Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Seismic Risk Reduction in Italy through Innovative Techniques: 1 - Progress of R & D on Seismic Isolation

Alessandro Martelli[1], Massimo Forni[1], Alberto Dusi[2], Giuseppe Bonacina[3] and Tito Sano'[4]

1) ENEA & GLIS, Italy
2) ENEL-Ricerca & GLIS, Italy
3) ISMES & GLIS, Italy
4) ANPA & GLIS, Italy

ABSTRACT: Summarised in this paper are the some of the most recent studies performed in Italy on seismic isolation (SI), partly funded by the European Commission (EC) or sponsored by the International Atomic Energy Agency (IAEA): (1) detailed numerical analyses of elastomeric isolators, performed in the framework of a IAEA Co-ordination Research Programme; (2) development of design guidelines for isolated nuclear plants applicable in the EC countries and Russian Federation; (3) analysis of the benefits of floor SI of strategic civil buildings with modular steel-frame structure; (4) records of an aftershock of the 1997 Marche & Umbria earthquake on a seismically isolated building; (5) promotion of demonstration applications of innovative anti-seismic techniques to both new constructions and existing buildings; (6) evaluation of the benefits of applying SI to chemical plant components. A separate paper deals with R&D in progress in Italy on passive energy dissipation (ED) systems.

INTRODUCTION

Large efforts are in progress in Italy on the development, validation and application of seismic isolation (SI) and passive energy dissipation (ED) for civil and industrial structures, including high risk plants such as nuclear reactors and chemical equipment [1, 2]. Such innovative anti-seismic techniques have already been adopted for over 150 Italian bridges and viaducts and over 30 Italian buildings [3]. The ongoing R&D activities are being performed in framework of both national collaborations among the members of the Italian Working Group on Seismic Isolation (GLIS), and international co-operative projects between GLIS members and other European and non-European partners.

Studies relevant to SI began in Italy in 1988, and concern experiments and numerical modelling of isolators and isolated structures, as well as development of design guidelines. In particular, a research project, funded by the European Commission (EC) and completed in 1996, allowed for the development of optimised High Damping Rubber Bearings (HDRBs) [1, 2, 4, 5]. In addition, wide-ranging numerical analyses and tests were carried out by ENEL for the enhancement of seismic protection of electric equipment using HDRBs, helical springs in parallel with viscous dampers and wire ropes [5, 6]. Based on the results of these studies, further R&D work has been carried out in Italy on both SI and ED systems [5-11].

This paper briefly summarises the main features and results of the most recent activities on SI which have been so far performed by the authors on the aforesaid items. A separate paper [12] deals with R&D in progress on ED systems.

Due to the complexity of dynamic behaviour of SI devices, high cost of their tests and non-negligible number of devices having excellent potential for nuclear applications, several countries judged of great interest to extend validation of their numerical models of such devices to the analysis of experimental data obtained by others [6]. Thus, a four-years Co-ordinated Research Program (CRP), proposed by ENEA, was endorsed by the International Atomic Energy Agency (IAEA) in 1996. There, Italy is jointly represented by ENEA, ENEL and ISMES, which supplied test results of project [4], concerning both HDRBs and the MISS (Model of Isolated Steel Structure) mock-up isolated using such bearings.

The first data, among those provided by other countries, which were jointly analysed by ENEL and ENEA, concerned U.S. scaled HDRBs that had been manufactured in Italy [5]; then, Japanese Natural Rubber Bearings (NRBs) and Lead Rubber Bearings (LRBs) and Korean HDRBs were analysed (Fig. 1) [5, 7]. Both three-dimensional (3D) and axisymmetric finite-element models (FEMs) of the isolators were developed and implemented in ABAQUS computer program, based on previous experience for the Italian HDRBs [1, 2, 5]. Hyperelastic models of the rubber, defined according to the results of suitable tests on both scragged and unscragged rubber specimens, were also implemented in ABAQUS. Extensive numerical work was performed by considering meshes with different refinements and different element types. The numerical analyses, aimed at investigating the effects of the numerous variables of the problem, allowed for optimising the type of material model, discretisation and elements to be adopted, up to large strains.

