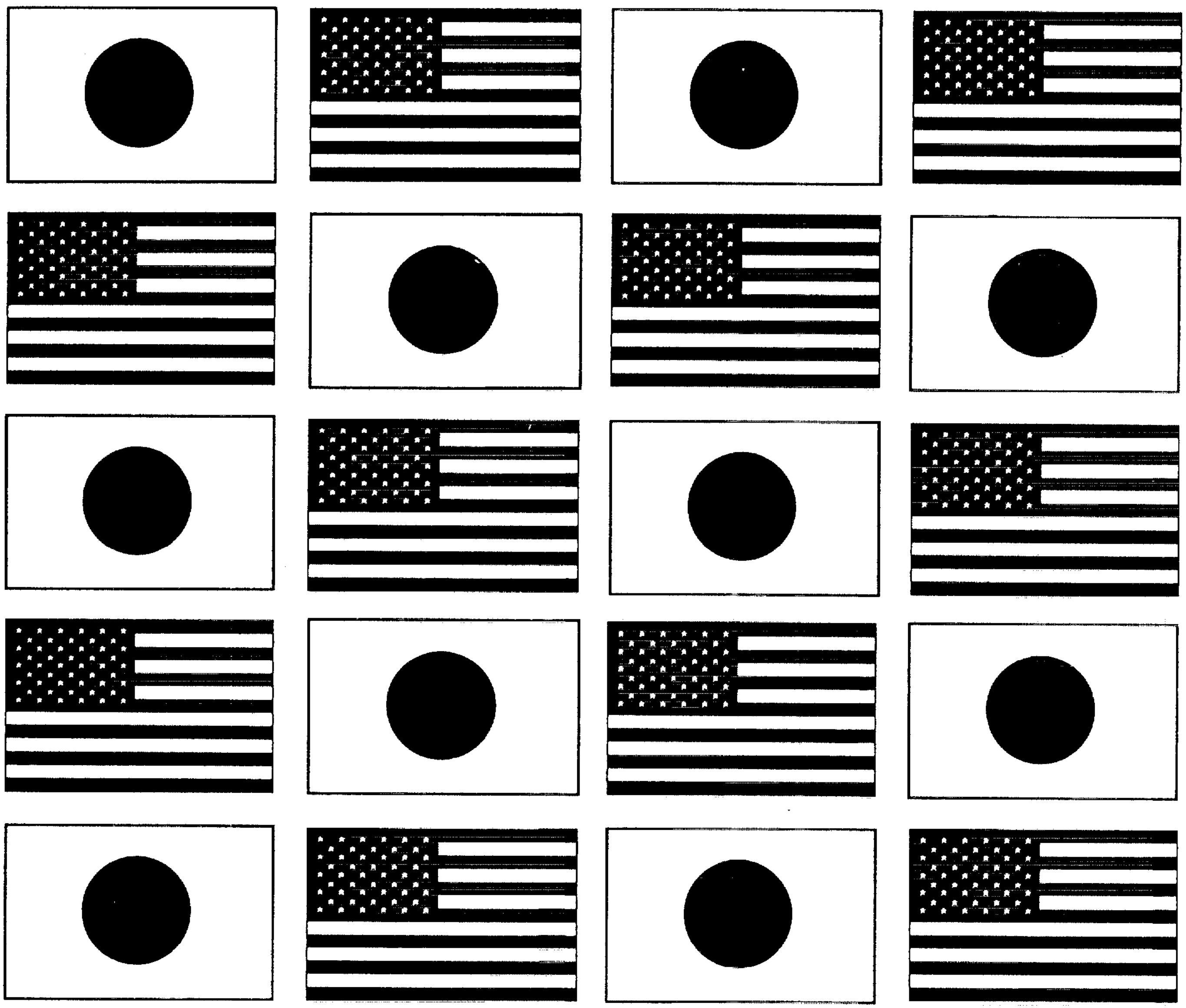
Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

NIST SP 931



U.S. DEPARTMENT OF COMMERCE
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Wind and Seismic Effects

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PROCEEDINGS OF THE 30TH JOINT MEETING OF THE U.S.-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES PANEL ON WIND AND SEISMIC EFFECTS

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EARTHQUAKE ENGINEERING

Project on 3-D Full Scale Earthquake Testing Facility
- First Report -

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ABSTRACT

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. It has emphasized the importance of earthquake engineering research into why and how structures collapse in real earthquake conditions and these processes are reproduced numerically. Considering the lessons learnt from recent earthquake disasters, NIED plan to construct a "3-D Full Scale Earthquake Testing Facility," which will be able to simulate the process of destruction of structures. This facility will be a central tool in a new concept of research bases for earthquake disaster prevention. NIED was conducted the research and development of core technology, such as the big and high performance hydraulic actuators, which have a long displacement and high velocity, and high performance three dimensional link joint since 1995 by the 4 year project. We constructed the prototype shaking table systems and confirmed the performance tests. NIED will begin the design and construction of this new facility in fiscal year 1998. This paper summarizes the fundamental concept of the facility and the result of R&D of core technology.

Key Words: Earthquake Disaster,
High-performance actuator,
3-dimensional earthquake motion,
Shaking Table,
Structural damages.

1. INTRODUCTION

The Hanshin-Awaji Earthquake gave a great impact to our society. More than 6,400 people lost their lives and a lot of structures, such as roads, railway bridges, buildings and other structures, suffered unexpectedly serious damages by this event. This earthquake event was made clear that our society, which is consisted the advanced, complexes facilities and concentrated population and city functions, has a over-expected weakness against natural disasters. The many major cities in Japan located a high potential area for earthquake hazard. Therefore, from this condition, it is pointed out that big hazard by a future earthquake at such big cities will affect the worldwide economic impact based on the border less, globalization, economic condition. And,

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the high potential area of earthquake hazard are also located the many countries, such as United State and Asian region. The progress of research for earthquake disaster mitigation is very important them to prove world widely. It is the urgent subject to decrease the potential of earthquake hazard risk by the effective and economical technology and measures based on the appropriate engineering and scientific knowledge.

