense

3. CONSTRUCTION AND MANUFACTURING OF E-DEFENSE

NIED have commenced the development work of shaking mechanism with very large size of hydraulic actuators in fiscal year 1995 and completed performance tests successfully in 1998. Following the above technical development and surveys in earthquake engineering and related fields, NIED have began the design and construction of E-Defense in 1998.

The construction work has been begun in 1998 and will be completed at the beginning of 2005. The new facility will start to operate at the 10 years after the Hanshin-Awaji earthquake.

The E-Defense is constructed in “Miki Earthquake Disaster Memorial Park (tentative name)”, which is being constructed in Miki city, on the north of Kobe city. The construction of shaking table foundation was started at the construction site in January 2000.

The manufacturing of testing equipments, such as actuators, 3-dimensional link joint, oil power pump unit, accumulator unit and so on, were started in 1998.

We will construct several buildings, such as Experimental Building, Operation Building, Hydraulic Unit Building, Preparation Building and so on. The reaction foundation (shaking table foundation) has weight of about 2 GN (200,000 tonf) and set to the bedrock directly.

Following the construction of shaking table foundation, we construct the experimental building and other buildings. The experimental building is 60 m X 85 m in plan and 45 m height and has tow sets of 400 tons crane. The construction of buildings was completed at the end of June, 2003. Fig. 2 is the aerial photo of buildings.

Fig. 2 Aerial Photo of Buildings

The manufacturing of the testing equipment, such as actuators, 3-dimensional link joint, oil power pump unit, accumulator unit and so on, were also started in 1998. By the condition of construction site, where is located at the hill area, the weight and length of manufactured unit are limited some size by the condition of transportation. The set-up working was done at the site. The installation of piping system, actuators, pumping units and accumulator units were started in 2000. Fig. 3 is shown the recent condition of installation

of shaking table equipments.

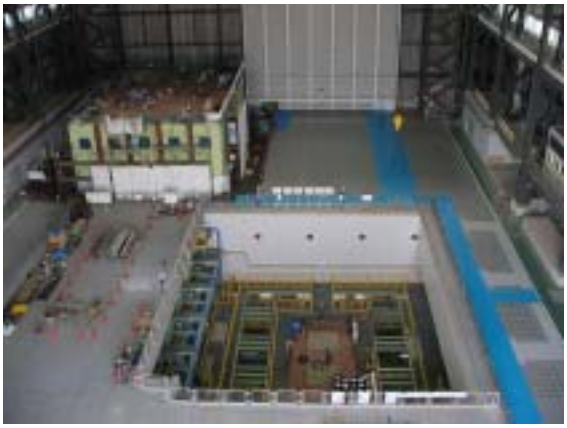

Fig. 3. Recent Condition of Installation of Shaking Table Equipments

4. MANAGEMENT MECHANIZM

For the management of E-Defense, we are thinking about following management mechanism. We will establish the Hyogo branch (tentative name) for the operation of facility and conducting the research works. But, by the limitation of number of regular staffs, we will establish the Support Company, such as outsourcing mechanism. This Support Company is functioned to conduct the smoothly operation of facility cooperate with the staffs of Hyogo branch.
We established one council and one committee for more effective management and operation of facility.
The Management Council is consisted by the representatives from government, academic and private sectors. Dr. S. Ito, President, Research Institute for Urban Disaster Mitigation, is chaired the Council. 18 members were nominated. This council will discuss the medium and long-term management plan and more effective management of facility.
The Utilization Committee is consisted by the active researchers from various fields of earthquake engineering. Prof. K. Kawashima, Tokyo Institute of Technology is chaired this committee. 19 members were nominated. This committee will discuss the research plan and research results by using this facility.
Fig. 4 shows the Management Mechanism.

