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CURRENT EARTHQUAKE ENGINEERING PRACTICE FOR JAPANESE NUCLEAR POWER PLANTS*

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ABSTRACT

This paper provides a brief overview of seismic research being conducted in Japan and describes USNRC efforts to understand Japanese seismic practice. Current earthquake engineering practice for Japanese nuclear power plants is described in JEAG 4601-1987, "Technical Guidelines for Aseismic Design of Nuclear Power Plants." The USNRC has sponsored BNL to translate this document into English. Efforts are underway to study and understand JEAG 4601-1987 and make the translation more readily available in the United States.

1.0 INTRODUCTION

During the last decade there has been a major investment in Japan to assure the safety and reliability of nuclear power plants if subjected to strong ground shaking. There are major programs in the areas of seismology; subsoil and foundation; structural, equipment and piping response; computer code development; proving tests and new siting methods. The emphasis has been on improved analytical modeling bench marked by both laboratory and field experiments, calibrated where possible by measurements at operating nuclear power plants. Recognizing the importance of the above activities, the U.S. Nuclear Regulatory Commission (USNRC) has undertaken a program to develop an understanding of the basis for Japanese earthquake engineering practice as applied to nuclear power plants. Ultimately, the goal of the program is to identify those experimental results and field measurements that can be utilized to enhance USNRC seismic design related activities, including those of advanced light water reactors.

2.0 OVERVIEW OF SEISMIC RESEARCH IN JAPAN

Under the sponsorship of the Ministry of International Trade and Industry (MITI), the Nuclear Power Engineering Corporation

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(NUPEC) has performed a number of large-scale seismic testing programs. The Japanese electric utilities, construction companies, equipment manufacturers and universities, as well as other government agencies and organizations, have participated in these programs and/or conducted seismic research activities on their own.

Since 1982, large-scale seismic proving tests of nuclear power components have been conducted on the world's largest shaking table at the Tadotsu Engineering Laboratory (Shibata, et al. 1992). Ten testing programs have been completed. These include test models of PWR and BWR reactor vessels, steel containment vessels, core internals and primary coolant loops. Full scale tests of an emergency diesel generator system and computer systems have also been completed. Future tests include a reactor shutdown cooling system, main steam and feedwater system and prestressed and reinforced concrete containment vessels.

Another major program involves the performance of tests for the verification of seismic analysis codes (Akino, et al. 1991). This program is being used to verify a series of 17 seismic analysis codes which have been under development since 1980 by the Japan Institute of Nuclear Safety (JINS) of NUPEC. These codes are used for the analysis of earthquake ground motions, soil-structure interaction, ground stability, structures, equipment, piping, and tsunami propagation. The verification test program includes: (1) model tests on the embedment effects on reactor buildings, (2) model tests for the evaluation of the seismic behavior of reactor buildings, (3) model tests on the dynamic interaction between reactor buildings and soil, (4) model tests on base mat uplift of reactor buildings, (5) model tests for the evaluation of restoring force characteristics of reactor buildings, (6) tests on the development of floor response spectra, and (7) vibration tests on piping systems. These test programs use a combination of laboratory tests with a shaking table, field tests using hydraulic jacks and vibration exciters, and observed earthquake records.

The current policy in Japan is to construct nuclear reactor buildings on rock. Since this policy limits the number of sites, there is a program in Japan to establish new siting methods for nuclear power plant construction. As part of this program, large-scale field tests have been conducted to investigate the seismic stability of quaternary deposits (Watabe, et al. 1991). Other aspects of this program include studies to establish the methods for evaluating the seismic stability of reactor buildings and the seismic safety of associated equipment.

The results of the research mentioned in this paper, as well as many other programs not specifically mentioned, has brought about a major revision of seismic design practice in Japan, and further advances in seismic technology based on ongoing programs are expected. The revised practice has been documented in a standard published by the Japan Electric Association entitled JEAG 4601-1987, "Technical Guidelines for Aseismic Design of Nuclear Power Plants." A paper by M. Kato (1989) summarizes the content of

these guidelines, which will also be discussed further below. A supplement to this guideline was published in 1991.

3.0 USNRC EFFORTS TO UNDERSTAND JAPANESE PRACTICE

The USNRC has undertaken various efforts to understand Japanese earthquake engineering practice.

In 1984, the first MITI-USNRC Seismic Information Exchange Meeting was held in Palo Alto, California. The aim of this meeting was to improve understanding of the seismic research being conducted in Japan and the United States and to identify areas which could be the basis for future cooperation. Approximately 40 Japanese and U.S. technical specialists in the seismic area participated in this meeting, the proceedings of which were published in NUREG/CP-0059 (1985). A similar meeting was held in Tokyo, Japan in 1988.

One of the outcomes of the first information exchange meeting was the establishment of a cooperative agreement between MITI/NUPEC and USNRC/BNL to perform high level vibration tests and analyses of nuclear power piping. The resulting test program provided extensive non-linear dynamic response data of piping in the elastic-plastic region (Hofmayer, et al. 1990). Discussions are underway to establish another collaborative test program in the seismic area between MITI/NUPEC and USNRC/BNL.

In order to further understand Japanese practice, the USNRC sponsored an effort by BNL to translate JEAG 4601-1987 into English. This effort was a significant undertaking given that the document is approximately 900 pages of technical material.

JEAG 4601-1987 is a comprehensive handbook for the structural analysis and design of nuclear power plants. It contains chapters dealing with: (a) the selection of earthquake ground motions for a site, (b) procedures to be used to investigate foundation and bedrock conditions, (c) criteria for the evaluation of slope stability and the effects of ground movement on buried piping and structures, and (d) procedures for the analysis and design of structures, equipment and distribution systems (piping, electrical raceways, instrumentation, tubing and HVAC duct).

The document discusses the procedures for the selection of the S_1 and S_2 earthquakes, including the use of past earthquake and microtremor records and empirical equations for estimating ground motion intensities. It provides a comprehensive description of the requirements for detailing the site soil conditions. For buried structures conventional methods of analysis as well as more detailed finite element methods are presented, including items such as settlement induced by liquefaction, buoyancy effects and the evaluation of seismic effects on side walls. Procedures for the simplified nonlinear analysis of structures are presented, including empirical equations for the evaluation of shear walls and procedures for evaluating foundation uplifting. Simplified methods

to perform soil structure interaction analysis are presented, as well as detailed guidelines and formulas for the seismic analysis of equipment and supports.

As a result of efforts to study and understand the translation of JEAG 4601-1987, a number of differences between U.S. and Japanese practice have been observed, as well as some interesting approaches which might inspire further study. In order to fully understand the bases for Japanese seismic practice much more information will be required, including obtaining and studying the relevant references cited in JEAG 4601, as well as other publications in the Japanese literature.

Efforts are underway to make the translation of JEAG 4601-1987 more readily available in the United States. If this can be accomplished, it is hoped that various engineers will undertake an effort on behalf of their own organizations to obtain, translate and understand literature cited in areas of the document that are of greatest interest to them.

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