For the Japanese NRBs and especially U.S. HDRBs, good agreement between numerical and experimental results was found for horizontal stiffness; however, the agreement for compression tests was satisfactory only when compressibility was taken into account [5-7]. This confirmed the importance of volumetric tests on rubber specimens to correctly evaluate bearing vertical stiffness, especially in the case of large shape factors. Analysis also stressed that planar tests on specimens shall be performed to very large deformation, in order to allow for the definition of adequate hyperelastic models of the rubber [5-7]. Moreover, it was found that the unscragged rubber model should be used for reproducing bearing behaviour to 50% - 100% shear strain, while the scragged model should be used for larger deformations. Only slight differences were found between the results of 3D and axysimmetric models to 200% - 300% shear strain, while 3D models shall be used for larger deformations.

Also for the Korean HDRBs and Japanese LRBs (Fig. 1) [6, 7], numerical analysis was found to be adequate for horizontal stiffness, to 300% shear strain; however, at larger strains the numerical results showed hardening, contrary to test data. In addition, large discrepancy was found between the numerical results and test data for LRBs under compression with different offset strains: this must be attributed again to modelling rubber as incompressible in constitutive equations. Similar to the NRBs, for LRBs the need was stressed for an improvement of the analyses, based on more precise data concerning the characterisation of materials (natural rubber and lead), including effects of rubber compressibility. In addition, an attempt should be made to consider temperature effects on lead behaviour.

In any case, the already achieved results confirmed the conclusions of previous studies [1, 2, 5] that FEMs are useful tools for both the detailed design of elastomeric bearings and their qualification; for the latter, they allow for a considerable reduction of the number of tests to be performed (e.g. those concerning effects of parameters like temperature, ageing, vertical load on horizontal stiffness, initial or arisen defects, etc.).

With regard to the analysis of isolated structures [8], a new non-linear simplified isolator model was developed by ENEL, with an exponential constitutive law for describing rubber

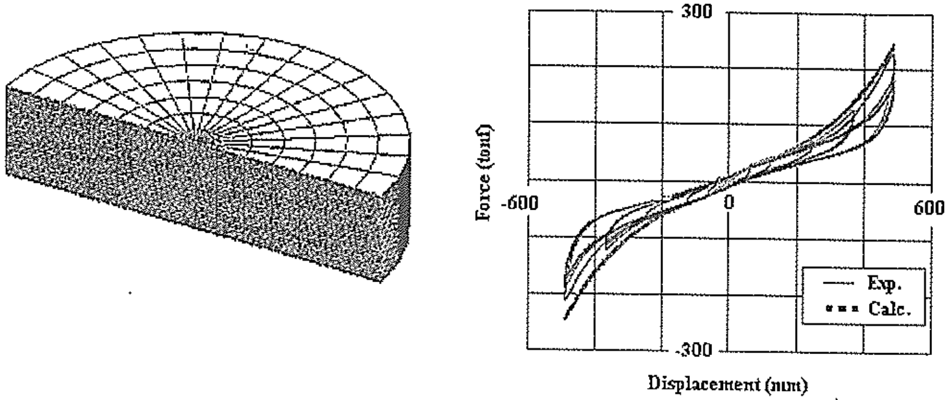

Figure 1: Finite element model of a lead rubber bearing and numerical - experimental comparison (combined vertical and horizontal cyclic tests up to 400% shear strain)

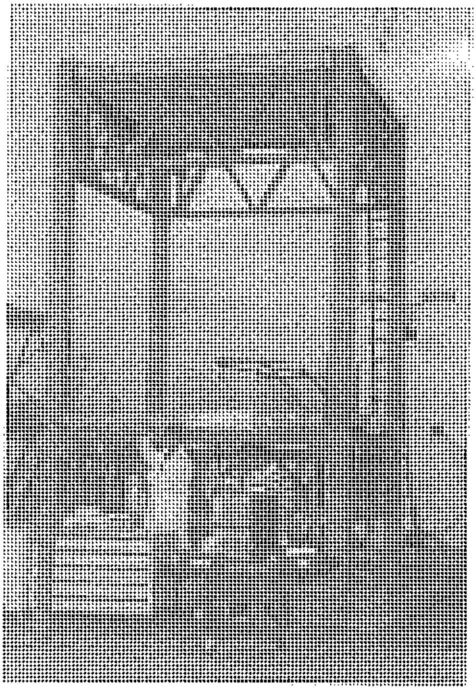

Figure 2: Model of a steel-frame (INSO hospital) with floor isolation during shaking table tests at ENEA laboratories at Casaccia (Rome)

