SMiRT–12 / K. Kussmaul (Editor)

K21/1

MOST RECENT EXPERIMENTAL AND NUMERICAL STUDIES PERFORMED IN ITALY ON SEISMIC ISOLATION

M. Forni[1], A. Martelli[1], B. Spadoni[1], G. Vernoni[1], F. Bettinali[2], A. Marioni[3], G. Bonacina[4], C. Mazzieri[5], F. Vestroni[6]

[1]ENEA, Department of Innovative Reactors, Bologna, Italy, [2]ENEL, Hydraulic and Structural Research Center, Milano, Italy, [3]ALGA S.p.A., Milano, Italy, [4]ISMES S.p.A., Bergamo, Italy, [5]ANSALDO-Ricerche, Genova, Italy, [6]University of L'Aquila, Italy

ABSTRACT

In order to verify the applicability of seismic isolation to high risk plants such as nuclear reactors, static and dynamic tests have been performed in Italy on isolation rubber bearings, rubber specimens, isolated structure mock-ups and actual isolated civil buildings since 1989. Simplified and detailed numerical models of isolators and isolated structures have also been developed and applied, and considerable work has been made for the preparation of design guidelines for isolated structures. This paper summarizes the main features and results of R&D activities, focussing on those performed after the 11th SMiRT Conference.

1 INTRODUCTION

The use of techniques capable of reducing the seismic loads acting on structures (isolation and passive energy dissipation) began in Italy in 1974. The first applications concerned bridges and viaducts; in 1983, the construction of seismically isolated buildings also began. At present, passive energy dissipation and seismic isolation systems are being used in more than 150 Italian bridges and viaducts, while 8 isolated buildings have been completed and 5 are in advanced construction in Italy (Martelli et al. 1993a). Preliminary design analysis has also been performed by Bonacina et al. (1993) to support the application of seismic isolation to conventional energy production plants. Detailed studies for the development of seismic isolation began in Italy in 1988, in order to permit the safe use of this technique in civil buildings and in view of its possible adoption for industrial facilities, including high risk nuclear and chemical plants. Indeed, in spite of the very encouraging results that had already been obtained, further research and development (R&D) work was considered to be still necessary to fully verify the adequacy of seismic isolation for high risk plants. In addition, the development of appropriate design rules was also judged essential, because of both the key role of isolation system for plant safety and its important effects on the structure design. It is noted that a fairly large amount of information needed for the use in high risk plants can (and will be) provided by the experience gained on the design and behaviour of isolated civil buildings.

2 STUDIES IN PROGRESS IN ITALY

Italian studies concern: (a) preparation of design guidelines and national standards for isolated

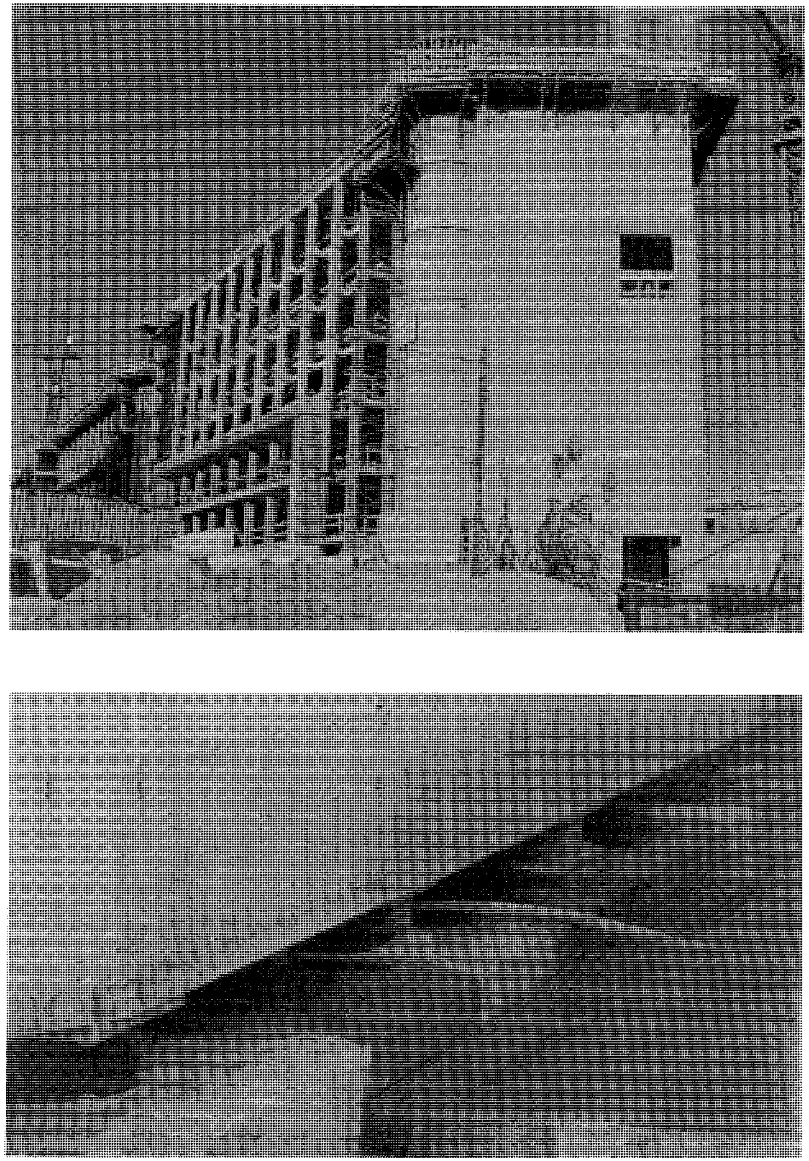

Fig. 1. *View of the isolated SIP building at Ancona which was subjected to in-situ tests and detail of the isolation system (October 1990).*