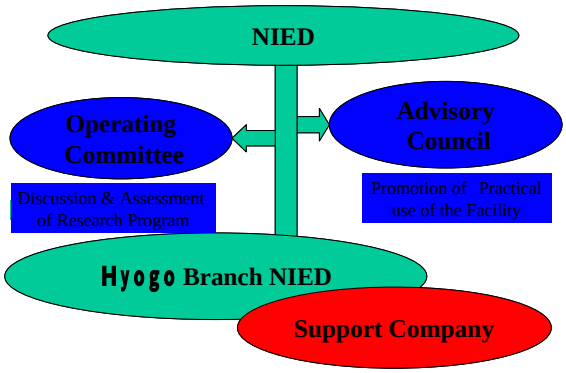

Fig. 4 Management Mechanism

5. EARTHQUAKE ENGINEERING COLLABORATION

E-Defense should be operated the international common use. To ensure the international common use and disseminate the test results, we will construct and install the E-Defense Network (ED-Net).
The ED-Net has tow major functions: The one is the connection tool between E-Defense in Miki and the Super Computer in Tsukuba. The other one is the connection tool between NIED and the other organization, such as research institute, university, private sector and so on. This function is not only limited to domestic, but also international manner.
We will install the tele-observation and tele-discussion capabilities, but not install the tele-operation function. Because, conducting of shaking table test, especially failure test, has very delicate and dangerous factors. Therefore, the operation of shaking table will limit by the shaking table administrator, who is the specialist of operation. Figure 7 shows the schematic image of ED-Net.

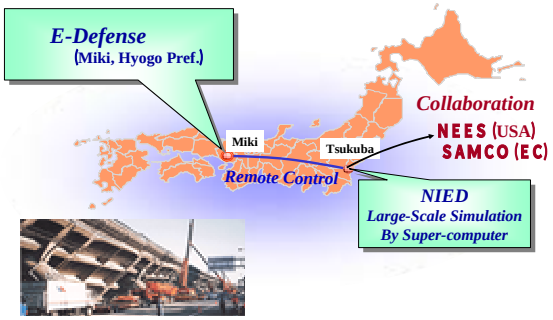

Fig. 7 Schematic Image of ED-Net

6. RESRAHC PROJECTS BY USING E-Defense

For considering how to use E-Defense most effectively, there are many research subjects, which NIED should make clear before the operation of the facility becomes possible. In order to contribute in improving the seismic performance and design of structures by utilizing E-Defense, NIED conducted a new research project, tilted as “Significant improvement of seismic performance of structures” in a special project for earthquake disaster mitigation in urban areas. The project is the part of “Special project for Earthquake Disaster Mitigation in Urban Areas,” which is sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and has been started from September 2002.

Currently, we are heavily involved in preparation of the practical plans for full-scale shaking table test models of reinforced concrete structures, soil-pile-structure systems and wooden structures.

The duration of this project is for about five years, which has been started from September, 2002 and will end in March, 2007. The first phase of the total period is the preparation time to provide the requirements for the experiment and research related to the utilization of E-Defense. The second phase is the period to perform experiments and research using E-Defense to improve the seismic performance and design of structures.

6.1 Research on RC Structures

The purpose of tests of full-scale reinforced concrete (RC) structures using E-Defense is to investigate a three-dimensional dynamic response and failure mechanism of real structures, and to obtain the data for establishment of 3-D numerical simulation techniques, which can evaluate and predict the dynamic behavior of a structure with sufficient accuracy. Further, the results can directly lead to the developments of an advanced method for evaluation of the earthquake-resisting capacity of RC structure, an advanced earthquake-resistant design of a structure and the new structure systems which aim at improvement of seismic performance and the proposal of specific methods for seismic examination and anti-earthquake reinforcement of the existing structures.

As preliminary research on full-scale RC structures leading to collapse using E-Defense, the dynamic shaking table tests of RC structure in a 1/3 scale model are being conducted by using the existing 1-D and 3-D shaking tables. The results are being studied as the basic data to prepare the full-scale RC structure test plans using E-Defense and to accumulate experiment technology. The data are also being used for studies on dynamic behavior and failure mechanisms of RC structures. Fig. 8 shows a shaking table test for RC wall-frame structure, which was conducted in March, 2003 in NIED.

Fig. 8 Test Model of RC Structure

Fig. 9 shows the plan for the model shake table test to be used in E-Defense. The designed RC frame consists of 2x3 spans and the space between the columns in both directions will be 5m. The frame will also consist of six floors and the total height of the structure will reach to 18 m. The total weight of the model structure shown in Figure 3 will reach to about 1000 tonf.

