DEVELOPMENT OF CORE TECHNOLOGY FOR 3-D 1200 TONNE LARGE SHAKING TABLE

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SUMMARY

After the 1995 Great Hanshin-Awaji Earthquake Disaster in Japan, Science and Technology Agency (STA) and National Research Institute for Earth Science and Disaster Prevention (NIED) have planned construction of a new large scale shaking table as 3-D earthquake damage testing facility. The basic perfomances of this facility are maximum velocity 200cm/s and maximum displacement 200cm p-p in horizontal excitation with test weight 1200tonf. To realize such perfomance, we need much larger actuators than those used in former shaking table systems. However such large actuator system requires some basic technologies such as a bearing system against elastic deformation of actuator piston. Then the development of core technology for large actuator manufacturing and verification of its perfomance were started from 1995 and completed in 1998. This paper describes the outline of the development of core technology and verification tests.

INTRODUCTION

The 1995 Great Hanshin-Awaji Earthquake Disaster in Japan clearly showed that the occurence of very strong ground motion in the area nearest to the seismic fault is capable of causing severe structural damage beyond general estimation. More than 5000 people were killed by sudden unexpected collapse of wooden houses and urban structures, especially aged structures. It has emphasized the importance of earthquake engineering research into why and how structures collapse in real conditions and how these processes could be reproduced numerically.

It is known that a big earthquake accompanied with severe disaster occur meanly once in ten years in Japan . In order to reduce the hazard due to future great eqrthquakes, it is basic measure to improve reliability of earthquake resistance estimation and reinforcement method for urban and important structures. For that, failure mechanism and collapse process of various types of real scale structures must be investigated. Many types of experimental apparatus such as shaking table have been used for static and dynamic failure mechanism research. However, research of failure mechanism and process of real scale structures during earthquake require a large and real type strong motion simulator because of the limitation of the similarity law.

Considering the lessons learnt from recent earthquake disasters and experience of using the 1-D Large Scale Shaking Table, NIED and STA have planned to build a new "3-D Full Scale Earthquake Testing Facility", which can carry large size soil and structure model and simulate the process of structural failure. After basic planning, NIED and STA have commenced the development work of shaking mechanism with very large size of hydraulic actuators in fiscal 1995 and completed perfomance tests sucessfully in 1998. Following this technical development and surveys in earthquake engineering and related fields, NIED and

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STA have begun the design and construction of this new facility in fiscal 1998. This paper summarizes the results of technical development work of NIED and STA during the past four years.

2. OUTLINE OF THE 3-D FULL SCALE EARTHQUAKE TESTING FACILITY

2.1 Basic Specifications of The Facility of Main Plan

Table 1 shows the basic specifications of the facility. Table size planned is the world largest at this moment. Driving method is electro-hydraulic servo control system which use hydraulic pressurized oil charged in main accumulators. There are different driving method such as pure electric, explosion excitation method or liquid fuel rocket engine. But in this project, common and traditional system is selected considering stability. Maximum acceleration 0.9G for horizontal is decided from the consideration that the facility mainly simulate ground motion rather than floor response. In addition, high velocity and large displacement are useful for floor response of high rise building and other flexible structures.

Table 1 Basic specifications of the main plan

	Horizontal (X and Y)	Vertical (Z)
Table	15m × 20m	
Max. test weight	1200tonf	
Drive mechanism	Accumulator Charge/Electro- Hydraulic Servo Control	
Max. displacement	±100cm	±50cm
Max. velocity	200cm/s	70cm/s
Max. accleration (at maximum test weight)	0.9G	1.5G
Max. ovturning moment (at Z=1G)	≥15000tonf·m	-

2.2 Basic Requirements for The Large Actuator System

Basic requirements to the large actuator system are summarized as the followings. These requirements are based on effective performance of dynamic failure test in order to clear the structural damage mechanism, mode of failure and collapse process.

1) 3-D earthquake motion
   This is basic requirement for the new facility to simulate real ground motion. In addition, rotational motion such as rocking of floor is also required. 3-D motion may be unstable if rocking motion of the test structure and the table strongly occurs, then as possible as large allowable overturning moment has to be considered.

2) High velocity and large amplitude
   The strong motion recorded at JR Takatori Station in the 1995 Hyogo-Ken-Nanbu Earthquake shows the velocity of about 170cm/s and the displacement of about 50cm in the maximum direction. In the 1994 Northridge Earthquake, ground motion larger than the velocity of 128cm/s and the displacement of 30cm are reported. Considering future great earthquakes with long duration, the new facility is needed to have the maximum perfomance of 200cm/s for velocity and ±100cm for displacement.