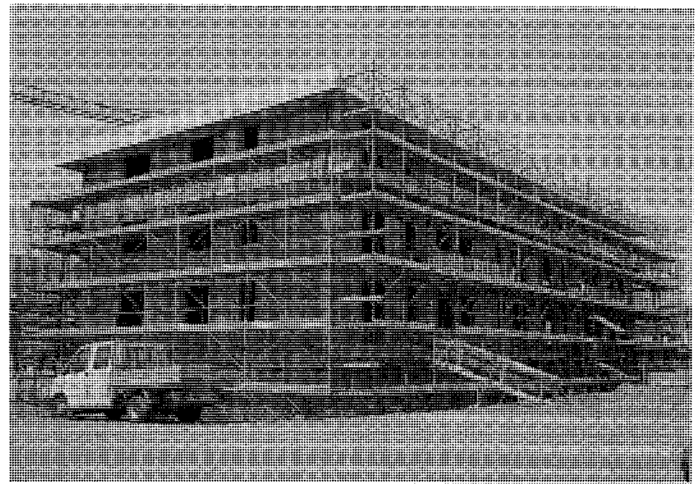

Fig. 2. *View of the isolated house at Squillace Lido, at the time of in-situ tests (June 1991).*

structures; (b) development of isolation and energy dissipation systems; (c) laboratory tests on rubber specimens, individual isolators and isolated structure mock-ups; (d) in-situ tests of isolated buildings; (e) seismic monitoring of such buildings; (f) development of simple and detailed numerical models for isolators and isolated structures. These studies are being jointly performed by several organizations and universities, in the framework of the activities of the Italian Working Group on Seismic Isolation (GLIS).

It is noted that in-situ tests were performed on both one of the five large isolated buildings of the Administration Center of the National Telephone Company (SIP) at Ancona (Fig. 1), and the twin three-story houses (one being conventionally founded, the other being seismically isolated) which were constructed at Squillace Lido, Calabria, South of Italy (Forni et al. 1991a&b, see Fig. 2). Both SIP buildings and twin houses at Squillace have just been provided with seismic monitoring systems (Forni et al. 1993).

This paper provides a short overview on the R&D work which is being performed in Italy, focussing on the most recent, namely on that performed after the 11th SMiRT Conference (thus, integrating the information given there by Martelli et al. 1991a&b and Forni et al. 1991a&b). Information on the progress on guidelines development is given by the separate paper of Martelli et al. (1993b). Only a few recent R&D results are shown here; more details will be presented by Forni et al. (1993) at the Post-SMiRT Conference Seminar on Isolation, Energy Dissipation and Control of Vibrations of Structures (Capri, Italy, August 23 to 25, 1993).

3 BEARINGS USED IN THE EXPERIMENTS

Several types of energy dissipation and seismic isolation devices have been used in Italy for brigde applications, while, with regard to buildings and plants, applications (Martelli et al. 1993a) and R&D studies in progress in Italy are at present mainly based on the high damping steel-laminated rubber bearing (HDRB).

R&D work was undertaken in 1989. At present, it is being jointly performed by ENEA, ENEL, ISMES, ALGA and ANSALDO-Ricerche. This work concerns both experimental and numerical studies of HDRBs, bearing materials and isolated structures. Tests have been performed at ISMES and the ENEA/ANSALDO Centre of Boschetto (Genova) on rubber specimens, bearings in various scales, structure mock-ups isolated by means of such bearings, and the previously mentioned isolated SIP and Squillace buildings.The first tests were based on one (the 500 mm diameter) of the two HDRB types used in SIP buildings. These are characterized by a horizontal displacement equal to 144 mm at 100% shear strain, and a "containment" system for bearing attachment (Martelli et al. 1991a). Several bearings in full scale and 1/2, 1/3 and 1/4 scales were fabricated and tested. Tests followed a very detailed acceptance campaign of SIP HDRBs.

In the second phase of tests (which is still in progress), use is being made of modified (full and half scale) bolted and dowelled isolators and modified rubber materials (Fig. 3).

Some bearings equal to those used in the isolated house at Squillace (Fig. 8) were also fabricated and tested: these isolators have diameters of 400 mm and 500 mm, a total rubber height of 136 mm, and an attachment system similar to that used for the SIP bearings at Ancona.

4 TESTS ON RUBBER SPECIMENS

Tests on rubber specimens are being performed by ENEA in cooperation with ALGA and ANSALDO, with the aim of improving fabrication processes, controling bearing quality and determining rubber properties. Shear tests on rubber specimens preceded all experiments on bearings and isolated mock-ups. These were carried out for all bearing batchs, to mainly measure

Fig. 3. View of the modified SIP-type bearings in full and half scales.

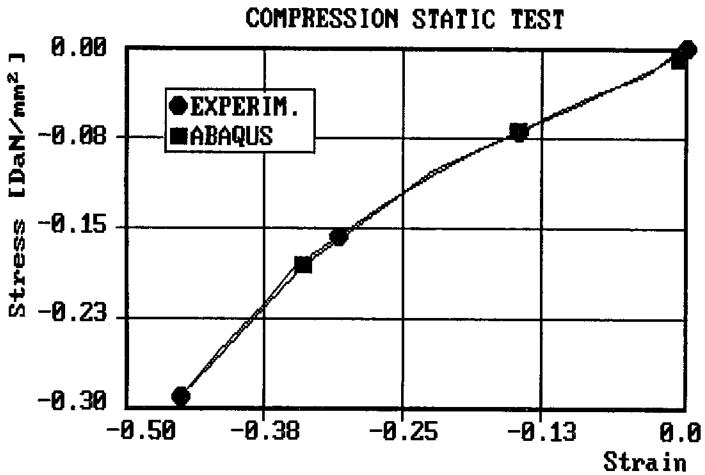

Fig. 4. Comparison between the results of tests on specimens with compression loads and ABAQUS calculations with a hyperelastic model.

