UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAY 11 1980

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 89, "STRUCTURAL AND MECHANICAL COMPONENT TEST TECHNIQUES"

INTRODUCTION

Section 3.9.2 of the Standard Review Plan, NUREG-75/087, entitled "Dynamic Testing and Analysis of Systems, Components and Equipment," gives NRC requirements for dynamic qualification testing. These requirements include seismic qualification tests, usually limited to tests of prototype equipment conducted on shake tables, and in situ flow-induced vibration tests of piping and reactor internals. Ordinarily, significant measurement and analysis of the test results does not occur, except for reactor internals. This is in contrast with Japanese practice in which an in situ preoperational confirmatory seismic test is performed on each nuclear power plant using large shakers mounted directly within the containment. These large shaker tests yield confirmatory model information on virtually all structures and piping systems within the containment, including the containment building. The information so obtained is subjected to considerable scrutiny and analysis during the seismic safety assessment.

This RIL transmits the results of studies which explore and investigate the feasibility, costs, benefits, reliability, limitations and potential plant degradation associated with confirmatory in situ dynamic testing utilizing various means of exciting vibrations in safety-related structures and mechanical equipment. Initially, the focus was on seismic testing; nonetheless, the same experimentally verified analytical models could equally be useful for calculating response for other dynamic situations, such as LOCA blowdown and different missile impact situations. This RIL treats only the various testing methods. A forthcoming RIL will deal with the computer codes used to interpret data collected from these testing methods and the compatibility between test techniques and computer codes.

DISCUSSION

The test methods evaluated in this RIL are intended to be used with in situ, full-scale and fully built nuclear power stations. Approximately 30 such nuclear power plants have, so far, been tested worldwide since 1965 using confirmatory dynamic test techniques and plans of different scopes. Several of these tests were conducted in the USA. Potential objectives for confirmatory dynamic testing are:

- For new plants, dynamic testing may be used for confirmation of design models employed in safety evaluations, and experimental assessment of the assumptions in computer codes.
- For older operating plants, dynamic testing may be used for assessment of dynamic parameters, particularly damping.
- For plants subjected to severe environmental or accidental events, dynamic testing may be used for damage assessment and requalification subsequent to the event.
- For improved safety at all plants, dynamic testing may be used to detect structural degradation and construction errors.
- For decommissioned plants, dynamic testing may be used to establish fragility levels of safety-related structures and mechanical equipment. The lack of good fragility data is a serious impediment to quantitative risk assessment.

As indicated in RESULTS, not all these objectives are presently achievable. The confirmatory dynamic test methods evaluated include snap-back experiments, pulse generators, rockets, buried explosives, ambient vibrations and shakers. No attempt to indicate how confirmatory dynamic testing can be integrated into NRC licensing practice was made, although further effort is planned in this direction.

APPROACH

RES required that its contractor, Lawrence Livermore Laboratory, engage consultants possessing significant experience in confirmatory dynamic testing of nuclear power plants. The contractors were then asked to critique the reports prepared by their competitors. Lawrence Livermore Laboratory then reviewed and commented on the work of their contractors and presented RES with their recommendations. The results reported below are based on NRC's evaluation of the work of Lawrence Livermore Laboratory and its contractors.

RESULTS

The practical choice for conducting confirmatory dynamic tests at nuclear power plants calls for the use of sinusoidal vibrators, especially eccentric mass units. Linear hydraulic, reciprocal hydraulic and electrodynamic shakers may also be used. Hydraulic units are less portable while electrodynamic units are typically of much smaller capacity.

There is no known case where a nuclear power plant was dynamically tested using buried explosives and, subsequently, produced electricity. Although buried explosives (more closely than other methods, but still with some deficiencies) model earthquake motions better than other techniques, they present problems in controlling damage, particularly for facilities in the vicinity of the power station not designed for intense seismic motions. Buried explosives also give rise to various environmental and safety concerns, do not offer great opportunity for repeating tests and lead to difficulties in handling data and extracting from these data high-quality estimates of dynamic parameters. Nonetheless, it is recognized that the evaluation of dynamic parameters is dependent on the test technique; thus, buried explosives, which most closely simulate earthquakes, may give more representative dynamic parameters appropriate for seismic safety evaluations.