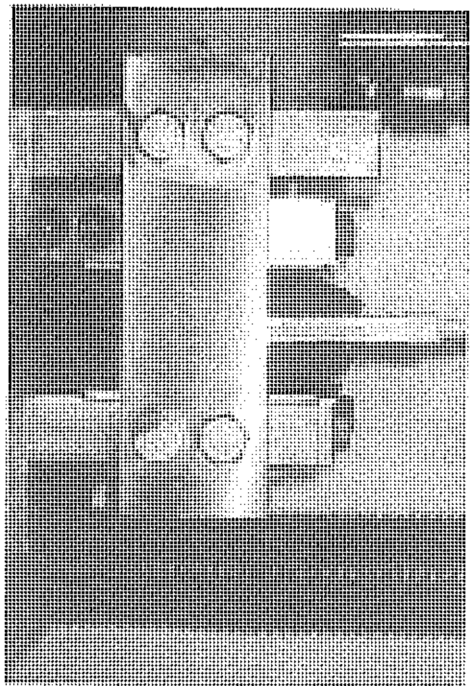

Figure 3: Floor isolation devices with innovative high-friction attachment system during qualification test (ALGA) at 400% shear strain

behaviour [9]. It was implemented in ABAQUS as a "User Subroutine". It is based on three rubber parameters and allows for a very accurate evaluation of the response of seismically isolated structures, as shown by comparison with the results of shake table tests carried out on MISS [8, 9]. Although it was developed for elastomeric bearings, it may be also applied to other kinds of SI devices having a continuously decreasing stiffness with increasing displacement (e.g. rubber or helical springs coupled with metallic yielding elements, wire rope friction isolators, etc.).

DESIGN GUIDELINES FOR ISOLATED NUCLEAR PLANTS AND CIVIL BUILDINGS

The development of design guidelines for isolated structures was initiated in Italy by ENEA in 1989, making reference to the nuclear plants. The most recent activities were performed, with the co-operation of ENEL, ISMES and other partners, in the framework of EC-funded projects and concerned harmonisation of such guidelines between the EC countries and Russian Federation and their extension to Russian 3D SI systems and innovative rolling systems, developed in a further ongoing EC-funded project (REEDS) [10, 11].

In addition, ANPA, ENEA, ENEL and ISMES co-operated on the development of national rules for civil buildings, by supporting the Italian National Survey on the assessment of a proposal for guidelines which was submitted to the Ministry of Constructions in 1993, by collaborating with the National Standard Authority (UNI) and European Code Committee (CEN) on the development of national and European rules for the isolation devices and in 1998, by collaborating with other GLIS members on the preparation of comments to guidelines drafted by the Italian Ministry of Constructions [11].

FLOOR ISOLATION OF CIVIL BUILDINGS WITH MODULAR STRUCTURE

In the framework of a study contract of "Studio Antonucci" [11], numerical analyses and shake table tests (Fig. 2) were performed by ENEA in 1998 for a full scale portion of a steel structure building of the Company INSO, which has the patent for the construction method ("Oxford Method"). It is a modular structure, which is being used for the construction of public buildings (in the our case, a hospital). The purpose was the evaluation of feasibility and technical and economic benefits of floor SI. This is a very innovative technology, for which no applications exist yet (to the knowledge of the authors), in Europe at least.

In addition to the above-mentioned analyses and tests, ENEA also designed the isolators (HDRB type); in particular, it designed a new, very innovative and low cost isolator restraint system, consisting of shagreened plates (Fig. 3) and designed and supervised the isolators' qualification tests. Such tests stressed the great efficiency of the new restraint system, which allows for isolator lateral deformation to about 400% shear strain, i.e. very close to those typical of more complicated and expensive systems, such as bolting [1, 2, 4, 5]. Numerical analyses of the isolated structure and the related tests also provided excellent results [11].