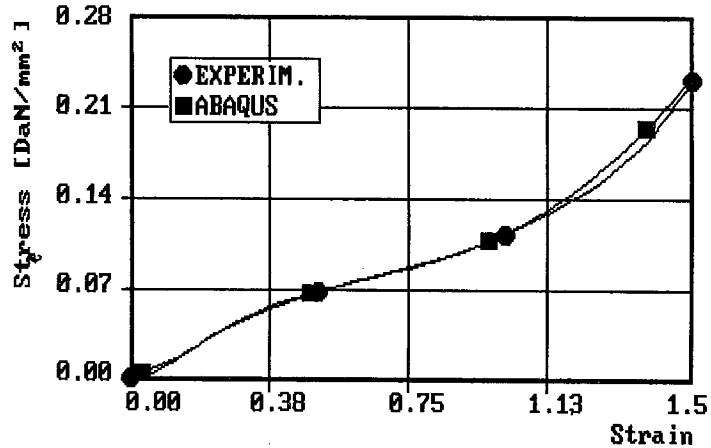

Fig. 5. Comparison between the results of tests on specimens with tensile loads and ABAQUS calculations with a hyperelastic model.

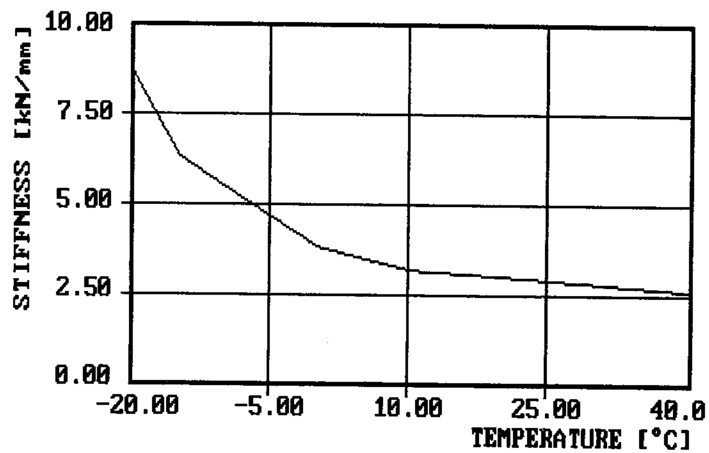

Fig. 6. Temperature effects on stiffness, measured in shear tests of rubber specimens using the HDRB compound of SIP bearings.

the shear modulus of elasticity, G; they stressed the importance of an adequate G measurement.

Tests on specimens formed by new rubber materials allowed for the definition of three HDRBs with improved rubber-steel bonding and different compounds (Forni et al. 1993), and for the assessment of a hyperelastic model of the rubber (Figs. 4 and 5).

Accelerated aging experiments on specimens formed by the compound used in the SIP HDRBs, performed by ALGA, showed that the isolator life is larger than 110 years (Forni et al. 1993), and tests carried out at the Boschetto Centre demonstrated that temperature does not produce any permanent modification of compound features, but has a non-negligible effect on horizontal stiffness at the low values (Fig. 6).

5 TESTS ON ISOLATION BEARINGS

Tests of individual bearings have been performed at ISMES using the SISTEM machine (designed and fabricated by ENEA, see Fig. 7). Those completed on the SIP-type bearings were already mostly described by Martelli et al. (1991a) and Forni et al. (1991b). They include: (a) quasi-static vertical compression tests; (b) cyclic quasi-static shear tests under vertical design load; (c) sustained compression tests; (d) quasi-static shear tests under different vertical loads; (e) four sets of quasi-static tests for the analysis of natural aging effects, performed on bearings mantained in actual installation conditions; (f) sinusoidal horizontal excitation tests at fixed frequencies; (h) one quasi-static cyclic failure test.

As mentioned in Sect. 3, static and dynamic tests were also performed (on behalf of ENEL) on Squillace bearings, and some first ENEA tests were carried out on the modified SIP bearings.

The results of more recent tests confirmed the conclusions of Martelli at al. (1991a) and Forni et al. (1991b) and provided further important data for the development of design guidelines, the development and validation of numerical models, and comparison with the results of tests on isolated structure mock-ups and actual buildings. In particular, it has been confirmed that: (a) large horizontal stiffness variations with displacement occur to about 50% shear strain; (b) damping nature is mostly hysteretic; (c) equivalent viscous damping ratio is larger than 10% for the HDRBs used; (d) creep effects are limited; (e) the effects, on vertical stiffness, of dynamic excitation are small; (f) sufficient margins exist before failure. Furthermore, no effects of natural aging were detected, yet, on SIP-type bearings after more than two years, during which some of these bearings were mantained under the actual vertical load (cooperation for the analysis of these effects has been started by ENEA and the owner of SIP Center, SEAT).

As to margins before failure, we remember that the quasi-static test mentioned by Martelli et al. (1991a) concerned a 1/2 scale bearing without lateral rubber cover: for this isolator some damage had began at about 160% shear strain, although the bearing was still capable of sustaining the vertical load - in spite of very severe damage - at 260% shear strain (test had been interrupted at this level). The reasons for damage beginning at a relatively low displacement and the subsequent severe damages at larger displacements were attributed by Martelli et al. (1991a) to some initial damage caused by bearing reworking performed to remove the lateral rubber cover. This explanation was later confirmed by the results of a dynamic test of a 400 mm diameter Squillace bearing (Fig. 8). This test was performed at a frequency of 0.45 Hz under the design vertical load of 700 kN, by gradually increasing displacement (every five cycles) from the initial value of 13 mm to the maximum force compatible with SISTEM capabilities (corresponding to about 290 mm, i.e. more than 210% shear strain, see Fig. 9). Only very limited damage occurred to this displacement: it began at about 200% shear strain, probably also due to the large number of cycles and friction between bearing borders and the containing steel plates (see the time-history of the applied force in Fig. 9, which might also have been affected by temperature raise inside bearing, due to cycling).

