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Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

**07-Jul-2004**

**English - Or. English**

**NUCLEAR ENERGY AGENCY**
**COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

**NEA/CSNI/R(2004)10**
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# EXPERIMENTAL FACILITIES FOR EARTHQUAKE ENGINEERING SIMULATION WORLDWIDE

## Are Large Testing Facilities for Nuclear Power Plants Design and Verification at Risk?

**English - Or. English**

**JT00167275**

## ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14 December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

### NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

## COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA) is an international committee made up of senior scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety among the OECD Member countries.

The CSNI constitutes a forum for the exchange of technical information and for collaboration between organizations, which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of the programme of work. It also reviews the state of knowledge on selected topics on nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus on technical issues of common interest. It promotes the co-ordination of work in different Member countries including the establishment of co-operative research projects and assists in the feedback of the results to participating organizations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups, and organisation of conferences and specialist meetings.

The greater part of the CSNI's current programme is concerned with the technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment, and severe accidents. The Committee also studies the safety of the nuclear fuel cycle, conducts periodic surveys of the reactor safety research programmes and operates an international mechanism for exchanging reports on safety related nuclear power plant accidents.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

# FOREWORD

In the report "*Nuclear Safety Research in OECD Countries: Summary Report of Major Facilities and Programmes at Risk.*" published by the NEA/CSNI Senior Group of Experts on Nuclear Safety Research Facilities and Programmes (SESAR/FAP), facilities for earthquake engineering were not pointed out as facilities at risk due to their large numbers. The recommendations of the SESAR group were: in the short term to promote data exchange, including earthquake observation data, and in the longer term to monitor status and identify opportunities for co-operative programmes using large shaking tables.

The first recommendation is addressed by the CSNI Working Group on the Integrity of Components and Structures (IAGE) through its expert group on the seismic behaviour of components and structures.

The latter recommendations led the IAGE Working Group to prepare this report listing large facilities available worldwide having testing facilities relevant to nuclear industry and having associated knowledge/competencies. The report concludes that there are sufficient testing capabilities throughout the world. The situation is not the same if regions are considered individually. New techniques under development may also help in using existing smaller size tables to test large components/structures.

This product might be used by the CSNI, National Organizations and utilities to identify laboratories having testing facilities relevant to nuclear industry and having associated knowledge/competencies. Ultimately co-operative programmes could be set up on an international or multi-lateral basis.

The complete list of CSNI reports and the text of reports from 1993 onwards is available on http://www.nea.fr/html/nsd/docs/

**ACKNOWLEDGEMENT**

Gratitude is expressed to Dr Vito Renda (EC), Dr Andrew Murphy (USNRC, USA) and Mr Pierre Sollogoub (CEA, FR), chairman of the CSNI/IAGE[♣] sub-group on the Seismic Behavior of Structures and Components for collecting information and preparing this report.

Gratitude is also expressed to official delegates of the CSNI/IAGE sub-group on the Seismic Behavior of Structures and Components whose contributions helped in building an international review on the topic.

The authors would like to acknowledge the work done by the US National Science Foundation through the Network for Earthquake Engineering Simulation (NEES) compiling and making available a directory of International Earthquake Engineering Research Facilities which served as a basis for the work presented here.


[♣] Integrity and Ageing of Components and Structures

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# INTRODUCTION

In 2001, the CSNI published a report prepared by a senior expert group "Report on facilities and programmes (SESAR/FAP): major facilities and programmes at risk"1.

The CSNI has expressed concern that dwindling budgets and support as well as stagnant or even reducing programmes may lead to the untimely shut down of large facilities and the breaking up of experienced research teams. This will result in a consequent loss of competence and the reduced capability to deal efficiently and in a timely manner with future safety problems. In addition, research and educational programmes play a key role in attracting training and retaining new talent in nuclear safety. As an expression of these concerns, the following is a statement of the overall goal of the SESAR/FAP activity: "To ensure timely CSNI action is taken, as needed, so that an infrastructure of safety research facilities and programmes is maintained that assures the safe generation of electricity via nuclear power now and in the future."

In the report published by the SESAR/FAP group, facilities for earthquake engineering were not pointed out as facilities at risk due to their large numbers. The recommendations of the SESAR group were: in the short term to promote data exchange, including earthquake observation data, and in the longer term to monitor status and identify opportunities for co-operative programmes using large shaking tables.