Ambient vibrations, primarily due to the need to extrapolate through several orders of magnitude in response accelerations and the need to make statistical assumptions about the source of vibrations, usually lead to poor estimations of dynamic parameters. However, costs are low for ambient tests.

Rocket and pulsor techniques are recently-developed methods in which experience is still being gained. At the present time, with respect to nuclear power plants, it appears that relatively low levels of excitation can be achieved using rockets and pulsors. Moreover, rockets may not be readily used in enclosed facilities and present safety problems during handling, installation and testing.

Snap-back tests are useful in studying local response, but cannot be employed for exciting containments or large equipment within containments due to the difficulty in achieving appropriate force levels.

In terms of reliability of the test data obtained, repeatability, control of plant degradation during testing, maintaining moderate cost, minimizing safety and environmental concerns, and imposing fewer constraints on utility of results, sinusoidal shakers are the preferred excitation source. Snap-back and pulsor devices (not including rockets) may also be used, but are less attractive. Buried explosives, ambient vibrations and rockets can be used, but are the least desirable.

Of the potential objectives listed under DISCUSSION of this RIL, two may not be achieved by confirmatory dynamic testing. Studies indicate that dynamic parameters change substantially even when no damage occurs in structures and equipment; thus, damage assessment by monitoring changing dynamic parameters does not appear feasible. In addition, dynamic testing may not reveal structural degradation or construction errors of importance in many situations, but could assist in identifying very gross degradations and errors.

Not as a stated objective, but as an accrued side benefit, confirmatory dynamic testing can uncover previously unrecognized phenomenology or sensitivities which affect safety evaluations. Examples of this include energy transfer between steam generators undergoing vibratory motions, initially decreasing damping with increasing excitation level, as observed at Diablo Canyon, and the great sensitivity of equipment eigenfrequencies to the torque applied to tighten supporting bolts.

Confirmatory dynamic testing, except when the objective is to establish fragility data, will be at low excitation levels in order to forestall damage, regardless of the test technique selected. A limitation of low-level testing is that it may not yield accurate information for design basis level situations. Usually, however, bounding values of dynamic parameters can be of considerable value.

Costs of confirmatory dynamic testing vary depending on the comprehensiveness sought. A reasonably thorough in situ test of a large commercial nuclear power plant including all planning and preparations, data reductions and associated modeling and analyses would cost on the order of 0.3 to 1.0 million current dollars. For the lower cost estimate, a single test technique may be applied to a limited number of structures and systems. For the upper cost estimate, a few different techniques, useful for checking experimental results, may be applied to a larger number of structures and systems.

CONCLUSIONS

1. In situ confirmatory dynamic tests of nuclear power plants to assess design models and dynamic parameters are feasible, have been proven over the last 15 years, and have become the practice in Japan regarding seismic design adequacy. Confirmatory dynamic testing can also be beneficial with respect to other severe environmental and accident situations.

2. The use of shakers appears to be the preferred and the best established test technique for the routine acquisition of confirmatory dynamic test data. Shakers may be used for buildings, equipment, and components, but other methods may be used.

3. There is not enough evidence to believe that confirmatory dynamic testing can contribute at this time to damage assessment or requalification,for example, in post-OBE inspection.

4. Confirmatory dynamic testing can reveal phenomenology and sensitivities presently ignored or not understood, but which may be significant in seismic or other environmental and accidental safety evaluations.

5. Confirmatory dynamic testing can detect only very gross and major structural degradation and construction errors. This could, however, be of great value despite the limitation to large effects.

The three contractor reports obtained through Lawrence Livermore Laboratory which document these findings and give greater detail are published as NUREG reports.