Based on these condition, National Research Institute foe Earth Science and Disaster Prevention (NIED) has planned to construct a "3-D Full Scale Earthquake Testing Facility." NIED was conducting the research and development of core technology since 1995 and will start the design and construction works of this new facility in fiscal year 1998.

This paper summarizes the fundamental concepts of this facility and the current results of research and development of the core technology.

2. BACKGROUND

STA was enforced several actions relating with the promotion of research and development for earthquake disaster prevention since the occurrence of Hanshin-Awaji earthquake.

2.1. Basic plan for research and development on disaster prevention

The promotion of research and development of disaster prevention in Japan accelerated of the clutch based on the "Basic Plan for Research and Development on Disaster Prevention" reported by the Prime Minister's Council of Science and Technology, and finally approved by the Prime Minister on December 1993.

2.2. Investigative committee for promoting earthquake disaster prevention

Given this Basic Plan, and in light of the lessons learnt from the recent earthquake devastation, an "Investigative Committee for Promoting Earthquake Disaster Prevention (Chairman: Prof. Shigeru Ito, Keio University)" was set up within the Research and Development Bureau, Science and Technology Agency (STA) in March 1995. This committee was investigated the research and development issues that need to be accelerated in disaster prevention related science and technology. The mandate of this committee was to quickly propose the research and development issues that need to be addressed, after which, on May 31, 1995, they published a report entitled "Policies for Accelerating Earthquake Disaster Prevention Based on the Experience of Great Hanshin-Awaji Earthquake and the Other Destructive Earthquakes."

This report produced the following four research and development issues for urgent attention:

1) Research and development into earthquake disaster prevention by appraisal methods that would act as a comprehensive basis for accelerating earthquake disaster prevention,
2) Research and development into information about earthquake disaster prevention and how to support the daily existence of the people,
3) Research and development into the strengthening of urban environment against earthquake,

4) Research and development into the maintenance of daily order and social activities during an earthquake.

2.3. Committee to examine the research bases for earthquake disaster prevention

Based on the lessons learnt from Hanshin-Awaji earthquake, the various research institutions, such as governmental, academic and private sectors, were conducting the research work for earthquake disaster prevention. Furthermore, the existing research institutions are encouraged the expansion, reinforcement and arrangement of organization for it's research potentials. But, we strongly recognized that the difficult problem, which is requested from the experience of Hanshin-Awaji earthquake to the science and technology of earthquake disaster prevention, was raised. For answer to this problem, we think to build up the new type research organization.

Based on this recognition, STA established a "Committee to examine Earthquake Disaster Research Bases (Chairman: Prof. Tuneo Okada, Shibaura Institute of Technology)" in November 1995. This committee published the report entitled "Promotion of Effective Improvement of Research Bases for Earthquake Disaster Prevention based on Consideration of Hanshin-Awaji Earthquake" in May 1996.

The following research needs were realized with the chain of comprehensive research to aim the mitigation of earthquake disasters in and around the urban areas;

1) The research and development required the arrangement of new large-scale experimental facilities,
2) The research and development by the fluid organization, such as participation of researchers from many research fields and different countries,
3) The comprehensive research and development for earthquake disaster prevention based on the non-physical aspects.

From these research needs, the committee recognized of new research bases for earthquake disaster prevention. The concepts for this research base were stated clearly the following five items;

1) By the basic consideration is sitting on the protection of human lives, this bases will be functioned the progress of cooperation, exchange and mutual comprehension with various fields of researchers, such as engineering, science, humanity-social science, information technology, medical science and other sciences,
2) The research subjects, which is difficult to conduct the fixed research organization, will promote by the fluid organization systems,
3) By the arrangement the common-use research facilities, the new research organization and personnel structures will arrange for the response the wide research needs from wide areas of research field and existing organizations,
4) To construct the bases of international research exchange for the focus to the Asia and Pacific region,
5) The bases will contribute the effective transmission of the experience of the Hanshin-Awaji earthquake to the future generation and the comprehension and support by the public for the research of disaster prevention.

Considering these concepts, the committee proposed the construction (arrangement) of new research bases for earthquake disaster prevention. The committee's report suggested the need in future comprehensive research to reduce earthquake damage mainly of urban area. As part of such research, the report indicated the need to establish a new research base with subjects of (1) comprehensive anti-seismic, base-isolation and response-control systems, (2) relation between active faults and earthquake disaster prevention, (3) comprehensive earthquake information. The report insisted upon the significance of further increasing the promotion of science and technology for earthquake disaster prevention.

2.4. Discussion at the Council for Aeronautics, Electronics and Other Advanced Technology

At the latest stage of discussion at the Committee to examine the Research Bases for Earthquake Disaster Prevention, STA recognized to need the wider discussion with the persons from various fields. The Minister of State for Science and Technology was refer to the Council for Aeronautics, Electronics and Other Advanced Technology, which is the one refer organization of the Minister, for the discussion of the effective arrangement of research bases for earthquake disaster prevention at March 29, 1996. The Council was requested the charge of discussion to the Sub-committee for Earth Science. The sub-committee was established the Sectional Committee for Research Bases of Earthquake Disaster Prevention (Chairman: Prof. Tuneo Okada, Shibaura Institute of Technology). And, following three working groups were established under this sectional committee for the concrete discussion. (1) Working Group on Research Bases (Chairman: Prof. Hiroyuki Kameda, Kyoto University), (2) Working Group on the Objective Earthquake (Chairman: Prof. Syunsuke Otani, University of Tokyo), (3) Working Group on Large-Scale Three-Dimensional Earthquake Simulator Facility (Chairman: Prof. Emeritus Heki Shibata, University of Tokyo).