RECORDS OF AN AFTERSHOCK OF 1997 MARCHE - UMBRIA EARTHQUAKE

Some interesting records of an aftershock (March 1998) of the earthquake which struck Central Italy (Marche and Umbria Regions) on September 26, 1997, became available for one of the five isolated buildings of the National Telephone Company ("TELECOM Italia") Centre at Ancona (Fig. 4). This building had been subjected to both forced and free-vibration excitation tests in 1990, just after completion of structure construction [2, 5]. The first,

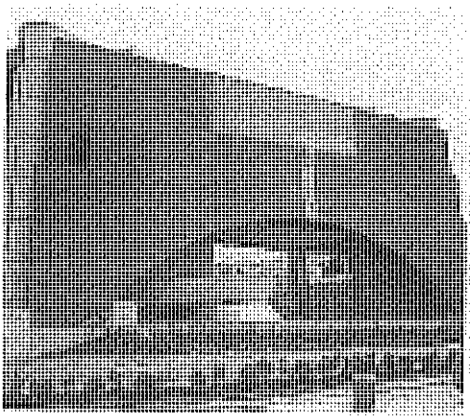

Figure 4: Telecom building (Ancona) subjected to on-site tests and provided with monitoring system.

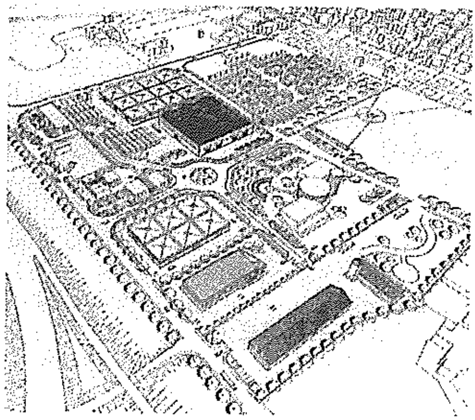

Figure 6: Plan of the new Emergency Management Centre of Central Italy, Foligno, Umbria.

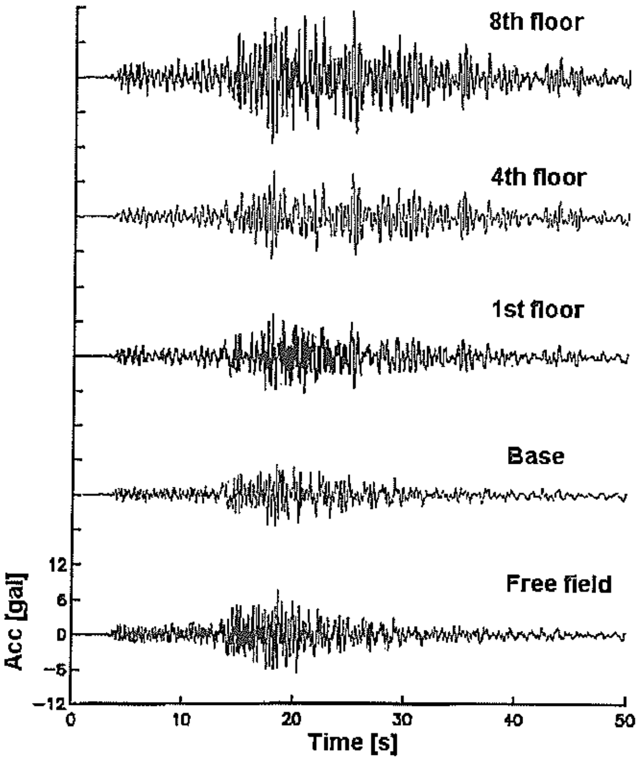

Figure 5: Telecom building: aftershock records (March 1998) of the 1997 Umbria & Marche earthquake

carried out by means of an eccentric mass mechanical vibrator located on the roof, had allowed for the dynamic characterisation of the superstructure and evaluation of the behaviour of the SI system at low excitation level (lateral displacement being only a few millimeters). The second, on the contrary, had enabled the characterisation of SI system at high excitation: they had been conducted by laterally displacing the building (to a maximum of about 110 mm) by means of hydraulic jacks, then replacing them with collapsible devices provided with explosive bolts and finally, exploding bolts.