The first recommendation is addressed by the CSNI Working Group on the Integrity of Components and Structures (IAGE) through the expert group on the seismic behaviour of components and structures.

The latter recommendations led the IAGE Working Group to first list such large facilities. The product might be used by the CSNI, National Organizations and utilities to identify laboratories having testing facilities relevant to nuclear industry and having associated knowledge/competencies. Ultimately co-operative programmes could be set up on an international or multi-lateral basis.

The IAGE Working Group has been also charged to investigate if and how the significant decrease of investments in research and construction of new nuclear power plants (NPPs) has affected the laboratories for earthquake engineering simulation. The point is to determine if the actual testing capability in the field of earthquake engineering is adequate for the verification of new design standards and guidelines for nuclear power plants and for the seismic re-evaluation of existing nuclear plants and facilities.

The present analysis leads to the conclusion that only Japan is fully equipped for facing the testing needs of large mock-ups. The USA will further improve its significant testing capability through the NSF/NEES programme. Europe has significant potential testing capability although limited to middle-size mock-ups. To further optimize the use of existing facilities or ultimately stress the need for new ones, experimental needs and associated programs following different approaches (global behaviour tests, small size mock-ups and scale effect, substructurizing) should be defined. Currently the USA is making an important effort in this direction through the NSF/NEES initiative while nothing similar actually exists in Europe.

The current document presents the scope, the methods of work and the list of relevant earthquake engineering facilities to support this conclusion.

**Scope**

The closure of large facilities may impact the safety of future nuclear installations, and to less extent existing installations, by the lack of seismic qualification of large components and structures. Building new facilities when needs arise in the future may not be an option considering their high cost of construction and the tendency to reduce cost of the generated electrical power. Nevertheless it should be pointed out that the cost of construction of nuclear installations may increase if no large scale tests of important structures/equipments are performed because of the increase of the safety margins necessary to compensate for.

The concern of the CSNI is on large facilities that may need support from the OECD member countries. The scope of the report is thus limited to large shaking tables and reaction walls. Neither smaller tables devoted to seismic qualification of electro-mechanical equipment, nor explosive and centrifugal facilities, tsunami wave basin facilities are included in the report.

**Method of Work**

An existing list established by the US National Science Foundation (NSF)2 in 2001 was used as a starting point. Only facilities within NEA member countries have been reviewed and the list was completed by IAGE delegates as necessary. The list gives a clear view of the capacities in NEA member countries and its geographical distribution.

**The Need for Facilities for Earthquake Engineering Simulation**

For a number of years the nuclear industry has been on the sidelines with respect to research and construction of nuclear power plants (NPPs) and other nuclear facilities. Many important laboratories for earthquake engineering simulation have been constructed and operated to support research and structural validation for the development of the civil nuclear energy programme. In the last few years, civil engineering for non-nuclear structures made remarkable advances in particular in the seismic protection of buildings, bridges and industrial plants.

Testing facilities (TF) at large have several different destinations:

- Seismic re-evaluation of NPPs is ongoing in several countries in the frame of life extension management programs. In addition technical areas like near field earthquakes need specific TF experiments with specific skills. In addition, many of the oldest NPPs and some other nuclear facilities are not specifically designed with nuclear codes seismic rules. There is the necessity to perform tests for assessing the safety of such facilities and for designing appropriate upgrading;

- Verification of new guidelines and new designs: In the last ten years, highly populated and densely industrialized regions in the world have been strongly affected by both medium and high magnitude earthquakes. For each significant event, specialists have gathered relevant information with respect to design practice and given expert judgement regarding the nuclear design and the specific needs for codes and standards. If only for the nuclear industry, these indications and design guidelines call for verifications based on experimental testing;

- The assessment of margins for materials (such as concrete beams and slabs, masonry, pipings and others) that may be affected by significant non-linearity under strong loads cannot be obtained by using only numerical analysis; Moreover laboratory tests play a major role in the assessment and in the validation of design guidelines;

- Qualification of innovative devices: A large number of technologies have been developed and investigated. A significant number of innovative devices were designed and constructed; related to base isolation, energy dissipation, active and semi-active control of vibration of structures. These new innovative technologies for earthquake protection and vibration control need laboratory tests for assessment, optimization, improvement and validation of both the devices and the associated design guidelines.