RECOMMENDATIONS

Based on technical and economic considerations, this research indicates that it is feasible to use in situ dynamic seismic testing to confirm and resolve issues regarding seismic vulnerability at new and already operating plants. Good confidence exists that the results of such testing will assist in licensing decision making. However, in situ dynamic testing cannot be a major contributor to damage assessment and identification of construction and installation errors at this time.

Robert Budnitz

Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

The three contractor reports obtained through Lawrence Livermore Laboratory which document these findings and give greater detail are enclosed.

Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

Enclosures:
1. "Methods and Benefits of Experimental Seismic Evaluation of Nuclear Power Plants," ANCO Engineers, Inc., dtd July 1979.
2. "Verifying Seismic Design of Nuclear Reactors by Testing," Volume I and II, Agbabian Assoc., dtd July 1979.
3. "Detection of Damage in Structures from Changes in their Dynamic (Modal) Properties," SMS Inc., dtd September 1979.

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RECOMMENDATIONS

Based on technical and economic considerations, this research indicates that it is feasible to use in situ dynamic seismic testing to confirm and resolve issues regarding seismic vulnerability at new and already operating plants. Good confidence exists that the results of such testing will assist in licensing decision making. However, in situ dynamic testing cannot be a major contributor to damage assessment and identification of construction and installation errors at this time.

Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

bcc: V. Stello, NRR

NOTE: Draft RIL was sent to NRR and RES for comment on March 19, 1980. Written comments were received from S. N. Hou (NRR), S. Chan (NRR) and Jim Costello (RES). Telephone comments were received from C. Hofmayer (NRR) and T. Cheng (NRR). Comments have been incorporated into final version of the RIL. (NRR-77-18)

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JUN 27 1980

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

SUBJECT: SUPPLEMENT TO RESEARCH INFORMATION LETTER NO. 89

Information has been submitted which documents dynamic testing on eighteen nuclear power plants. Of the plants tested, six were in the United States, five in Japan, three in Germany, and the remaining four were performed in Italy and India. The primary methods of excitation were sinusoidal vibrators and snap-back testing. The structures most often tested include containment buildings, piping, and internal equipment.

Valuable information about dynamic behavior has been gained from dynamic testing without significant damage to reactor components or systems and should be considered as a part of our regulation effort.

An enclosure to this memorandum gives greater detail.

Original Signed By
Robert J. Budnitz

Robert J. Budnitz, Director
Office of Nuclear Regulatory Research

Enclosure: Nuclear Power Plants Subjected to Dynamic Testing with Post-Test Operability Requirements

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Nuclear Power Plants Subjected to Dynamic Testing with Post-test Operability Requirements

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
Diablo Canyon (1977)	Calif.	ANCO Engineers Santa Monica, California	Model verification to support licensing activities/Snap back, sinusoidal at response levels in range of 0.1 g to 1 g for piping systems, from 0.03 g to 0.2 g for balance of systems.	Six piping systems, fluid tanks, heat exchangers, gas storage vessels, valves	Excited by direct load application to test object; determined frequencies, modal damping, mode shapes; used results for some design modifications where indicated; pipe restraint stiffness measured. Piping system damping varied from less than 1% to nearly 15%, depending upon amplitude, degree of restraint, pipe dimensions. Typical piping behavior was that more flexible systems exhibited higher damping in lower modes. Piping system example by mode: 7%-8% first 3 modes, 4%-5% damping for second 3 modes. The high value of 15% was measured at low levels of response; friction effects were overcome and dropped to 7% at ∿ 1 g. Piping system #2: 3%-4% damping for first three modes at ∿ 1 g, next two modes at 1%-2%. Valves: 1%-4%, with 2% typical. Diesel generator - first two transverse/rocking modes were 5% damped at 0.2 g; higher modes 2%-3%. /ANCO Report 1122-4.b. volumes 1-9 (Proprietary)
Indian Point - 1* (1979, 1980)	New York	ANCO Engineers Santa Monica, California	Nonlinear piping-dynamics research and effects of modern support hardward at moderate response levels/ Sinusoidal and snap back testing.	Feedwater piping: 20 cm diameter, 30 m length	Testing system as-built and after installation of variety of supports in different configurations. Peak amplitudes > 2 g; peak uniaxial strains 20% of yield in first phase of testing. Damping ∿ 2% for lightly supported original design. Modified systems to be tested late 1980 at higher strain levels

* at time of test initiation no test amplitudes was permitted which would impair IP1 license. Thus, was tested consistent with any operational plant.