3) Large shaking force for large size test structure
   In order to verify the study of failure mechanism of real structures, as possible as large test structure is required. Although technical and economical condition must be taken into account, minimum size real structures such as multi-storied building are required for future verification tests of failure process or structural control. Then, size of table is better to be equal or larger than 1-D large shaking table (15m×14.5m, the maximum test weight of 500tonf, NIED, Tsukuba) or 2-D large shaking table (15m×15m, the maximum test weight of 1000tonf, NUPEC, Tadotsu) known as verification test facility. In addition, a rectangular table is effective for building or soil movement tests. So that the table size of 20m×15m and the maximum test weight of 1200tonf have been planned for the new facility.

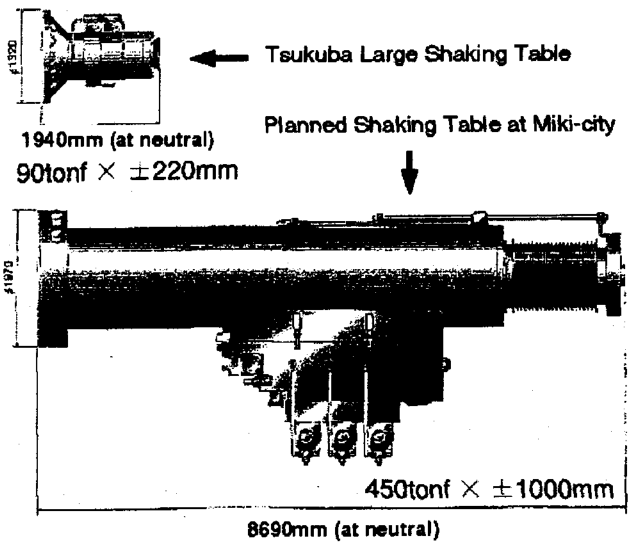

Fig.1 Comparison of horizontal actuator of Tsukuba and the planned new facility

3. TECHNICAL DEVELOPMENT FOR LARGE ACTUATOR SYSTEM

3.1 Objectives

Basic technology to make shaking table has been established through development and construction of various scale shaking tables in the past years. However, the facility in this project requires large scale shaking actuators beyond those of the past facilities (Fig.1). Then some technical developments in order to realize stable motion of large actuators were needed. Furthermore, perfomance of 3-D smooth motion of large shaking mechanism using joint system were also needed to be verified.

3.2 Technical Development of Basic Components

Typical developments related mechanical components are summarized as follows:

1) Bearing system for actuator piston
   Hydraulic actuators to realize large amplitude and high power requires long piston and cylinder in its mechanism. Then bending effect of piston due to self weight and dynamic lateral load become not to be negligible. Although bending of piston is small, it may cause seizure and failure of piston if it is supported by traditional bearing. In addition, it may increase friction between piston and bearing and give bad effects on table perfomance such as acceleration wave distortion.

   To solve this problem, a new bearing system with spherical hydrostatic sliding is adopted to support piston (Fig.2). This bearing system has made possible to follow piston deformation and reduce friction to near zero at support position.

2) High pressure seal mechanism
   At the piston land between both chambers of cylinder, a new type piston ring seal has been applied in place of traditional labyrinth seal. This was found to act as effective seal and reduce friction and oil leak between both chambers for long scale actuator. And further, non-contact high pressure oil seal using hydraulic force balance was adopted to prevent leak to the outside from the cylinder chamber considering piston deformation.

3) High flow rate servo valve
   In order to realize table velocity 200cm/s, about 45000ℓ/min flow rate is needed for one horizontal actuator. So that a new servo valve with 15000ℓ/min flow rate was developed. Three servo valves are equiped for one horizontal actuator and one for vertical actuator.