After the total 30 meeting at the council, subcommittee, sectional committee and working groups, 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 the research bases for earthquake disaster prevention.

3. PROJECT ON 3-D FULL SCALE EARTHQUAKE TESTING FACILITY

NIED initiated the project on the large-scale 3-dimensional earthquake simulator facility just after the occurrence of Hanshin-Awaji earthquake. The research and development for core technology for this facility was conducting since 1995.

At the initiated stage, we named the "Large-Scale 3-Dimensional Earthquake Simulator Facility." But, at this moment, we renamed to the "3-D Full Scale Earthquake Testing Facility."

The fundamental concepts of this project based on the report by the Council for Aeronautics, Electronics and Other Advanced Technology.

3.1. Position to the project

This facility will construct as the core facility of the research bases for earthquake disaster prevention. Therefore, we need to clear the positions of this facility.

1) Position of earthquake simulator for the main element of development of the "Time-Space Domain Simulation System for Earthquake Disaster."

By the accumulation of the failure testing result for different type of structures, it will be possible to make a rapid progress the usefulness of numerical shaking table. This progress will connect the development of the "time-space domain simulation system for earthquake disaster prevention." This simulation system is imaged to the total simulation system of the sequence of earthquake disaster, such as where and how large earthquake occur, what kind of damage occur and propagate and other related events.

2) Position of the clearly understanding of failure mechanism of structures.

During the Hanshin-Awaji earthquake, the structures were suffered over-expected damage and failures. Therefore, it is necessary to arrange the high performance earthquake simulator for the understanding of failure process of structures during earthquake.

3) Position of the response mechanism for the request from major subject of earthquake engineering.

To apply the experience of structure damage and failures learnt from Hanshin-Awaji earthquake and other recent destructive earthquakes, and to create the safer city and society against earthquake, it is necessary to test the following items;

[1] Development and verification of new design and construction technology for the building structures,

[2] Development and verification of new design and construction technology for the civil work structures,

[3] Development and verification of new design and construction technology for the structures sited on different soil conditions,

[4] Verification of development, adaptability and safety of base-isolation system and response control technology

[5] Verification of advancement of seismic performance and safety of the importance industrial facilities and equipment, such as to keep the social functions and to prevent disaster propagation.

3.2. Requested fundamental performance

This facility is requested the realization with fundamental performance as follows;

1)To be able to perform the failure test

It is necessary to have a performance of reproduce of failure phenomena by the long-period pulse waves (killer pulse), which was the one characteristics of Hanshin-Awaji earthquake motions.

2)To be able to produce the three-dimensional movements

It is necessary to perfectly reproduce the 3-dimensional strong motions of Hanshin-Awaji earthquake, including the displacement and velocity. This performance will set up to the minimum requirement.

3)To be able to test for the real-size structures

Many phenomena of structural failure were occurred at only the real size structures. For the detailed understanding of such phenomena, it is necessary to conduct the test for the real size structural specimen. Therefore, it is necessary to have the sufficient specification of maximum model weight, allowable overturning moment capacity and others for the test of large-size specimen.

3.3. Major specification

Sufficient information needs to be gathered on how structures and foundations behave, and whether or not they are destroyed, during a major earthquake. The importance of promoting the strengthening and rationalization of earthquake-proof structural design is just one of the lessons learnt from the 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. More than 30 three-dimensional shaking table have already built throughout the world, but they are all only small- or medium-sized devices. To perform tests on real-size objects or large-scale models of test structures and foundations, it is desirable to have the large-scale 3-dimensional shaking table. If large-scale 3-dimensional shaking table was available, tests could be performed to shed new light on the mechanism of dynamic failure using real-size structures as test objects and on the mechanism that destroys submerged structures when soil liquefaction. If a stage reached whereby design based on such discovery can be performed, this will contribute immensely to reducing earthquake disaster.

1) The main specification is shown in Table 1. The actuator performance for three axes, (X, Y (horizontal axis) and Z (vertical axis)), are shown in Fig. 1 to Fig. 3, respectively. The table size and maximum test model weight are the largest specification of the world. These specification was determined for the conducting to the almost real-size 4 story, 2 X 3 span reinforced concrete buildings and the real-size reinforced concrete bridge columns.
2) The driving method is choose the accumulator charge and electro-hydraulic servo control system, which is very common method to make the earthquake simulator.
3) The maximum acceleration of shaking table is determined by the model weight. At the maximum test model weight, maximum accelerations for horizontal axis are limited to 0.9 G. This value was determined by the reproduce of ground surface earthquake motions, not reproduce the response movement of structures, which is the basic conception of this facility.
4) The maximum velocity and maximum displacement are set up to the maximum value of future imaged earthquake motions.
5) The maximum overturning moment is set to perform the real-size subjects.

We will construct several buildings, such as the control and measurement building, testing building, oil source building and others. The layout of the facility is shown in Fig. 4.

3.4. Construction site and time schedule

The government of Hyogo prefecture will develop the Miki Memorial Park of Hanshin-Awaji earthquake at the city of Miki. This park have been functioned three zones, such as athletic park zone, citizen recreation zone and disaster prevention zone. This facility will construct as the core facility of disaster prevention zone. For this zone, the disaster prevention center of Hyogo prefecture, school for fire defense and helicopter spots will also construct in the near future.