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
Indian Point - 2 (1972)	New York	Westinghouse	Linear regime piping dynamics research/ Sinusoidal	Primary coolant loop	Peak amplitudes: 0.1% - 1% g. Damping from 1% - 5% of critical / Westinghouse Report WCAP-7920, 1972
*Heissdampf-reaktor (1975, 1979)	Federal Republic of Germany	ANCO Engineers Santa Monica, California	Research in small amplitude and moderate amplitude nuclear power plant dynamics/Snapback, sinusoidal, impact, blast testing, rocket tests	Containment building, primary coolant piping, experimental piping, reactor pressure vessel, flood water storage tank	1975 Tests - excited up to ∿ 1% g on containment, 0.5% - 40% g on equipment maximum piping strain less than 5% of yield strain. 1979 Tests - Using 110 ton (1100 k N) shaker forces, containment excited to ∿ 6% g at fundamental, equipment up to 1 g; one piping system loaded above yield on one or more strain gauges. Containment damping: 1% - 6% (fundamental about 1.5 Hz, force ≃ 36 tons) 3% - 4% in higher modes/ ANCO Proprietary Reports; also 4th SMIRT, Paper K 8/5; and 5th SMIRT, Papers K 13/2, K 13/3.
Kernkraft-werk Phillipps-berg - 1 (1976)	Federal Republic of Germany	ANCO Engineers Santa Monica, California	Model verification study for licensing support/Snapback; peak responses ∿ 0.2 g, ∿ 1.0 cm	Piping for ECCS; approximately 20 m length by 0.25 m diameter; piping system strongly restrained	First made theoretical frequency was 35% less than that measured and was 25% less after model modifications which reflected 'as-built' conditions. Analysis performed by separate companies with comparable results. Piping system appeared stiffer than expected; hypothesized was support effect after ultrasonic mapping of piping dimensions. Nonlinear effects significant at low response levels. At high response (with gaps shimmed),

* test amplitudes limited by licensing considerations; later blowdown testing required strict dynamic test control during 1975 tests. 1979 tests permitted larger amplitudes.

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subject	Significant Aspects of Testing/ Reference
Kernkraftwerk Phillippsberg - 1 (continued)					first mode was 9% damped at 2.1 Hz. Next seven modes $\beta > 6\%$ (up to 5Hz); next eight, $\beta \simeq 2\% - 4\%$, average about 3%. Reanalysis with experimentally based models indicated seismic loads were overestimated in design by factor of two. /ANCO Proprietary Report 1098-2
Fukashima #1 (1969) See Shimane test below for comparison investigation)	Japan	Muto Institute, et al Tokyo	Research to investigate site effects for two identical plants on different soils (see Shimane test below). Plants were 460 MWe BWR/ Sinusoidal	Containment Building	Excited in refueling floor with peak sinusoidal forces up to three tons; peak amplitudes of order 10^{-4} g's on refueling floor Fukashima in firm soils; shear wave velocity, 2000 ft/sec; pressure wave velocity, 5576 ft/sec. (This site had shear wave velocity of only 1/3 of Shimane site.) Results: Mode Period (Frequency) Apparent Damping 1 0.25 sec (4.0Hz) 34% 2 0.17 sec (5.9Hz) 8% 3 0.089 sec (11.2Hz) 5% /Paper K 5/3 SMIRT II, 1973 (Berlin)
Shimane (1972) See Fukashima test above)	Japan	Muto Institute, et al Tokyo	Research to investigate site effects for two identical plants on different soils (see Shimane test below). Plants were 460 MWe BWR/ Sinusoidal	Containment Building	Same test conditions as above except site was rock; shear wave velocity, 5900 ft/sec; p-wave velocity, 12,140 ft/sec; Youngs modulus, 220 ton/cm^2, about 12 times greater than Fukashima site. Results: Mode Period (Frequency) Apparent Damping 1 0.19 sec (5.3Hz) 2% 2 0.13 sec (7.7Hz) 5% 3 0.086 sec (11.6Hz) 5%