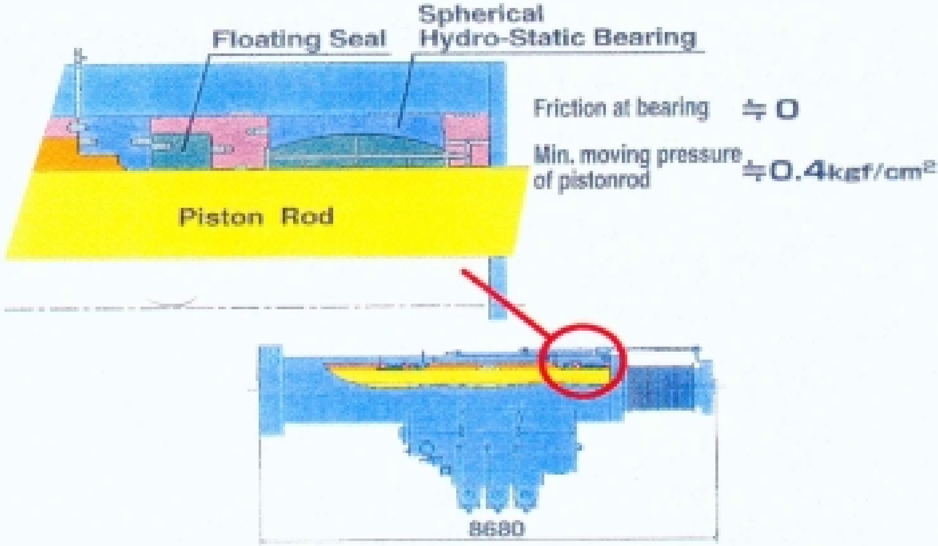

Fig.2 Horizontal actuator and its bearing mechanism

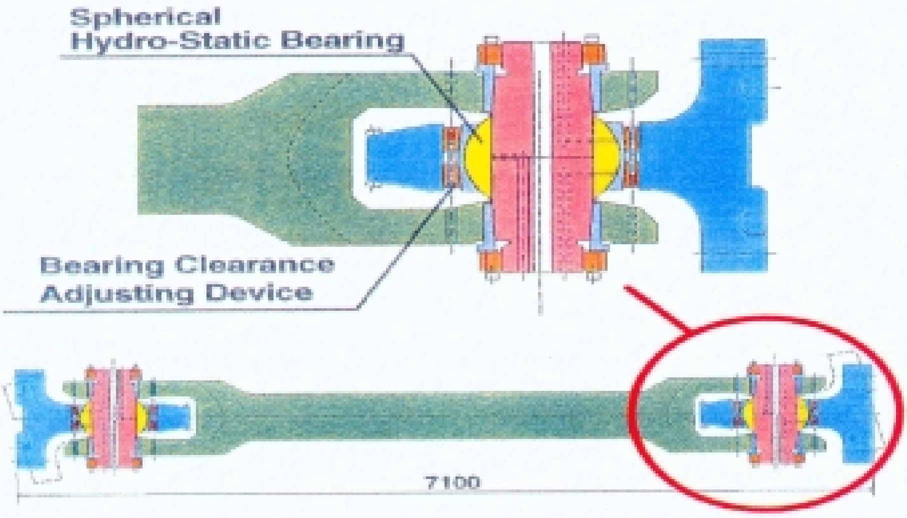

Fig.3 Large 3-D mechnidal joint with high pressure spherical bearing

4) Large mechanical 3-D joint
A 3-D joint is needed between actuator and table. The joint must satisfy requirement of 3-D flexible motion and force transmission without friction. For the planned facility a new spherical hydraulic bearing with high pressure forced-feed lubrication has been adopted in place of traditional grease lubrication (Fig.3). These joints acted as effective components in the verification test.

4. VERIFICATION TEST OF LARGE ACTUATOR SYSTEM

4.1 Setup of the Large Actuator Test System

In order to verify actuator perfomance as a 3-D system, a large actuator test system was designed and constructed parallel with components development. Table 2 shows main specifications of the test system, and Table 3 shows the constitution of the test system. The components and their configuration are basically same as the past electric-hydraulic servo control shaking table systems. The table (6m × 6m) was made only for this verification test. However, main equipments like as

Table 2 Main specifications for the large actuator test system

Item	Sub item	Specification
Table	Max. test weight Total Movable Mass Natural freq.	50 tonf 230 tonf（Table, joint etc. ） 50 Hz 以上
Vibration direction	Translation Rotation	x,y,z x-,y-,z-axes
Drive method	Accumulator Charge/ Electro-Hydraulic Servo Control	
Max. displacement	Horizontal (x,y) Vertical (z)	±100 cm ± 50 cm
Max. velocity	Horizontal (x,y) Vertical (z)	200 cm/s 70 cm/s
Max. acceleration	Horizontal (x,y) Vertical (z)	0.4G * 0.4G *

* This is decided by limitted strength of reaction wall.