The land for this park is located hilly area, and is not developed at this moment. Based on the result of soil condition survey, the foundation of shaking table will set the bottom of small valley. The current sectional design of foundation arrangement is shown in Fig. 5. The waved line illustrated the existing land profile in this figure. The bottom of foundation will construct on the Kobe layer, which is belonging with the tertiary layer.

The detailed design of mechanical system, such as shaking table, actuator, 3-dimensional link joint, oil supply system, control system and other equipment, and buildings will start in fiscal year 1998. The completion of this facility will be scheduled in fiscal year 2004 after 7 years plan.

3.5. Matter for management

The report by the Council was suggested that the management of this facility would be considered the following condition;

1) The international common use facility

This facility is the very large scale and high performance testing facility in the world. Therefore, many researchers, which are belong not only Japan but also worldwide organizations, can use this facility for their researches. This facility should be operated the international common use. It is important to arrange the utilizing structures, equipment and support section for the outside users.

2)Operation autonomous

The operation and maintenance of this facility should be done the professional experts, who have the professional knowledge and enough experience. It is important that to secure those experts and to establish the operation organization.

3) Fundamental important matters

For the effective operation of this facility it is important to enough care the following items;

[1] To operate the common use, such as users from government, academia, private sector and overseas organization,

[2] To establish the appropriate administrative and operate mechanisms.

[3] To secure the high carrier personnel and the continuous budget for the smoothly management of this facility.

[4] To establish the encouragement, support and evaluation system for the testing research project by using this facility.

[5] To arrange the good environment for the conducting research works.

4. RESEARCH AND DEVELOPMENT OF THE CORE TECHNOLOGY

4.1. Objectives of R & D of the core technology

The specification of the 3-D Full Scale Earthquake Testing Facility will be the largest and highest performance shaking table facility in the world. For the establishment of manufacturing technology of core technology for the new facility, we are conducting the research and development works since 1995.

The items of this research and development are as follows;

1) Development of the high performance actuator
2) Development of the three dimensional link joint
3) Conducting the performance test by the prototype facility

4.2. Development of the actuator

We set up that the maximum amplitude, maximum velocity and maximum load of the actuator are +-100 cm, 200cm/s and 450 tonf, respectively. These values are the largest ones, which were never condcted.

For establishment of this high performance actuator, we mainly considered the following point. The drawing of horizontal actuator is shown in Fig. 6.

1) To prevent seizure between cylinder and piston rod,
   After the several design-work, we developed the spherical hydro-static bearing. The structure of this bearing is shown in Fig. 7. By using this bearing system, the friction between cylinder and piston rod is established nearly zero.
2) To establish low friction capacity between cylinder and piston, as possible as we can,
   We used the floating seal mechanism for the actuator. Then, we established very low friction capacity, which is 0.4 kgf/cm2 of minimum moving pressure of piston rod. The relation between the hydraulic pressure and tolerance is shown in Fig. 8. The relation between hydraulic pressure and leakage is shown in Fig. 9. The measured value is shown good coincidence to calculated one at the using pressure region, which is greater than 100 kgf/cm2.
3) To develop the large flow servo valve.
   For the establishment of high velocity, 200 cm/s, we need to develop the 45,000 l/min servo valve for one horizontal actuator. We decided to use 3 servo valves for each actuator. Then we established 15,000 l/min servo valve, which is the largest flow rate servo valve in the world.

4.3. Development of 3-D link joint

To establish the three-dimensional movement of shaking table, we need to insert the link joint between the shaking table and actuator. For this shaking table system, the swing angle of link joint is reached to 12 degree. We used the spherical hydro-static bearing, which is same system as actuator, and the bearing clearance adjusting device for establishment of such large swing angle. The sectional drawing and bearing structure of link joint are shown in Fig. 10 and Fig. 11, respectively.

4.4. Conducting the performance test

We constructed the prototype facility by using the developed actuator and 3-D link joint. The specification and layout of prototype facility are shown in Table 2 and Fig. 12, respectively. The prototype facility are consisted 4 horizontal actuators and 4 vertical actuators. These actuators have same capacity as the 3-D Full Scale Earthquake Testing Facility. By the condition of construction site of this prototype facility, the capacity of maximum acceleration is limited to 0.4 G.

We conducted the following performance tests for the establishment of research and development result.

1) Maximum amplitude test
   For the confirmation of maximum amplitude establishment, we conducted the maximum amplitude test by the sinusoidal wave. And, we confirmed the performance of cross-talk compensation at this test. Fig. 13 shows the test result of X-axis vibration of +-100 cm. The movement of X-axis is shown the establishment of +-100 cm vibration. The

movements of Y and Z axes are shown almost zero by the good accuracy of the cross-talk compensation.

2) Maximum velocity test
This test is the confirmation of maximum velocity establishment. By the limitation of the oil power supply, we conducted this test by the deformed sinusoidal wave. Fig. 14 shows the test result of maximum velocity establishment. The maximum velocity of 200 cm/s is established as planned.

3) Test by random vibration
We established the reproductive performance by the random vibration. Fig. 15 shows the of time history and frequency characteristics during random vibration. This result shows that the prototype shaking table system has good accuracy for the conducting of random vibration test.

5. CONCLUSION

We learnt many lessons from Hanshin-Awaji earthquake and other recent destructive earthquakes. Especially, we need more research to understand the failure mechanism of different types of structures during earthquake. For this research needs, NIED will begin the construction project of the "3-D Full Scale Earthquake Testing Facility" in fiscal year 1998 for the 7 years plan. After the completion, this facility will be perfectly opened to international use.

We consider that the researchers together from worldwide to this facility and the research projects will determine and evaluate by the international committee. We hope that this facility will be situated to one of the cooperative research organization for the earthquake disaster mitigation in the world.