Widely used for several purposes, a large number of laboratories for earthquake engineering exist in the world. The US National Science Foundation (NSF) compiled them.

## Existing Testing Facilities

***The USA NSF/NEES Directory of International Earthquake Engineering Research Facilities***

A preliminary investigation led to the identification of a list of existing testing facilities in the world having capability of performing tests for earthquake engineering purpose and of interest for NPPs design and verification. The US National Science Foundation (NSF) initiative to set-up a Network for Earthquake Engineering Simulation (NEES), was checked to determine if a similar investigation were done, even though for other purposes. In 2001, the NSF/NEES published the "Directory of International Earthquake Engineering Research Facilities" on the internet site below:

http://www.sri.com/policy/csted/sandt/DirectoryEarthquake.html.

After having analyzed the Directory, it was evident that this was an excellent basis also to answer the concern of CSNI; i.e. to verify that adequate testing facilities exists for the assessment and re-evaluation of existing NPPs and other nuclear facilities as well as for supporting a possible restart of research and construction of innovative NPPs.

It was decided not to further investigate the facilities for earthquake engineering simulation and adopt the above-mentioned Directory as a basis document to address its concerns. As mentioned before, the Directory was reviewed and completed by IAGE delegates.

While the Directory includes different kinds of facilities and field-testing equipments, only shaking tables and reaction walls have been considered in this study.

Data in tables 1 and 2 includes additions by NEA member countries.

**Synthesis of the Characteristics of the Facilities**

The present executive summary will present a synthesis of the most significant characteristics of the facilities; for the majority all details are included in the above-mentioned NSF/NEES Directory.

Some of the shaking tables considered, in particular in Japan and in Europe, were built and are owned by companies or research centres involved in activities directly related to nuclear facilities and energy plants.

A selection of 51 shaking tables and 32 reaction walls was considered. The distribution is as follows (see tables 1 and 2):

***Shaking Tables***

- ✓ Europe 10 (distributed in various European countries)
- ✓ America 8 (all in USA)
- ✓ Asia 33 (30 in Japan + Taiwan, Korea and China)

Limiting the payload to more than 30 tons, there are 28 shaking tables in the list distributed as follows:

- ✓ Europe 4
- ✓ America 5
- ✓ Asia 19

The maximum payload varies considerably by continents; in Europe the max payload is about 100 tons, in North America about 50 tons while in Asia it is more than 1000 tons (i.e. NIED, Japan).

With regard to frequency range most of the tables can cover frequencies typical of earthquakes. Future issues might come from near field earthquake loadings that may not be adequately addressed using existing shaking tables.

***Reaction Walls***

- ✓ Europe 1 (owned by the European Commission)
- ✓ America 16 (15 in USA + 1 in Mexico)
- ✓ Asia 15 (all in Japan)

Reaction walls allow pseudo-dynamic testing of building structures (which can be modelled as lumped mass systems); while for many components typical of NPPs and other nuclear facilities, it is necessary to perform tests on shaking tables.

USA and Japan are strongly involved in this kind of testing facilities based on the pseudo-dynamic methodology for earthquake simulation. Universities and other US organizations performing tests for third parties manage most of the facilities. US facilities are available commercially and can be used for nuclear applications.

Japan operates two very large reaction walls and several smaller ones.

In Europe, there is only one large reaction wall, which is networked with some medium size shaking tables. The network is potentially interesting for testing NPPs buildings and components.

**Synthesis**

The most significant characteristics of the facilities for earthquake simulation are presented in this report while, for the majority, full details are collected in the NSF/NEES Directory.

It is evident that the best-equipped country for testing nuclear facilities against earthquakes is Japan since it owns and manages the largest shaking tables and reaction walls in the world.

Moreover it must be stressed that Japan is the only country having shaking tables allowing large scale model testings.

The USA is well equipped particularly with regards reaction walls, while shaking tables are limited to 50 tons. It must be stressed that a very significant effort is underway to improve, through the NSF/NEES programme, the earthquake engineering simulation facilities in the USA.