Table 3 Main equipments for the large actuator test system

Name	Number	Specification
Table	1	6m × 6m, 45 tonf
Horizontal actuator(x)	2	Max. disp. ±100cm (with 3 Servo valves)
Horizontal actuator(y)	2	ditto
Vertical actuator(z)	4	Max. disp. ± 50cm (with 1 Servo valves)
Servo valve unit	16	15000ℓ/min/unit
3-D joint	8	Rot. angle ±12° and ±4°
Hydraulic supply system	1 set	
Controler	1 set	

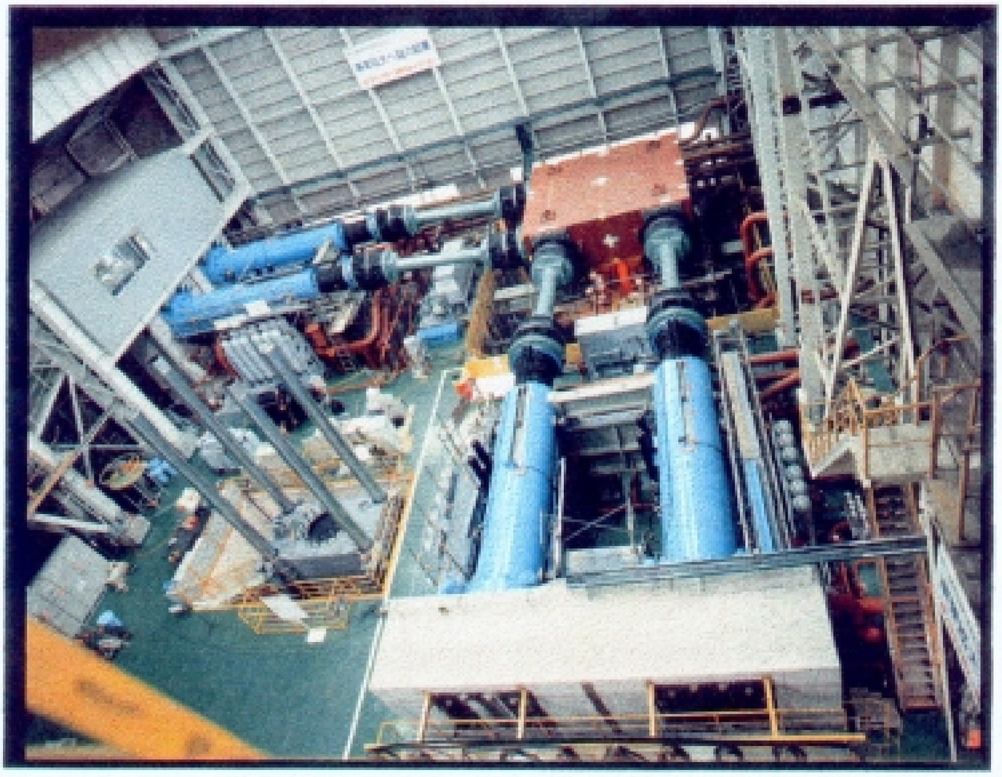

Photo.1 Main part of large actuator test system

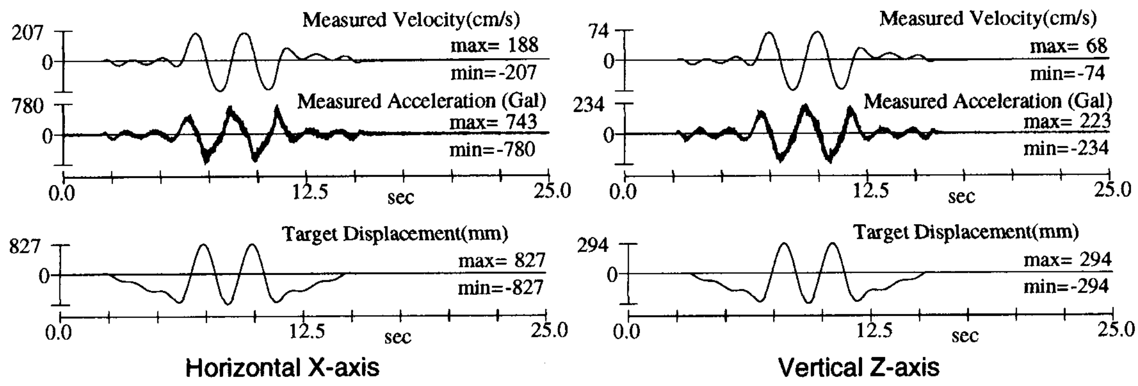

Fig.4 Table response at maximum velocity excitation test

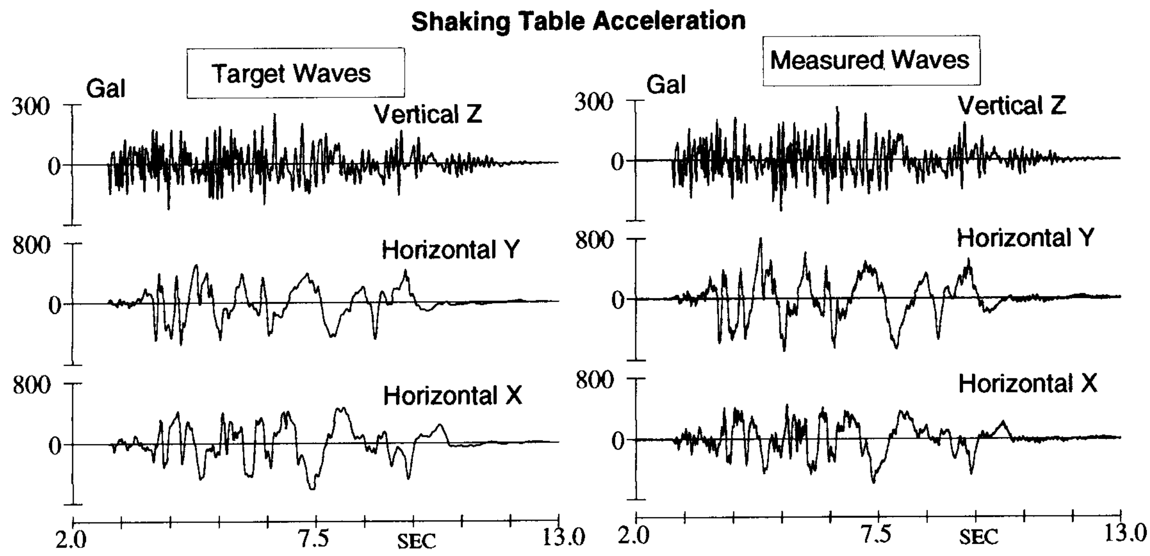

Fig.5 Comparison of acceleration waves at earthquake wave excitation test

actuators and joints are planned to be used for the main plan through necessary improvement. Main hydraulic pumps are driven by engine in place of electric motor. Photo.1 shows main part of the test system.

4.2 Results of the Verification Test

After each component test, three types of verification tests for shaking performance have been conducted. In the first stage of the tests, basic perfomance on displacement, velocity and acceleration were verified with table only. In addition, other mechanical perfomance such as the oil leak, friction etc. were examined. At the second stage, frequency response test, oil column resonance test, cross talk control tests etc. were performed with and without additional test weight 50tonf. At the final stage, with an elastic test model on the shaking table, dynamic property tests such as control of interaction between the shaking system and the test structure were conducted.