TABLE 1 MAIN SPECIFICATION OF THE FACILITY

Item	Horizontal X	Horizontal Y	Vertical Z
Table Size	20 m x 15 m		
Driving Method	Accumlator Charge / Electro-Hydraulic Servo Control		
Maximum Test Weight	1200 tonf		
Maximum Acceleration (at Max. weight)	0.9 G	0.9 G	1.5 G
Maximum Velocity	130 cm/s	200 cm/s	70 cm/s
Maximum Displacement	±50 cm	±100 cm	±50 cm
Maximum Overturning Moment	≧15,000 tonf · m (at Az=1G)	≧15,000 tonf · m (at Az=1G)	——

TABLE 2 SPECIFICATION OF PROTOTYPE FACILITY

	Horizontal X	Horizontal Y	Vertical Z
Table Size	6 m X 6 m		
Maximum Model Weight	50 tonf		
Maximum Acceleration	0.4 G	0.4 G	0.4 G
Maximum Velocity	200 cm/s	200 cm/s	70 cm/s
Maximum Displacement	+- 100 cm	+- 100 cm	+- 50 cm
No. of Actuators	2	2	4

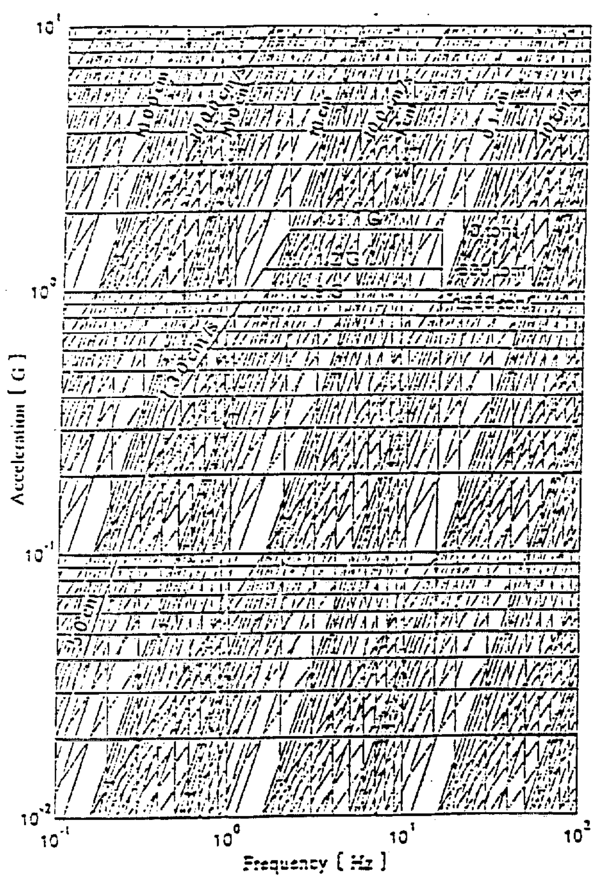

Fig. 1 Actuator Performance of X Axis

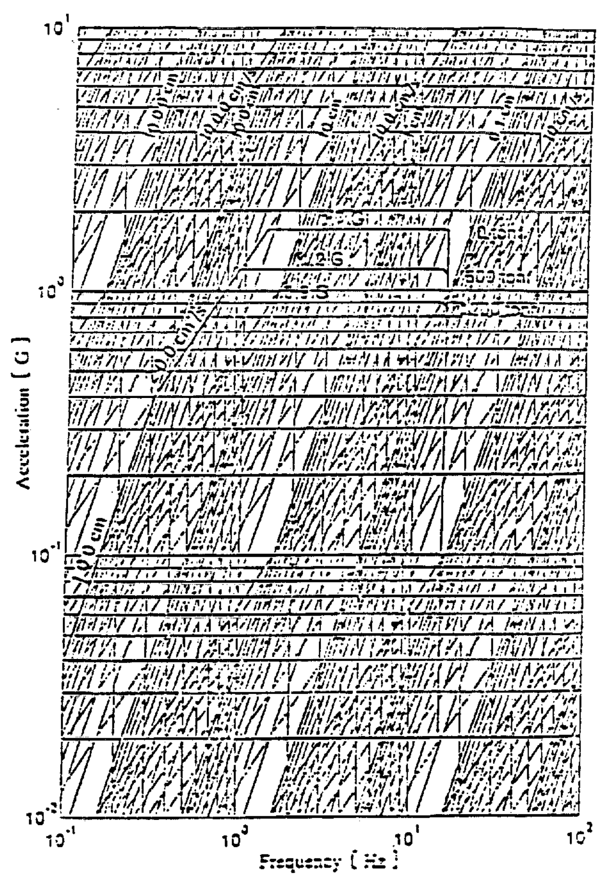

Fig. 2 Actuator Performance of Y Axis

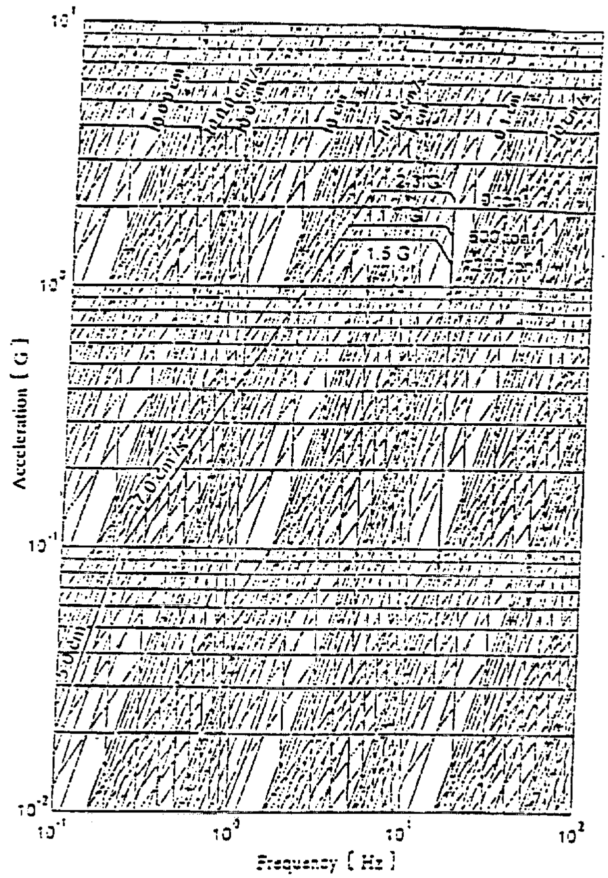

Fig. 3 Actuator Performance of Z Axis