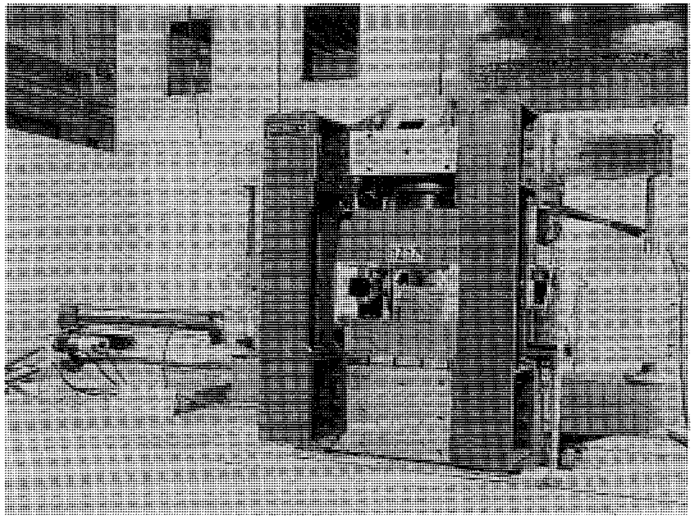

Fig. 7. *View of SISTEM after modifications to allow for tensile vertical loads and better guide of vertical jack.*

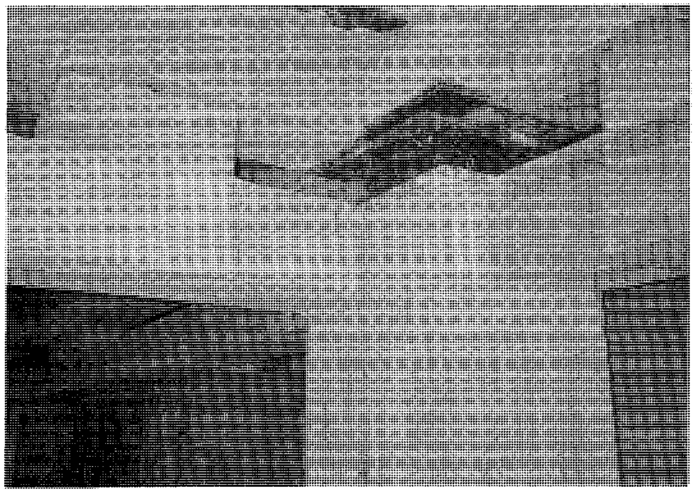

Fig. 8. *View of an isolator in the house at Squillace.*

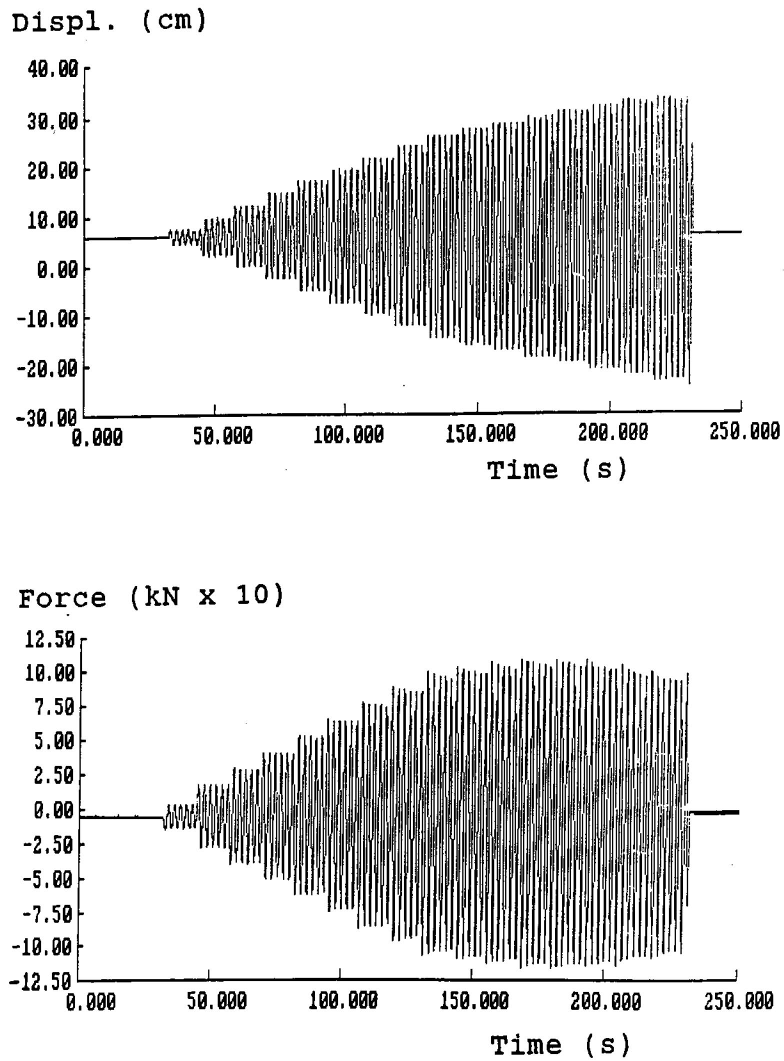

Fig. 9. *Displacement and horizontal force time-histories in a dynamic test of Squillace bearings.*

Finally, as to the experimental analysis of the effects of bearing attachment and compound features, the first results indicated some (hardly explainable) non-negligible effects: these must be verified through further tests in progress (the results of experiments performed later at Boschetto on a seismically isolated structure mock-up did not confirm such effects - see Sect. 6).