Fig.4 shows the test records of the maximum velocity verification test without test weight. Because of the limitation of hydraulic flow supply, two cycle sinusoidal wave was used. Fig.5 shows the results of the earthquake wave excitation test with no test weight. In this test, main part of the strong motion recorded by JR alarm seismometer at Takatori Station in Kobe City was used [NAKAMURA, 1995, ID-No.T065]. Although this test was performed without best tuning of controler, target and measured waves show fairly good agreement.

From these verification tests, it was found that developed large actuators are capable to be applied to the main plan of the 3-D Full Scale Earthquake Testing Facility. Though, some technical items such as advanced control method effective for large scale collapse tests are remained to be developed .

5. CONCLUSION

Technical development of core technology for 1200tonf large shaking table and verification test have successfully completed, and based on the results, now the construction work has begun in fiscal 1998. The new facility will start to work in 2005, 10 years after the 1995 Great Hanshin-Awaji Earthquake Disaster. Technical investigations for the new facility construction plan have been performed by much helps and valuable suggestions of so many specialists of earthquake engineering and related fields. The authors are so much grateful to them.

6. REFERENCES

NAKAMURA, Yutaka(1995); "Waveform and its Analysis of the 1995 Hyogo-Ken-Nanbu Earthquake", JR Earthquake Information No.23c, Railway Technical Research Institute.