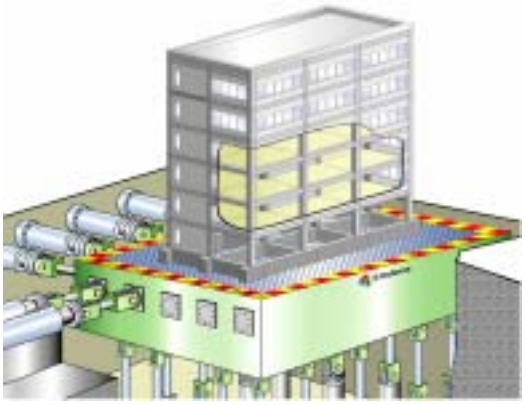

Fig. 9 Overall Plan of Full-Scale RC Structure

6.2 Research on Soil-Pile-Structure Systems

The purpose of tests of soil-pile-structure system using an ultra large cylindrical laminar box and a long rigid container in E-Defense is to investigate a three-dimensional dynamic response and failure mechanism of soil-foundation system, and to obtain the data for development of 3-D numerical simulation method which can evaluate and predict the dynamic response of soil-foundation system. Further, the obtained results are contributed to evaluation and improvement of the existing earthquake-resistant design, and development of new technologies and new methods for improving the seismic performance of soil-foundation systems.

Fig. 10 illustrates an overall image of the first soil-pile-structure interaction shaking table test using an ultra large cylindrical laminar box on E-Defense. In this test, the behavior of the liquefied sand as well as the pile-supported structure on the consequences of the extensive liquefaction will be examined by means of a full-scale model.

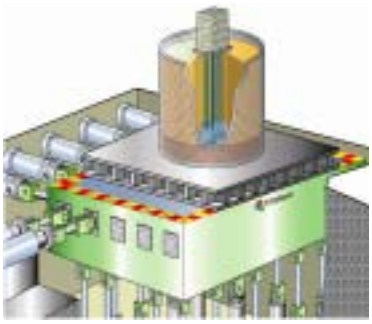

Fig. 10 Overall Image of Large Cylindrical Laminar Box

Fig. 11 shows the schematic illustration of the shaking table with the new long rigid container with quay wall sheet pile, group pile foundation and super-structure which are planed to extensive lateral deformation of the liquefied soil. In this test, the behavior of the liquefied sand as well as the foundation system due to lateral spread of the liquefied sand will be examined by means of a full-scale model.

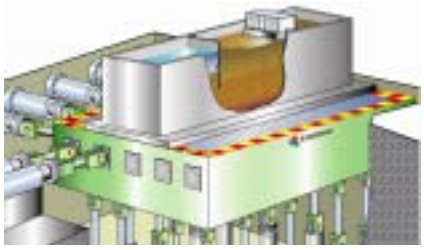

Fig. 11 Overall Image of Long Rigid Container

6.3 Research on Conventional Wooden Structures

The tests of full-scale wooden structures using E-Defense have two major purposes. The one is to investigate a three-dimensional dynamic behavior and evaluation of the earthquake-resisting capacity of the existing conventional wooden structures during major earthquakes, such as Hanshin-Awaji Earthquake, January 17, 1995.

The other one is to develop an advanced earthquake-resistance design and anti-earthquake reinforcement of conventional wooden structures.
As preliminary research, 3-D middle-scale shaking table tests are being conducted on three models; i.e., the wall element unit extracted from an existing conventional wooden structure, full-scale frame model designed by the standard used before the revision of earthquake-resistant standard in 1981, and a wooden frame model with tradition method. These test results serve as the basic data for the full-scale shake table test plans on E-Defense and establishment of the numerical simulation system for dynamic behavior and failure mechanisms of conventional wooden structures. A preliminary shaking table test on 3-D is shown in Fig. 12. Fig. 13 is shown the Image of full-scale test model for wooden houses. We will construct two houses with 2m thick ground on the shaking table. The one house is constructed by the conventional way, the other one is constructed by conventional way with reinforcing.

Fig. 12 Preliminary 3-D Shaking Table Test

Fig. 13 Image of Wooden Structure Test

7. CONCLUDING REMARKS

Based on the lessons learnt from Hanshin-Awaji earthquake, we, NIED, need more research to understand the failure mechanism of different kind of structures during earthquake. For this research needs, we began the construction project of E-Defense (3-D Full-Scale Earthquake Testing Facility) and ED-Net (E-Defense Network). After completion, these tools will be perfectly opened to international use.
We strongly hope that these tools are contributed to the dramatic progress of the earthquake engineering research, especially the understanding of structural failure mechanism, the progress of the earthquake resistant design of structures and the evaluation/reevaluation of structural performance during earthquake, by the coordination and collaboration research works in the worldwide bases.

ACKOWLEGEMNTS

For the progress of Project E-Defense, NIED established the Technical Advisory Committee (Chairman: Prof. H. Sato, University of Chuo, Committee members: 10 Professors). The authors acknowledge the Committee members for the support and kindly advice.

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