6 TESTS ON ISOLATED STRUCTURE MOCK-UPS

The mock-ups used in the laboratory tests performed to date, at both ISMES and Boschetto, were such as to only reproduce the mass of actual structures, being characterized by very large stiffness (reference was made to SIP buildings). Forni et al. (1991a&b) already mentioned that experiments at ISMES concerned: (a) snap-back tests of a full-scale mock-up (weighting 9,500 kN), supported by six SIP bearings, with a maximum initial displacement of 85 mm (more than 60% shear strain); (b) snap-back, sinusoidal, and one-directional (1d), 2d and 3d simultaneous seismic excitation tests - corresponding to rigid, medium and soft soil conditions in Italy - of a 1/4 scale mock-up (weighting 394 kN) supported by four 1/4 scale bearings, which was tested on the six-degrees-of-freedom (6-dof) MASTER shaking table with a maximum initial displacement of about 36 mm (100% shear strain).

Experiments recently carried out at Boschetto (November-December 1992) consisted of snap-back tests on a half-scale mock-up formed by the inertial mass of SCORPIUS shake table (weighting about 1,600 kN), which was supported by four 1/2 scale SIP-type bearings. The effects of the original and the dowelled attachment systems have been tested to date, by increasing the initial displacement to 150% shear strain (Fig. 10).

The results of the full-scale mock-up tests have already been presented in detail by Forni et al. (1991a&b), together with some data concerning the 1/4 scale mock-up. A detailed description concerning the 1/2 scale mock-up tests will be presented by Forni et al. (1993), while more information on the 1/4 scale mock-up tests is separately given to this Conference by Serino et al. (1993).

We can state here in general that all mock-up tests provided essential information on the behaviour of isolated structures and isolation systems and for the assessment and validation of calculation procedures. In all snap-back tests, the motion in the initial displacement direction lasted very few seconds only (about 3 s), and consisted in three appreciable cycles only (see Forni et al. 1991a&b and Fig. 10). Residual displacements of some millimeters (partly recovered within some hours and never additive with respect to those of previous tests) were always detected at ISMES at test conclusion: these can be attributed to the presence of later rubber cover (which can be deformed), quite long time necessary to reach the initial displacement and attachment type (which allows for a small gap between bearing and the borders of the containing steel-end plate). On the contrary, tests at Boschetto (Fig. 10) have correctly shown some effects (but more limited due to the much faster loading phase) for the original attachment system only; no other effects of dowels have been found.

The first response frequency increased considerably during motion, as displacement amplitude decreased (see Forni et al. 1991a&b and Fig. 10). This behaviour is consistent with the non-linear correlation which exists between bearing elastic forces and displacements. For similar reasons it was impossible to define an unique damping value for each entire test. The assumption of equivalent viscous damping (ß), and use of the logarithmic decrement technique, led to ßs that were rather larger than those obtained in single bearing tests, due to the strong increase of ß with decreasing displacement during each test and the hysteretic nature of energy dissipation.

In seismic tests of the 1/4 scale mock-up, large amplifications of the actual ground motion were necessary to attain 100% shear strain for medium soils (a factor 2.5 for the Tolmezzo records of 1976 Friuli earthquake), and especially, for rigid soils (such as for the San Rocco record of the