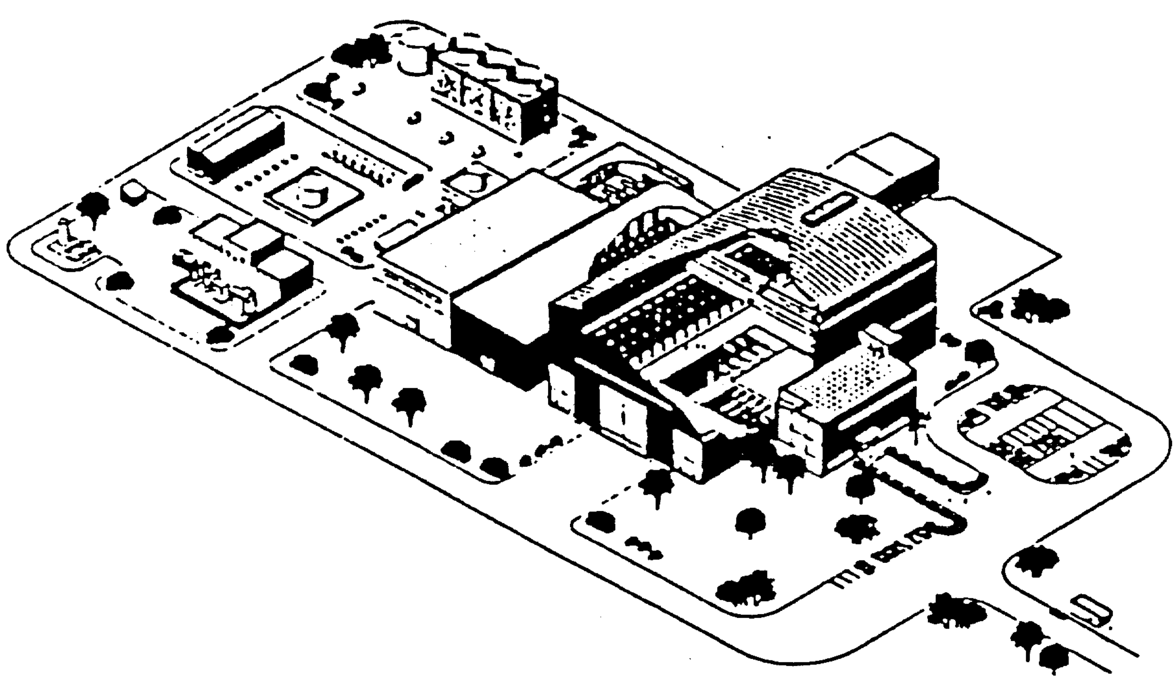

Fig. 4 Layout of the Facility

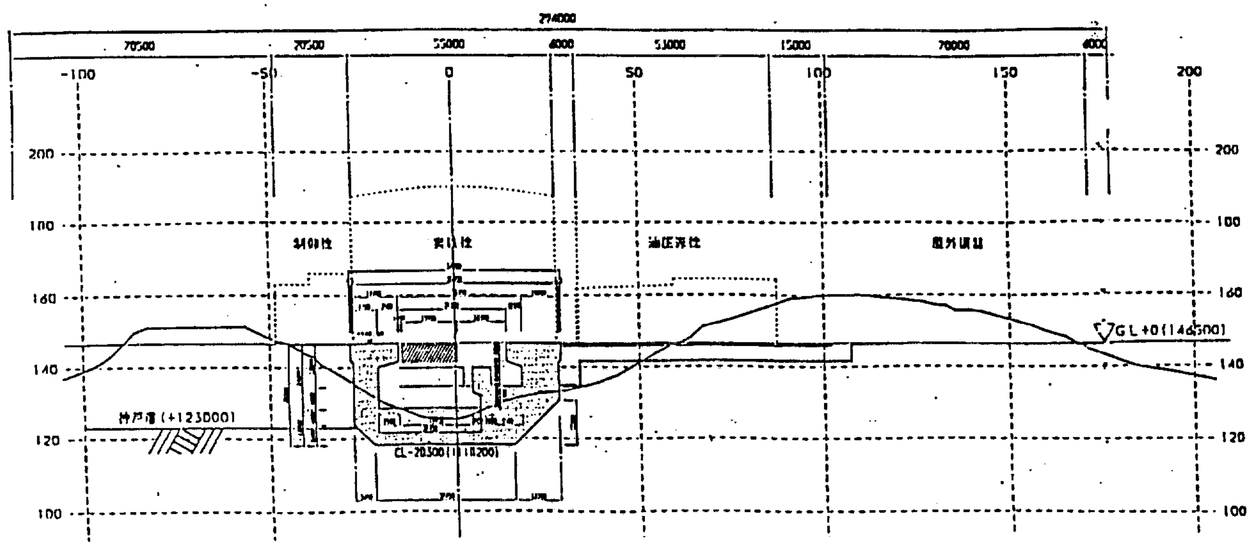

Fig. 5 Sectional Design of Shaking Table Foundation

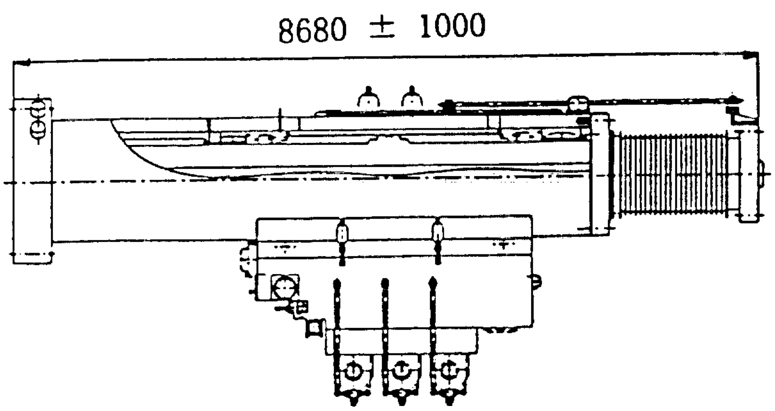

Fig. 6 Horizontal Actuator

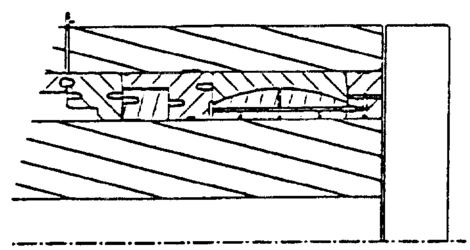

Fig. 7 Bearing of Actuator

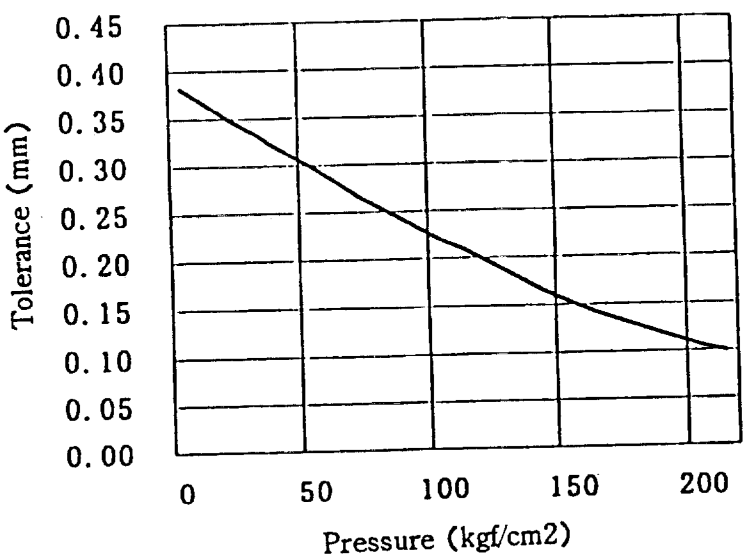

Fig. 8 Hydraulic Pressure vs. Tolerance

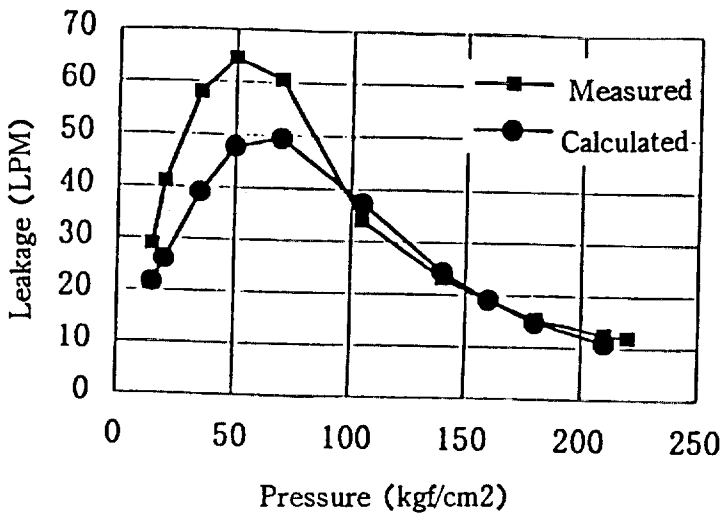

Fig. 9 Hydraulic Pressure vs. Leakage