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
Fugen (1979)	Japan	Takasago/ Mitsubishi Tokyo	Verification of dynamic parameters used in seismic design for licensing purposes/ sinusoidal and snap-back	Primary coolant piping and feed-water piping in BWR pressure-tube reactor (165 Mwe D_2O moderated)	Tested 267 mm to 508 mm outside diameter piping runs. Forces limited to 220 lbs (980 N) on primary piping and 110 lbs (490 N) on feedwater piping. Peak response levels about 0.1 g on feedwater piping; about 0.02 g on primary piping. In all tests gaps closed to eliminate nonlinear effects from seismic support elements. Results showed primary piping damping at 6% at 13.5 Hz first mode, 8% second, 2% third, 6% fourth, 6% fifth, 3% sixth; 1% seventh, unspecified eighth, and 7.5% ninth (at 19.6 Hz). The primary system was complicated, consisting of down comers, headers, manifolds. Feedwater piping relatively simple, smaller diameter (267 mm) with 5 straight runs and 6 elbows, 12 snubbers, plus spring and constant force hangers. Test results were damping of 0.7% first mode (8.6 Hz), 2.1% second mode, 4.5% third mode (17.0 Hz). Agreement between analysis and results good only in lower modes./5th SMIRT Paper K 13/8.
Hamaoka 1 & 2 (1973, 1974, 1977)	Japan	Chubu Electric/ Takenaka Technical Research Lab. Tokyo	Research in soil-structure interaction and through space soil coupling of two BWR/Sinusoidal Additional Note Paper K 2/16, 4th SMIRT reports that 1 ton force produced peak response of	Containment building tested with forces up to 100 tons; forces applied to refueling floor of BWR MK1-type plant	1973, 1974 - low level tests of unit 1; papers K 3/2, K 2/16 (3rd SMIRT, 4th SMIRT) 1977 - Higher level tests (5th SMIRT, paper K 13/4 At maximum force at first mode (about 18 tons at 2.5 Hz), generated peak displacement of 10 microns or 2.5 x 10^{-4}g's at 2.5 Hz. Results of testing at accelerations up to 3 x 10^{-3}g's (0.3% g) gave following containment building results for east-west direction (N - S about same.)

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
Hamaoka 1 & 2 (continued)			about 7.5 microns at 4.6-4.8 Hz first and second mode and damping of 23% each mode. Paper K 13/4 suggests that force increase of 18 times reduces first and second mode frequency to 2.5 Hz and 3.4 Hz and increases β to 40% - 50%.		Freq., Hz / Damping, % of Critical: 2.49 / 39.6 3.44 / 49.3 4.63 / 19.9 5.02 / 20.4 5.67 / 19.2 6.11 / 17.2 6.59 / 15.2 7.08 / 3.1 7.50 / 2.7 7.89 / 13.5 8.70 / 12.4 9.14 / 15.6 1 Hz to 4 Hz were soil-structure modes; 4 to 5.7 Hz were building-building interaction effects. Site soil shear were velocity, 2600 ft/sec (800 m/sec); unit weight, 125 lb 7 ft 3 (density of 2.01 ton/m^3/3rd SMIRT paper K3/2; 4th SMIRT paper K 2/16; 5th SMIRT paper K 13/4