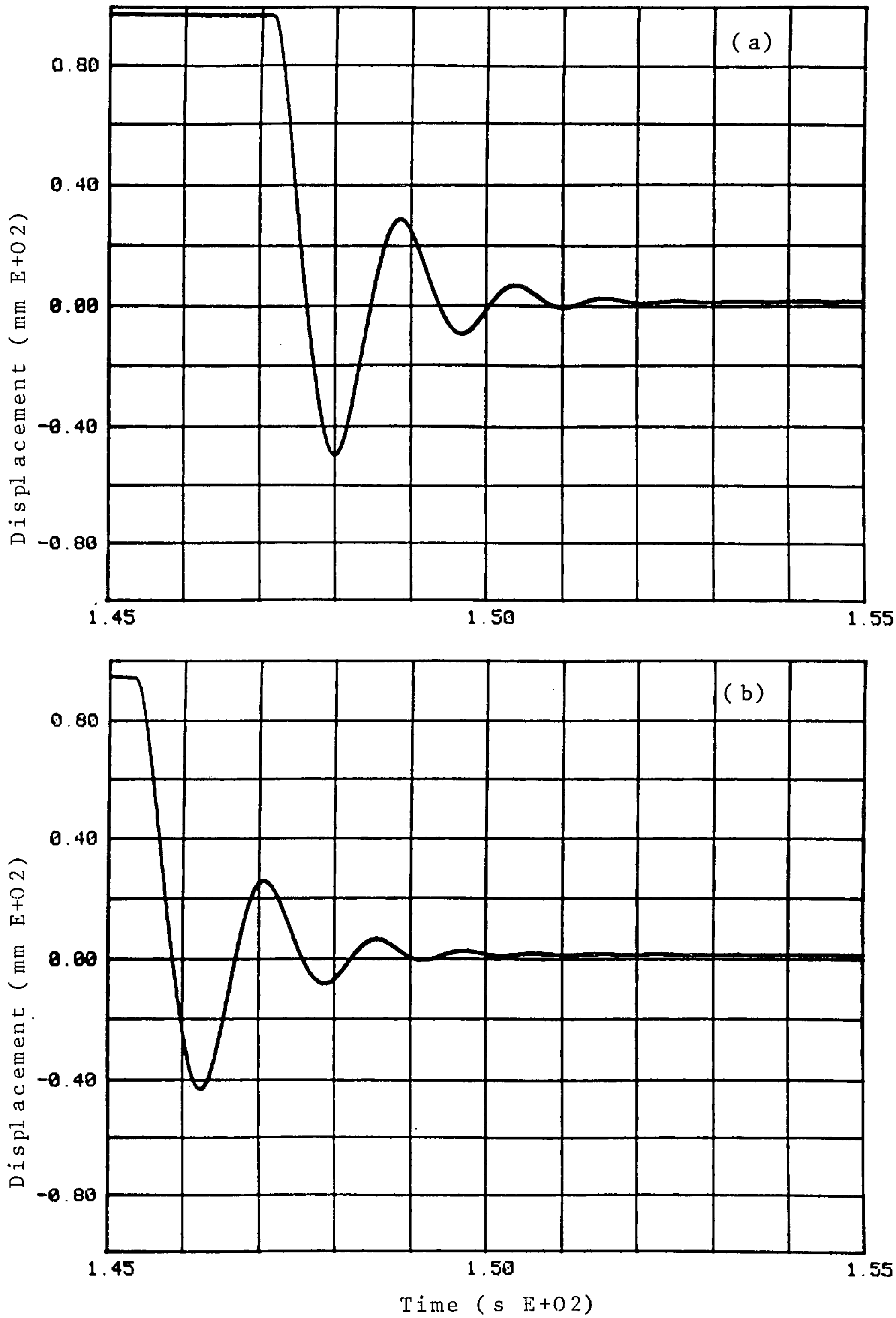

Fig. 10. Displacement time-histories measured in snap-back tests at Boschetto: initial displacements corresponding to 150% shear strain; "containment"-type (a) and dowelled (b) attachments.

same earthquake, for which the application of a factor 7 produced a displacement of some millimeters only). Even for relatively soft soils, margins - although obviously rather reduced - still exist (the design displacement was reached by increasing the Calitri record of 1980 Irpinia earthquake by a factor 1.12). A significant reduction of the motion through the isolation system was obtained (peak accelerations was reduced by 85% for San Rocco records, 90% for Tolmezzo records and 60% even for Calitri records). 2d and 3d interaction effects on isolation bearings were found very small. Peak response acceleration varied almost linearly versus the scale factor applied to each input acceleration record in the various tests concerning each of the three eathquakes (despite the strongly non-linear behaviour of bearings). Also, no residual displacements were detected, according to the fast load application in shake table tests.

Finally, reproducibility of test results was successfully verified for all mock-ups.

7 IN-SITU TESTS OF ACTUAL ISOLATED BUILDINGS

Forni et al. (1991a&b) presented the main features and results of the in-situ dynamic tests of the SIP building (Fig. 1) and the related numerical analysis. These tests had been performed by ENEL, ENEA and ISMES in 1990. We recall that the building had been subjected to both forced excitation and snap-back tests. Maximum initial displacement attained in the latter had been 107 mm (75% shear strain). The results demonstrated the safety of isolated buildings and confirmed those obtained for the mock-ups, as to variation and level of horizontal stiffness, damping, residual displacements and reproducibility of data; they showed that the building quasi exclusively behaves as a rigid body and demostrated the adequacy of the isolation system. Forced excitation tests - performed by use of a mechanical vibrator installed on the building roof - allowed for the dynamic characterization of the superstructure and verification of design and pre-test analysis.

Forni et al. (1991b) also presented the main features of in-situ tests performed by ENEL and ISMES on both twin houses at Squillace (Fig. 2) in 1991. These houses were subjected to both forced excitation tests (by use of a mechanical vibrator located on the roof) and ambient vibration measurement of wind-, truck- and train-induced microtremors. We recall here that test results confirmed the large, beneficial effects of seismic isolation (an example of comparison between the responses of the isolated building and the conventional is shown here by Fig. 11).

8 NUMERICAL ANALYSIS OF INDIVIDUAL BEARINGS

Both simple bearing models and detailed finite-element (f.e.) three-dimensional (3D) models were set up (Martelli et al. 1991b and Forni et al. 1991b). Simple models have been based on the results of single bearing tests: models formed by a spring in parallel to a viscous damper, where both horizontal stiffness and viscous damping ratio vary with displacement, have been developed by ENEA; models based on hysteretic damping have also been developed at ISMES (Serino et al., 1993).

Detailed (3D) bearing models, to be used for design and the analysis of the effects of defects, have been considerably improved by ENEA with respect to some first attempts described by Martelli et al. (1991b). The details of these improvements will be reported by Forni et al. (1993). We note here that models are now consisting of separate 8-node solid elements for the rubber and 4-node shell elements for steel, which have been implemented in ABAQUS for both the original and modified SIP-type bearings (Fig. 12). While three axial subdivisions of each rubber layer have been found sufficient to correctly calculate bearing horizontal stiffness and vibrational behaviour, at least six were found necessary for the vertical.

Calculations by use of both an elastic bearing model and a hyperelastic model of the rubber

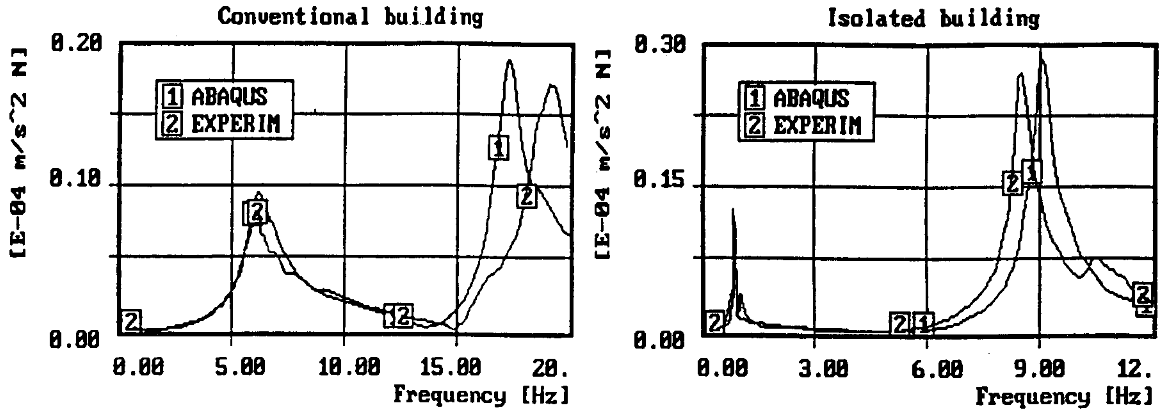

Fig. 11. Measured and calculated transfer functions at the roof of Squillace buildings.