In Europe, there is only one large reaction wall, which is managed by the Joint Research Centre (JRC) of the European Commission at Ispra (VA, Italy). It is networked with shaking tables limited to a maximum payload of 100 tons. In principle this network can provide significant testing capability for earthquake engineering simulation for nuclear facilities and plants. However, JRC is engaged in its own institutional programme and its reaction wall could be unavailable for supporting the restart of nuclear energy or the seismic re-evaluation of existing NPPs. Further, the existing European shaking tables allow testing of middle-size mock-ups only. The most relevant evolution in Europe is oriented to the advance in testing equipments and methodologies; in particular a new system based on two middle size shaking tables allowing synchronous and asynchronous input signals is proposed by CEA, France, owner of the actual biggest shaking table in Europe. As to reaction wall, the pseudodynamic methodology is evolving from a step-by-step approach to continuous testing methods.

**Conclusions**

The present analysis leads to the conclusion that only Japan is fully equipped for facing the testing needs of large mock-ups. The USA will further improve its significant testing capability through the NSF/NEES programme; this improvement should be mainly oriented to the construction of a very large shaking table. Europe has significant potential testing capability but the only existing reaction wall could be phased out (due to the decrease in JRC's institutional programme funds); advances are limited mainly in testing techniques and methodologies while limited improvement of testing capabilities is foreseen, in particular for large shaking tables.

It is known that a nuclear energy programme could restart at a world-wide level; in particular advanced studies on new generation reactors (i.e. generation IV) with improved safety and having a fuel-cycle reducing proliferation risk are under study. When there is a restart in the design and the construction on NPPs, seismic loads (and several faulted conditions) will be considered from the early stage of the design (according to the "safety in depth" principle). Earthquake testing simulation, in particular for new generation reactors, will become very important and testing facilities will play a major role. In that case, the seismic testing capabilities in the USA and in Europe should be carefully assessed to be sure that they are congruent with the needs.

Seismic testing capacity strategy or programs should consider existing testing facilities as well as approaches available or in a research phase (global behaviour tests, small size mock-ups and scale effect, sub-structurizing). Such programs may optimize the use of existing facilities or ultimately may stress the need for new ones. Currently the USA is making an important effort in this direction through the NSF/NEES initiative while nothing similar actually exists in Europe.

Large testing facilities for nuclear power plants design and verification are not at risk per se. Nevertheless studies on future experimental needs should be conducted in OECD countries, and research on approaches should be pursued to allow an efficient response to needs to come.

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[1] *Nuclear Safety Research in OECD Countries: major facilities and programmes at risk Ref NEA3145 Published in 2002.*

[2] *Directory of International Earthquake Engineering Research Facilities - Prepared for: The National Science Foundation George E. Brown, Jr. Network for Earthquake Engineering Simulation By SRI International on October 22, 2001*