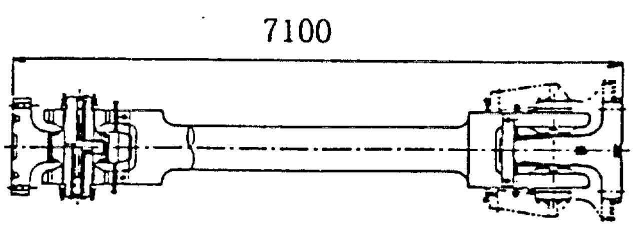

Fig. 10 Three Dimensional Link Joint

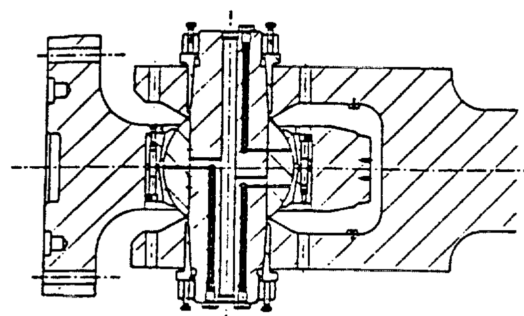

Fig. 11 Bearing of 3-D Link Joint

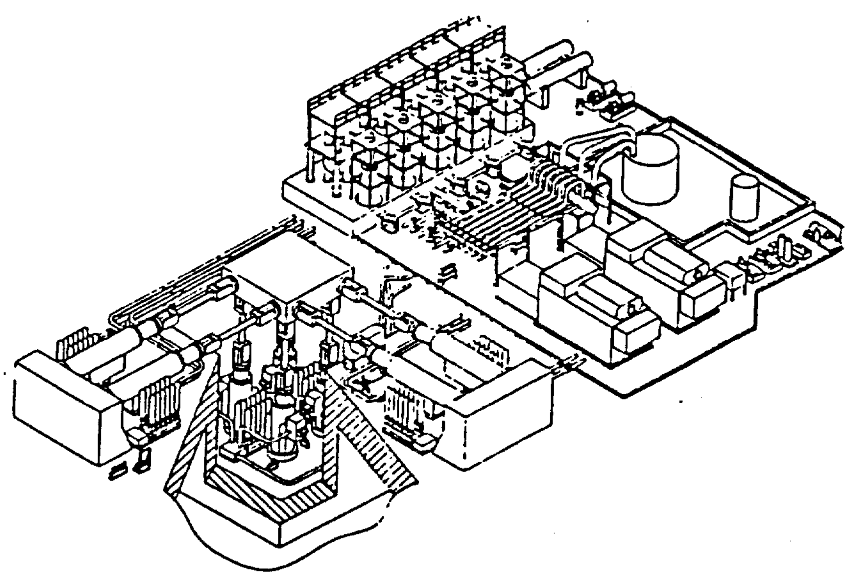

Fig. 12 Layout of Prototypr Facility

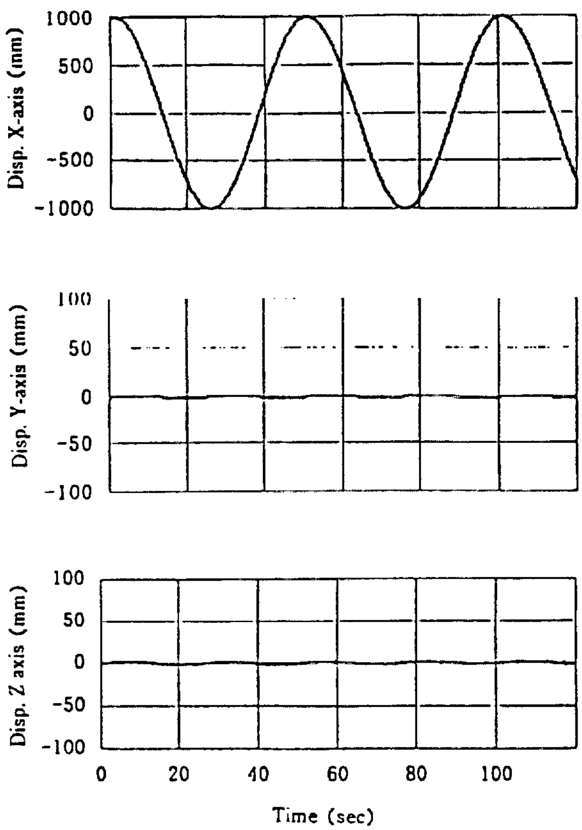

Fig. 13 Test Result of Max. Displacement

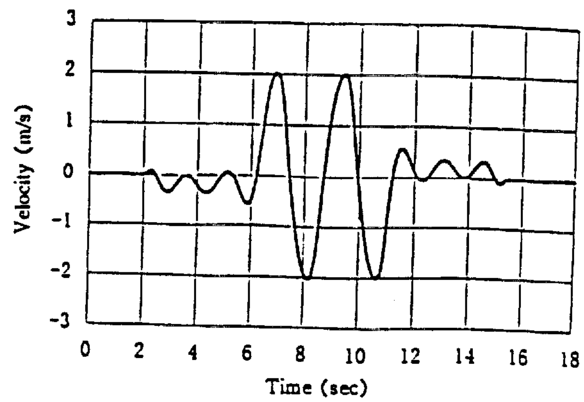

Fig. 14 Test Result of Max. Velocity

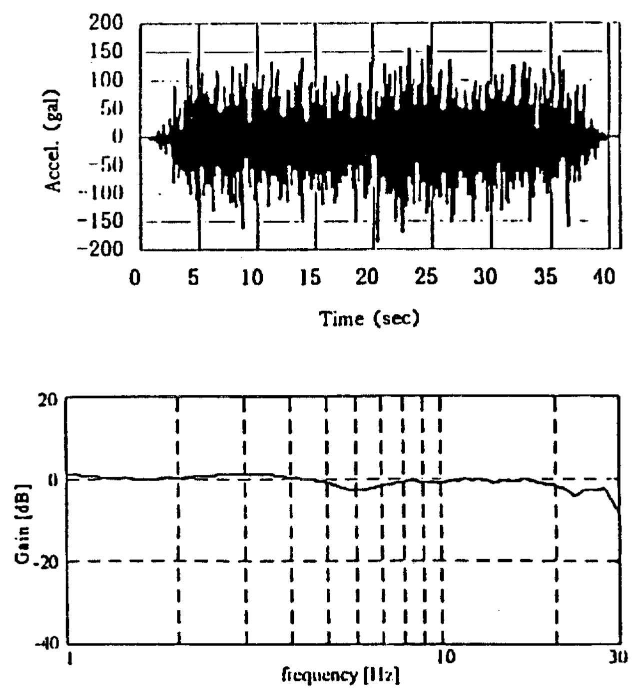

Fig. 15 Test Result of Random Vibration