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
Humboldt Bay (1974)	California U.S.A.	ANCO Engineers Santa Monica, California	Modeling verification to support seismic upgrading to new criteria/Sinusoidal and snapback testing	Storage tanks, pumps, motors, valves, electrical cabinets, piping, turbine pedestals, containment, stack	Five case studies reveal the benefits of testing: Case One is a Liquid Poison Tank, the testing of which was used to simplify the model of the existing tank and define stiffness properties for use in the analysis. Case Two involved the high level *in-situ* proof testing of an emergency generator. Case Three test results, for the Reactor Control Board, indicated the need to stiffen several panels and provided the necessary information for the development of a model which was used to predict input spectra for selected instruments mounted on the panel. Certain of these instruments were subsequently shake-table tested by others according to the developed spectra. The fourth case involves a 250 ft ventilation stack. Test data were used to verify the analysis of the stack. The final case concerns testing of the control room floor. Test results pointed out the need for structural modification. The basic conclusion of this paper is that *in-situ* testing is a feasible and useful method to improve and guide theoretical studies and seismic design of nuclear power plant equipment and structures./ K 8/3 SMIRT 4 1977.
San Onofre Unit 1 (1969 - 1972)	California U.S.A.	ANCO Engineers Santa Monica, California & U.C.L.A.	Model verification and research investigation of dynamics. Creation of validated models./ Sinusoidal		Excitation of the containment with up to 5 tons of force was used to investigate soil-structure interaction and primary loop dynamics. Results were compared to San Fernando e.q. response and to analytical models. Soil-structure modes were found to be highly damaged (16% to 18% @ 10^{-3}g sine tests, 20% at 10^{-2} g earthquake)

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
San Onofre (contd.)					Damping in primary loop ranged from 1.5% to 4.0% at 10^{-2}-10^{-1}g. Models of varying degree of sophistication were fit to the data and led to equipment support modifications./ Nuclear Engineering and Design, 25 1973 pp 51 - 94.
Quad Cities (1972)	Illinois, U.S.A.	U.C.L.A. & ANCO Engineers	Containment Dynamic Research/Ambient and Impact	Containment	Testing to plan longer program to validate models. Frequencies and damping were identified at very low response amplitudes./ ANCO internal memorandum.
VAK (1975, 1979)	Kahl, West Germany	ANCO Engineers, Santa Monica, California	Monitoring to assure no regulatory implication during nearby testing of Heissdampfreaktor (HDR)/ Blast Testing	Containment, primary coolant loop	Response to 10 kg blasting 200 meters distant measured. Results compaired to analysis and used to demonstrate safety of plant. /Heissdampfreaktor (See entry on HDR)
PEC (1972-1974)	Bologna, Italy	CNEN Roma	Forced vibration tests to validate models and effects of modifications./ Ambient and Sinusoidal.	Containment and Crane Bridge Structure	Ambient survey and shaker methods were found useful in identifying ovaling and breathing modes with minimum plant operation disruption. Model structures were also tested. Resonant frequencies of all three sources agreed to within 10%./ SMIRT II K 5/4, SMIRT III K 6/8
ENEL IV (1976)	Caorso, Italy	ISMES Bergamo	Ambient and forced vibration to validate test methods and computer models. Also correlated with actual earthquake responses./Sinusoidal and earthquake.		Damping of 10% - 15% measured, along with 10 modes 3 - 16 Hz. Effects of water level in pool investigated. Experimental frequencies higher than computed./ K 8/4 SMIRT IV

Plant Name (Date)	Location	Test/Analysis Organization	Purpose of Testing/ Test Methods	Major Test Subjects	Significant Aspects of Testing/ Reference
MAPP, RAPP (1975)	Two plants in India	PPED, Dept. of Atomic Energy, India, University of Roorkee	Snapback tests to determine frequency and damping to evaluate seismic capacity.	Internal Equipment (Condensers, tanks, heaters.)	Up to two tons of force were used to excite equipment. Damping from 1.6% to 6.5% measured. Found that piping attached to equipment greatly increased equipment damping./ K 8/7 SMIRT IV
Tokai - II	Japan		Investigate the safety of the seismic design via parameter investigation and research for future design purposes./ 150 tons maximum force at BWR refueling floor with sinusoidal force.	Containment building of 1100 MWe BWR	First mode damping with soil-structure interaction effects was estimated at 15% to 25% versus the value of .5% used in design./ Proceedings 5th Japan Earthquake Engineering Symposium, Tokyo, 1978.