**Table 1: Shaking Tables per Continent, Payload and Degree of Freedom**

| INSTITUTION | Continent | Country | Degrees Freedom | Payload [Ton met.] | Area [m2] | X-Displ [+/- mm] | X-Veloc [+/- mm/s] | X-Accel [g] | Max Frq [Hz] |
|---|---|---|---|---|---|---|---|---|---|
| **Commissariat a l' Energie Atomique** | Europe | France | 6 | 100 | 36 | 125 | 1000 | 2 | 100 |
| **Hydroproject Research Institute** | Europe | Russia | 3 | 45 | 36 | 100 | 600 | | 100 |
| **Labor. Nacional de Engen Civil** | Europe | Portugal | 3 | 36 | 31 | 175 | 700 | | 20 |
| **Univ. of St. Cyril and Methodius** | Europe | Macedonia | 3 | 36 | 25 | 125 | 640 | | 30 |
| **KFA Juelich** | Europe | Germany | 3 | 23 | 25 | 100 | 800 | | 100 |
| **Enel. Hydro-ISMES** | Europe | Italy | 6 | 15 | 16 | 100 | 550 | 5 | 120 |
| **Univ. of Bristol** | Europe | UK | 6 | 14 | 9 | 175 | 700 | | 20 |
| **ENEA** | Europe | Italy | 6 | 9 | 16 | 125 | 500 | | 50 |
| **National Tech. University Athens** | Europe | Greece | 6 | 9 | 16 | 100 | 890 | 2 | 100 |
| **Ansaldo Meccanica Nucleare** | Europe | Italy | 3 | 6 | 12 | 70 | 860 | | 60 |
| **Nishimatsu Construction Corp.** | Asia | Japan | 6 | 65 | 30 | 500 | 1500 | 2 | 50 |
| **NIED (Nat. Inst. for Disaster prevent.)** | Asia | Japan | 1 | 500 | 218 | 220 | 900 | 1(200ton) | 50 |
| **NIED (Nat. Inst. for Disaster prevent.)** | Asia | Japan | 3 | 1200 | 300 | 1000 | 2000 | 1 | 15 |
| **Nuclear Power Engineering Corp.** | Asia | Japan | 2 | 1000 | 225 | 200 | 750 | 2(1000ton) | 30 |
| **Public Works Research Institute** | Asia | Japan | 6 | 300 | 64 | 600 | 2000 | 2(100ton) | 50 |
| **Mitsubishi Electric Corp.** | Asia | Japan | 2 | 40 | 16 | 100 | 700 | 2.5 | 30 |
| **Mitsubishi Heavy Industries Corp.** | Asia | Japan | 3 | 100 | 36 | 50 | 1500 | 2(60ton) | 50 |
| **Hazama Corp Ltd.** | Asia | Japan | 3 | 80 | 24 | 300 | 1150 | 3(35ton) | 50 |
| **Kumagai-Gumi Corp Ltd.** | Asia | Japan | 6 | 70 | 25 | 80 | 600 | 3 | 70 |
| **Kumagai-Gumi Corp Ltd.** | Asia | Japan | 6 | 70 | 25 | 260 | 1500 | 1 | 70 |
| **Kajima Corp Ltd.** | Asia | Japan | 6 | 50 | 25 | 200 | 1000 | 2 | 60 |
| **National Institute for Rural Engineering** | Asia | Japan | 3 | 45 | 24 | 150 | 750 | 1 | 40 |
| **Obayashi-Gumi Corporation** | Asia | Japan | 3 | 50 | 25 | 600 | 2000 | 3 | 50 |
| **Instit. of Machinery and Metals** | Asia | Korea | 6 | 27 | 16 | 200 | 750 | | 50 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Nation Center for Research in EE** | Asia | Taiwan | 6 | 27 | 25 | 80 | 600 | | 50 |
| **Fujita Corporation** | Asia | Japan | 1 | 25 | 16 | 500 | 1500 | 1 | 50 |
| **NYK Logistics Technology Institute** | Asia | Japan | 6 | 20 | 16 | 200 | 600 | 2 | 80 |
| **Shimizu Corporation** | Asia | Japan | 3 | 20 | 16 | 200 | 1000 | 1(10ton) | 50 |
| **Tobishima Corporation** | Asia | Japan | 2 | 20 | 25 | 75 | | 1.5(20ton) | 30 |
| **Ishikawajima Harima Heavy Ind Corp** | Asia | Japan | 6 | 35 | 20 | 100 | 750 | 1.5(35ton) | 50 |
| **Taisei Corporation** | Asia | Japan | 3 | 20 | 16 | 200 | 450 | 1 | 50 |
| **Hitachi Ltd.** | Asia | Japan | 3 | 20 | 16 | 150 | 750 | 2(20ton) | 30 |
| **Kawasaki Heavy Industries Corp** | Asia | Japan | 3 | 30 | 12 | 75 | 400 | 1 | 50 |
| **JDC Corp.** | Asia | Japan | 6 | 20 | 16 | 300 | 1000 | 1 | 50 |
| **Penta-Ocean Construction Co., Ltd** | Asia | Japan | 6 | 60 | 27 | 300 | 1000 | 0.5 | 70 |
| **Penta-Ocean Construction Co., Ltd** | Asia | Japan | 6 | 60 | 27 | 200 | 750 | 1 | 70 |
| **Tokyu Const. Corp.** | Asia | Japan | 6 | 30 | 16 | 500 | 1500 | 1 | 30 |
| **Okumura Corp.** | Asia | Japan | 6 | 20(60) | 16 | 125 | 1000 | 3(20ton) | 70 |
| **Tobishima Corp.** | Asia | Japan | 6 | 20 | 16 | 200 | 800 | 1 | 30 |
| **Building Research Institute** | Asia | Japan | 1 | 20 | 12 | 150 | 1000 | 1(20ton) | 50 |
| **Port and Airport Research Institute** | Asia | Japan | 2 | 60 | 12 | 200 | 400 | 1 | 50 |
| **Kyoto University** | Asia | Japan | 6 | 14 | 15 | 300 | 1500 | 1 | 50 |
| **Tonji University** | Asia | China | 2 | 14 | 16 | 100 | 1000 | | 50 |
| **Univ. of Buffalo (NEES)** | America | USA | 5 | 50 | 13 | 150 | 1250 | 1 | 100 |
| **Univ. of Calif. at Berkeley (NEES)** | America | USA | 6 | 45 | 37 | 127 | 762 | 2 | 15 |
| **U.S. Army Civil Engin Rese Lab** | America | USA | 3 | 45 | 13 | 300 | 1300 | | 60 |
| **Univ. of Nevada at Reno (NEES)** | America | USA | 2 | 45 | 19 | 300 | 1000 | 2 | 30 |
| **Univ. of Calif at San Diego** | America | USA | 1 | 33 | 15 | 152 | 890 | 1 | 50 |
| **Wyle Laboratories** | America | USA | 2 | 27 | 37 | 152 | 890 | 6 | 100 |
| **Univ. of Illinois at Urbana (NEES)** | America | USA | 1 | 5 | 14 | 50 | 381 | 3 | 50 |
| **NASA - Alabama** | America | USA | 6 | 1 | 14 | 2440 | 100 | | |