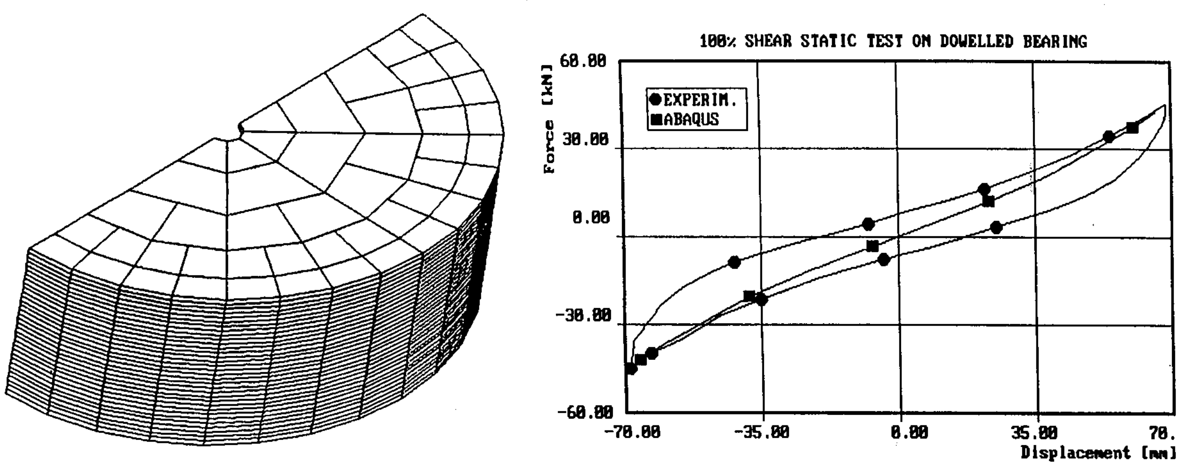

Fig. 12. 3D hyperelastic isolator model: comparison between measured & calculated response.

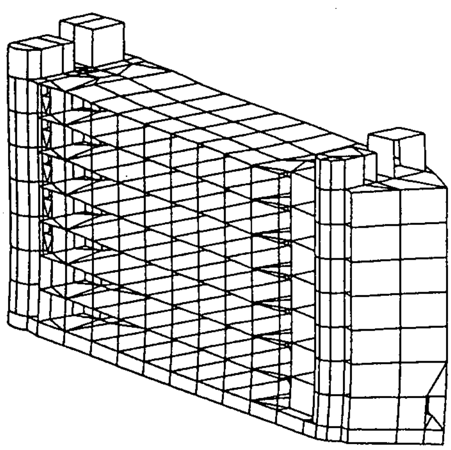

Fig. 13. First vibration mode computed with ABAQUS for the superstructure of the SIP building subjected to in-situ tests at Ancona in 1990.

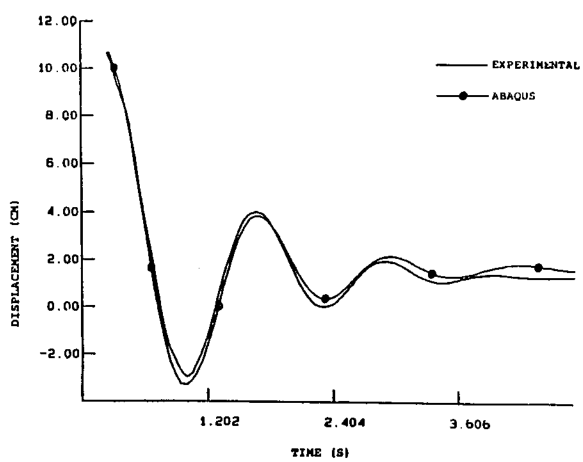

Fig. 14. Measured and calculated displacement of SIP building in the most severe snap-back test (single isolator stiffness; damping measured for the 9,500 kN mock-up).

(based on the results of tests on specimens) have been performed, to evaluate natural frequencies and stiffnesses of bearings. Moreover, an elastic-plastic model has also been used for steel. Mesh simplifications have been analysed, to limit the computer time which was necessary to calculate horizontal stiffness, to acceptable values, without significantly affecting the results. The effects of steel plastic behaviour has been found negligible to 100% shear strain. The use of the rubber hyperelastic model has already led to excellent results regarding both the behaviour of specimens in the different loading conditions (Figs. 4 and 5) and the horizontal stiffness of bearings to 100% shear strain (Fig. 12). Further specimen tests at large shear strain are initiating: they will also allow for a correct evaluation of bearings vertical stiffness. Studies are also in progress to implement an adequate damping model in ABAQUS.

9 NUMERICAL ANALYSIS OF ISOLATED STRUCTURES

Finite-difference programs were set up by Martelli et al. (1991b) and Forni et al. (1991b) for the analysis of isolated structures, in the case that they can be represented by sets of 1-dof oscillators. The program ISOLAE includes the aforementioned simple bearing model of ENEA, where both stiffness and damping depend on displacement and the effects of viscous creep are accounted for. In ISOLAE, the structure can be now represented by a system of 1-dof viscous linear oscillators, which represent the fundamental vibration modes. A similar program has been based by Serino et al. (1993) on the bearing model developed at ISMES.

ISOLAE analysis performed by Forni et al. (1991b), concerning test results for both isolated structure mock-ups and isolated buildings, demonstrated the applicability of single bearing test data (stiffness and damping dependences on displacement) to analyse the dynamic behaviour of isolated structures. The good agreement obtained by Forni et al. (1991b) for the SIP building also, confirmed that buildings can be really considered as rigid bodies, to evaluate their main seismic motion, if deformation frequencies of the superstructure are sufficiently larger than the rigid body values of the isolated construction.