After full construction completion, the building had been provided by ENEL and ISMES with an innovative monitoring system, capable of recording both seismic and wind vibrations. However, during the first two main shocks of September 26, 1997, of Marche and Umbria earthquake, the system did not record any signal, because its threshold level (0.01 g) was too high (Ancona is located at about 100 km from the epicentre). Thus, such a threshold was lowered to 0.005 g. This enabled for the aforesaid recording in March 1998 (Fig. 5). Data processing [11] showed results which are fully consistent with those of 1990 forced vibration tests (the structure displacement was about 3 mm, similar to that reached in those tests). They also showed that life effects of the SI system are negligible, in agreement with the results of natural ageing tests which are being periodically performed by ISMES, on behalf of the owner SEAT and with the co-operation of ENEA, on spare isolators stored on-site, under the vertical design load (through a suitable equipment), close to those supporting the building.

PILOT APPLICATIONS OF THE INNOVATIVE ANTI-SEISMIC TECHNIQUES

Although the innovative anti-seismic techniques are fully mature for an extensive use and excellent experience and knowledge are available for this in Italy [5], in our country the recent applications of these techniques are less numerous than in others that are characterised by high seismic risk. This is due to both the continuing absence, in Italy, of suitable design rules or guidelines, and construction costs which are usually larger than those related to conventional constructions (although only by about 10% and only if basing on the present law requirements, which are insufficient for strategic structures, at least) [11]. Thus, there is the need for stimulating new applications, with the collaboration, even from the financial point of view, of Regional Governments and through promotion actions towards Local Institutions, designers and public opinion.

For these reasons, in 1997, ENEA started actions to promote pilot applications of innovative anti-seismic techniques to both new constructions and existing buildings in Italian Regions. Such actions, which later became part of those foreseen by the 1998 National Conference on Energy and Environment [11], include formal agreements among ENEA, local Universities, Regional Governments, Local Institutions and other partners. The latter may comprise: (a) identification of the pilot applications, in co-operation all partners; (b) funding of Regional Governments of possible extra-costs due to the use of the innovative systems; (c) technical support of ENEA, local Universities and other technical partners, for the design phase (selection of the anti-seismic system, numerical analyses, assistance for qualification tests, verification of compatibility with design rules) and / or construction (verification of consistency with design requirements, assistance for the acceptance of anti-seismic devices and installation of seismic monitoring system), and /or certification of the building; and (d) technical support of ENEA for the adoption (where possible) of design solutions which are also capable of improving building energetic efficiency.

The aforesaid agreements have already been formally proposed to Marche, Tuscany and Umbria Regions, and in a preliminary way, to Sicilian Region. Umbria has already accepted the ENEA proposal and the agreement document has already been drafted. To develop the aforesaid proposals, numerous Local Institutions have also been contacted, by also organising or participating in various Seminars or Conferences for both engineers an the public.

In both Marche and Umbria Regions some pilot applications have already been identified. The most important is to the new Emergency Management Centre of Central Italy of Foligno, which is already partly under design (Fig. 6). Other already identified applications should be at Città di Castello, Camerino (the new Department of Biology and a building owned by the municipality) and Nocera Umbra (reconstruction of a village, strongly damaged by the 1997 earthquake, using original masonry materials and SI, possibly within an EC-funded project).

Finally, Regional and Local Institutions of Marche and Umbria ensured their collaboration to a national project concerning the "development and application of integrated innovative technologies and assessment of comparison methodologies to optimise interventions of seismic protection of cultural heritage by respecting safety and preservation requirements", which was proposed to the Italian Ministry of University and Scientific Research [11].

SEISMIC ISOLATION OF INDUSTRIAL PLANTS

A study, proposed by ENEA, ANPA and University of Rome "La Sapienza", was funded by the Italian National Research Council (CNR) in 1998 to evaluate the benefits of applying SI to the protection of industrial plant components [11]. The ongoing first step on the study concerns the identification of a reference typical component. The aim is also to make a real SI application possible, at the conclusion of the study. A chemical plant component was chosen, according to the particular seismic vulnerability of some of such plants. Contacts have been established with important national chemical companies, which anticipated their interest in collaborating to the project. The partners proposed a tank as the reference component. The final decision will be taken as soon as answers to such a proposal are received from contacted companies.

