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E-DEFENSE AND ITS HYDRAULIC POWER SUPPLY SYSTEM

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ABSTRACT

The Hanshin-Awaji Earthquake (January 17,1995) clearly demonstrated that the occurrence of very strong ground motion in the area near to the seismic faults is capable of causing severe structural damage beyond general estimation. It has emphasized the importance of earthquake engineering research into why and how structures collapse in real earthquake conditions. Considering the lessons learnt from recent earthquake disasters, National Research Institute for Earth Science and Disaster prevention (NIED) plan to construct the 3-D Full-Scale Earthquake Testing Facility (E-Defense is the nickname of this facility), which will be able to simulate the process of destruction of structures under the condition of real strong earthquake motions. The basic performances of E-Defense are maximum lording capacity 1,200 tons, maximum velocity 200 cm/s and maximum displacement 2 m p-p for two horizontal excitations and maximum velocity 70 cm/s, maximum displacement 1 m p-p for vertical excitation to realize destructive ground motion. The driving energies are mainly produced by the hydraulic power system, which is consisted 10 horizontal actuators, 14 vertical actuators, 20 main-accumulator units, 4 gas-engine units, oil supply system (include piping system) and others. The construction has begun at early 2000, five year after the Hanshin-Awaji Earthquake and was completed at the beginning 2005, ten year after that Earthquake.

KEY WORDS

Hanshin-Awaji Earthquake, 3-D Shaking Table, Structural Failure Mechanism
Hydraulic Power Supply System, Experimental Research

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.

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

The construction of facility has begun at early 2000, five year after the Hanshin-Awaji Earthquake and was completed at the beginning 2005, ten year after that Earthquake.

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 or research bases for earthquake disaster mitigation at March 29, 1996. The Council was reported to the Minister at September 3, 1997.

The report 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 were based on the report by the Council.

The E-Defense was constructed as the core facility of the research bases for earthquake disaster mitigation. Therefore, we need to clear the positions of the E-Defense.

1) Position of earthquake simulator for the main element of the “Time-Space Domain Simulation System for Earthquake Disaster”.
2) Position of the clearly understanding of failure mechanism of structures.
3) Position of response mechanism for the request from major subject of earthquake engineering.

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 disasters.

The main specification of E-Defense is shown in Table 1. The limit performance for horizontal and vertical axes is shown in Fig. 1. The basic performances of E-Defense are maximum lording capacity 1,200 tons, maximum velocity 200 cm/s and maximum displacement 2 m p-p for two horizontal excitations and maximum velocity 70 cm/s, maximum displacement 1 m p-p for vertical excitation to realize destructive ground motion.

Table 1 Main Specification of E-Defense

3-D Full-Scale Earthquake Testing Facility		
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/s²	>1,500cm/s²
Maximum Velocity	200cm/s	70cm/s
Maximum Displacement	±100cm	±50cm
Maximum Allowable Moment	Overturning Momnet 150MN・m	Yawing Moment 40MN・m

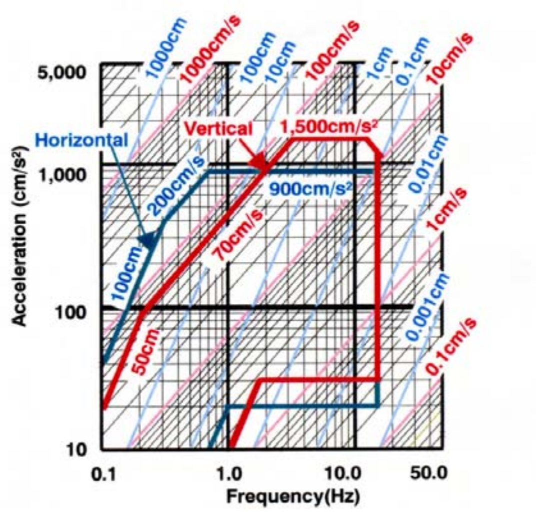

Fig. 1 Limit Performance of E-Defense

CONSTRUCTION AND MANUFACTURING OF E-DEFENSE

NIED have commenced the development work of shaking mechanism with very large size hydraulic actuators in fiscal year 1995 and completed

performance tests successfully in 1998. Following above technical development and surveys in earthquake engineering and related fields, NIED have began the design and construction of E-Defense in 1998.
Fig. 2 shows the drawing bird eye view of E-Defense.

Fig. 2 Layout of E-Defense

We were constructed several buildings, such as laboratory building, measurement and control building, hydraulic oil unit building, preparation building and so on. The 3-dimensional shaking table was installed in the laboratory building. Hydraulic oil will be supplied to shaking table by oil pipelines via underground culvert. 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 constructed the laboratory building and other buildings. The laboratory building is 60 m X 85 m in plan and 45 m height and has two sets of 400 tons crane. For the construction of large space frame, we developed and applied new construction methods, such as the sliding construction method for roof members using permanent traveling crane structure, and the large panel method of external wall by steel frame and sandwiches panel.
The construction work has begun in 1998 and completed at the beginning of 2005. The E-Defense is constructed in "Miki Earthquake Disaster Memorial Park", which is being constructed in Miki city, on the north of Kobe city.
The manufacturing of the testing equipment, such as actuators, 3-D 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 will be done at the site.