**Table 2: Reaction Walls (RW) per Continent, RW Hight and Strong Floor Area**

| Institution | Continent | Country | Reaction Wall Height (m) | Strong Floor Area (m2) |
|---|---|---|---|---|
| **EC Joint Research Centre** | Europe | Italy | 16 | 281 |
| **Building Research Institute** | Asia | Japan | 25 | 500 |
| **Nuclear Power Engineering Corp.** | Asia | Japan | 15.6 | 351 |
| **Fujita Corporation** | Asia | Japan | 10 | 300 |
| **CRIEPI (Central Research Institute of Electric Power Industry)** | Asia | Japan | 9 | 120 |
| **Okumura Corp.** | Asia | Japan | 12 | 210 |
| **Tobishima Corp.** | Asia | Japan | 12 | 410 |
| **Ishikawajima Harima Heavy Industries Co.** | Asia | Japan | 8 | 80 |
| **JDC Corp.** | Asia | Japan | 10.5 | 157 |
| **Tokyu Const. Corp.** | Asia | Japan | 18 | 430 |
| **Obayashi-Gumi Corporation** | Asia | Japan | 12 | 155 |
| **Kajima Corp Ltd.** | Asia | Japan | 12 | 900 |
| **Hazama Corp Ltd** | Asia | Japan | 18 | 423 |
| **Takenaka Corp.** | Asia | Japan | 9 | 570 |
| **Sumitomo Corporation** | Asia | Japan | 11 | 100 |
| **Nihon University** | Asia | Japan | 12 | 285 |
| **Kumagai** | Asia | Japan | 7 | 150 |
| **Shimizu Corporation** | Asia | Japan | 12 | 100 |
| **Southwest Research Institute** | America | USA | NA | 930 |
| **Univ. of Texas Austin (NEES)** | America | USA | NA | 670 |
| **Construction Technology Labs** | America | USA | NA | 630 |
| **Purdue University** | America | USA | NA | 465 |
| **Univ. of Buffalo (NEES)** | America | USA | NA | 453 |

| | | | | |
|---|---|---|---|---|
| **Univ. of Kansas** | America | USA | NA | 372 |
| **Univ. of Nebraska** | America | USA | NA | 319 |
| **Univ. of Colorado at Boulder (NEES)** | America | USA | NA | 260 |
| **Lehigh University** | America | USA | 15.2 | 381 |
| **Univ. of California at San Diego** | America | USA | 15 | 946 |
| **Nation. Inst. of Standards and Tech.** | America | USA | 14 | 345 |
| **Univ. of Calif. at Berkeley (NEES)** | America | USA | 13.3 | 590 |
| **Cornell University** | America | USA | 12 | 300 |
| **Univ. of Minnesota (NEES)** | America | USA | 12 | 297 |
| **Univ. Nacion. Autónoma de México** | America | Mexico | 10 | NA |
| **Univ. of Nevada at Reno (NEES)** | America | USA | 9.5 | 765 |