Furthermore, as already mentioned by Martelli et al. (1991b), f.e. models with constant viscous damping were implemented by ENEA in ABAQUS, and have also been used for the analysis of all tested isolated structures. ABAQUS calculations have included both the analysis of experimental data and the evaluation of building responses to the previously mentioned Italian earthquakes corresponding to rigid, medium and relatively soft soil conditions (the latter has accounted for simultaneous excitation effects also); they have been based on both models where a very large stiffness was assumed for the structure, and for buildings, sophisticated 3D f.e. models of the superstructure, as well. The 3D f.e. model of the SIP building (Fig. 13) has been derived from that used for design analysis and pre-test calculations. 3D models of the twin Squillace buildings will be described in detail by Forni et al. (1993).

Studies concerning the mock-ups tested at ISMES and both twin houses tested at Squillace have already been completed, while the analysis of the Boschetto test results and the data concerning SIP buildings is in progress. Forni et al. (1991b) already showed that mock-up and building calculations performed with ABAQUS by use of a rigid mass model have led to results which are very similar to those obtained by ISOLAE. As to the SIP building, 3D calculations by use of direct integration (Fig. 14) have already led to results which also agree with the experimental data and are very similar to those obtained by assuming the building as infinitely rigid. Good agreement between calculations and measurements has also been obtained for both twin houses at Squillace (Fig. 11), together with the demonstration that the isolation system used is effective in the case of severe Italian earthquakes.

10 CONCLUSIONS

This paper has shown that great efforts are in progress in Italy for the development and application of seismic isolation to nuclear and non-nuclear structures. The importance, for nuclear reactors, of information acquired on isolated civil buildings has been stressed. Some more details and some extensions of the work will be described by Forni et al. (1993). It has been mentioned that the development studies are being carried out in the framework of wide-ranging national collaborations, such as those foreseen by GLIS. They also take advantage of international cooperations: within these it is worth citing the organization of International Post-SMiRT Conference Seminars on seismic isolation and other innovative antiseismic design techniques: the third of these ("Isolation, Energy Dissipation and Control of Vibrations of Structures") will be held at Capri (Italy) on August 23 to 25, 1993.

REFERENCES

Bonacina, G., Venturuzzo, M., and Bettinali, F. 1993. *Seismic Isolation of Non-Nuclear Power Plants in Italy.* Proc. of the Post 12th SMiRT Conference Seminar on Isolation, Energy Dissipation and Control of Vibrations of Structures. Ascoli Piceno, Italy: CREA.

Forni, M., Martelli, A., Spadoni, B., Bonacina, G., Pucci, G., and Zola, M. 1991a. *Dynamic Experiments Performed in Italy on Seismically Isolated Structure Mock-Ups in the Framework of the R&D Studies for the Innovative Nuclear Reactors.* Proc. of the 11th SMiRT Conference. Tokyo: Atomic Energy Society of Japan. Vol. K2: 205-210.

Forni, M., Indirli, M., Martelli, A., Masoni, P., Spadoni, B., Bettinali, F., Bonacina, G., Pucci, G., Serino, G., Giuliani, G.C., and Marioni, A. 1991b. *Most Recent Results of R&D Studies in Progress in Italy on Seismic Isolation.* Proc. of the 11th SMiRT Post Conference Seminar on Seismic Isolation of Nuclear and Non-Nuclear Structures: 263-293. Tokyo: Shimizu Corp.

Forni, M., Indirli, M., Martelli, A., Spadoni, B., Di Pasquale, G., Pugliese, A., Sanò, T., Bettinali, F., Marioni, A., Bonacina, G., Mazzieri, C., Serino, G., Grassi, L., Sobrero, E., and Vestroni, F. 1993. *Most Recent Developments on Seismic Isolation of Nuclear Facilities in Italy.* Proc. of the Post 12th SMiRT Conference Seminar on Isolation, Energy Dissipation and Control of Vibrations of Structures. Ascoli Piceno, Italy: CREA.

Martelli, A., Forni, M., Spadoni, B., and Bonacina, G. 1991a. *Static and Dynamic Experiments Performed in Italy on Seismic Isolation in the Framework of the R&D Studies for the Innovative Nuclear Reactors.* Proc. of the 11th SMiRT Conference. Tokyo: Atomic Energy Society of Japan. Vol. K2: 199-204.

Martelli, A., Bettinali, F., Sanò, T., Bonacina, G., Giangreco E., and Marioni, A. 1991b. *Overview on the Activities in Progress on Seismic Isolation in Italy and Future R&D Work.* Proc. of the 11th SMiRT Post Conference Seminar on Seismic Isolation of Nuclear and Non-Nuclear Structures: 29-43. Tokyo: Shimizu Corporation.

Martelli, A., Parducci, A., and Forni, M. 1993a. *State-of-the-Art on Development and Application of Seismic Isolation and Other Innovative Seismic Design Techniques in Italy.* Proc. of the ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control. Redwood City, California: Advanced Technology Council.

Martelli, A., Carpani, B., Forni, M., Di Pasquale, G., Sanò, T., Bonacina, G., Olivieri, M., Marioni, A., Cesari, G.F.. 1993b. *Extension of Guidelines for Seismically Isolated Reactors.* Proc. of the 12th SMiRT Conference. Amsterdam: Elsevier Science Publishers B.V.

Serino, G., Bonacina, G., and Bettinali, F. 1993. *Proposal and Experimental Validation of Analytical Models for Seismic and Vibration Isolation Devices in Nuclear and Non-Nuclear Facilities.* Proc. of the 12th SMiRT Conference. Amsterdam: Elsevier Science Publishers B.V.