CONCLUSIONS

Activities on SI of the Institutions to which the authors belong have been shortly described. It has been shown that such activities cover numerous important fields, including R&D and design for civil and industrial structures, development of design rules and promotion of new applications. Work performed for energy dissipation systems is reported in a separate paper.

ACKNOWLEDGMENTS

Particular thanks are due to Mr. F. Bettinali of ENEL, Mrs. G. Bergamo of ISMES, Mr. A. Pugliese of ANPA and Mr. M. Indirli and Mr. G. De Canio of ENEA: their names were not included among those of co-authors only due to the limit to five co-authors which was allowed for this paper.

REFERENCES

1. Forni, M. et al., "Development and Validation of FEMs for the Design and Qualification of HDRBs," *Trans. of the 14th International Conference on Structural Mechanics in Reactor Technology*, Vol. 7, pp. 491-498, Lyon, France, August 1997.

2. Dusi, A. et al., "Experimental and Numerical Evaluation of Benefits of Optimized HDRBs for Seismic Isolation," *Trans. of the 14th International Conference on Structural Mechanics in Reactor Technology*, Vol. 7, pp. 507-514, Lyon, France, August 1997.

3. Martelli, A. and Forni, M., "Seismic isolation of civil buildings in Europe," *Progress in Structural Engineering and Materials*, Construction Research Communications Ltd., London, Vol. 1 (3), 1998, pp. 286-294.

4. Enel, Alga, Dywidag, Enea, Mrpra, Shw, Stin, *Optimization of Design and Performance of High Damping Rubber Bearings for Seismic and Vibration Isolation*, EC Contract BR2 CT93 0524, Project BE7010, Bruxelles, Belgium, 1993.

5. Martelli, A. and Forni, M. (eds.), *Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibrations of Structures - Proceedings of the International Post-SMiRT Conference Seminar, Taormina, Italy, August 25 to 27, 1997*, GLIS, Bologna, Italy, 1998.

6. Forni, M. et al., "Progress of Activities Performed in Italy by ENEA and ENEL on Seismic Isolation and Passive Energy Dissipation," *Proc. of the 1998 ASME-Pressure Vessel and Piping Conference*, PVP-Vol. 379 (Seismic, Shock and Vibration Isolation – 1998), pp. 19-41, San Diego, CA, USA, July 1998.

7. Dusi, A. et al., "Contribution of Italy to the Activities on Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures: Finite Element Analysis of Lead Rubber Bearings," *Proc. of the Third Research Co-ordination Meeting of IAEA CRP on "Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures", IAEA-RC-624.3 (IWGFR/95)*, pp. 50-63, Hertford, UK, May 1998.

8. Forni, M. et al., "Contribution of Italy to the Activities on Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures: Shake Table Tests on a Steel Structure Mock-up," *Proc. of the Third Research Co-ordination Meeting of IAEA CRP on "Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures", IAEA-RC-624.3 (IWGFR/95)*, pp. 63-100, Hertford, UK, May 1998.

9. Dusi, A. and Rebecchi, V., "Contribution of Italy to the Activities on Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures: a Parallel Elastic-Plastic Model for Non-Linear Analysis of Base Isolated Structures," *Proc. of the Third Research Co-ordination Meeting of IAEA CRP on "Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures", IAEA-RC-624.3 (IWGFR/95)*, pp. 42-49, Hertford, UK, May 1998.

10. Forni, M. et al., *Extension of the Available Design Guidelines for Seismically Isolated Nuclear Plants to 3D Systems Developed in the Russian Federation and Rolling-Ball Rubber-Layer Systems*, Final Report, EC Contract EC B7-6340/95/001169/MAR/C2, ENEA, Bologna, Italy, 1998.

11. Martelli, A. et al., "New Activities Performed in Italy on Innovative Anti-Seismic Techniques for Civil and Industrial Structures," *Proc. of the 1999 ASME-PVP Conf., Boston, USA*, Boston, USA, July 1999.

12. Dusi, A. et al., "Seismic Risk Reduction in Italy through Innovative Techniques: 2 – R&D on Passive Energy Dissipation Systems," *Trans. of the 15th International Conference on Structural Mechanics in Reactor Technology*, Seoul, Korea, August 1999.