HYDRAULIC POWER SUPPLY SYSTEM

The greater part of experimental equipment of E-Defense were composed by the hydraulic power supply system, such as shaking table, actuators (including servo-valves), 3-D link joint, oil piping, accumulator unit, main oil pressure pump unit, oil tank, oil filter and so on. We also installed the control system, measurement system and others. Here, we described the outline of hydraulic power supply system. The specifications of hydraulic power supply system were mentioned each equipments for the far side from shaking table. Fig. 3 shows the outline drawing of hydraulic power supply system.

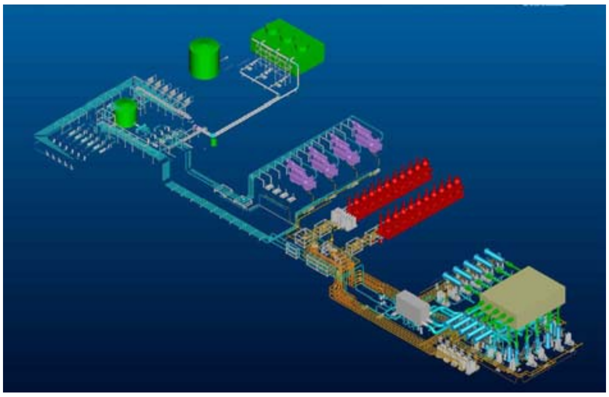

Fig. 3 Outline of Hydraulic Power Supply System

Oil Tank
Storage capacity 205 kL (This amount is only 30 % of total oil storage amount (750 kL). Remaining amount of oil was storage in the oil piping.)

Oil Piping
The total length and total weight of oil piping were 13 km and 1,200 ton, respectively. The maximum diameter of high pressure oil piping and low pressure oil piping were 350A and 1000A, respectively. By the advantage of flushing work of pipe inside, we used the non-welded flange method for the connection of these piping, which is consisted by the groove, retain ring and seal ring.

Main Oil Pressure Pump Unit
We installed 4 units of gas engine of 4000 Hp for the power-driven machinery of main oil pressure pump unit. These gas engines are derived 48 units of oil pressure pump and can generated 30,000 L/min (oil pressure: 20.6 MPa) of pressured oil. The reason of selection of gas engine was the consideration of environmental problem. We use the natural gas for minimize the nitrogen oxide and other noxious gas in exhaust fumes.

Accumulator Unit
This unit serve for the temporally storage of pressured oil. We installed 20 units, which storage capacity of each unit is 1,000 L, total capacity is 20,000 L. These 20,000 L of high pressured oil and oil from main oil pressure pump were combined and supplied to actuators

by the maximum flow late of 4,000 L/s.

Actuators
We installed 10 actuators for horizontal directions (5 actuators for X and Y axes, respectively) and 14 actuators for vertical direction. Each actuator has the driving force of 4,410 kN (450 tonf) and is derived by the electro-hydraulic servo control system. The maximum velocity 200 cm/s and maximum displacement 2 m p-p for tow horizontal excitations and maximum velocity 70 cm/s and maximum displacement 1 m p-p for vertical excitation to realize destructive ground motion by these actuators. The actuators were installed between the 3-D link joint and the shaking table foundation.

Servo Valves
The actuator was installed servo valve(s) for the control of the exciting movement. The maximum flow late of servo valve is 15,000 L/s. Each horizontal actuator has 3 units of servo valve (total maximum flow late: 45,000 L/s). Each vertical actuator has 1 unit of servo valve.

3-D Link Joint
Each 3-D link joint was installed between the shaking table and each actuator. The actuator should be move only on axial direction. The shaking table will be driven three-dimensional movement, therefore, we need to install the 3-D link joint.

Shaking Table
The size of shaking table is 20 m X 15 m X 5.5 m and the weight of itself is 775 tonf. It is impossible to transport such huge and heavy shaking table from the factory to construction site. Then, we made 32 blocks at the factory and transported them to the site. Next, we were conducted the assembling work at the site. Finally, the assembled shaking table was set in the pit by using the 2 sets of 400 tons crane.

CONCLUDING REMARKS

Based on the lessons learnt from Hanshin-Awaji earthquake, we, NIED, recognized to need more research to understand the failure mechanism of different kind of structures during earthquake. For this research needs, we conducted the construction project of E-Defense (3-D Full-Scale Earthquake Testing Facility) and completed on the beginning of 2005, just 10 years after the earthquake.
We already started the several research projects. Ministry of Education, Culture, Sport, Science and Technology (MEXT) was established the 5-year special project on “Seismic Hazard Mitigation in Megalopolis areas” in the fall of 2002. We started to the research program under this special project, which are (1) Experimental study on Reinforced Concrete Structures, (2) Experimental study on Liquefaction of Ground, (3) Experimental study on Wooden Structures and others. The large-scale model experiments for these 3 topics were conducted in 2005 and 2006.
In September 2006 NEES/ E-Defense meeting in Kyoto and Kobe built upon groundwork laid for collaboration. NEES is the special project for earthquake engineering sponsored by the US National Science Foundation (NSF). More than 100 attendees discussed the capabilities of NEES and E-Defense facilities in a program overview, and spoke of collaborative research in the area of steel buildings, bridge structures, wood structures, geotechnical study, and concluded the establishment of NEES/E-Defense Research Partnership.
We strongly hope that this tool is contributed to the dramatic progress of the earthquake engineering research, especially the understanding of structural failure mechanism, the progress of 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.

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