Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Progress of Italian experimental activities on seismic isolation

Martelli, A.[1], Forni, M.[1], Spadoni, B.[1], Bettinali, F.[2], Marioni, A.[3], Bonacina, G.[4], Pucci, G.[4], Cesari, F.[5]

1) ENEA, Energy Department, Nuclear Fission Branch, 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) Nuclear Engineering Laboratory, University of Bologna, Italy

ABSTRACT: Detailed studies have been performed in Italy since 1988 to verify the applicability of seismic isolation to high risk structures such as nuclear plants. These include experiments, development and validation of numerical models, and design guidelines development. This paper deals with the first item. In particular, information is provided as to the most recent progress concerning static and dynamic tests of high damping rubber specimens and bearings, and shake table tests of isolated structures.

1 INTRODUCTION

Large efforts are going on in Italy for the development, validation and application of seismic isolation (SI) techniques for civil and industrial structures. These are being performed in framework of both collaborative activities of the Italian Working Group on Seismic Isolation (GLIS), and international co-operative projects with other European and U.S. partners. As regards the applications to industrial structures, ENEA is particularly interested in those to nuclear reactors and other nuclear facilities (e.g. spent fuel storage pools), while the main interest of other Italian partners (e.g. ENEL) is at present mainly in conventional energy production plants (Bonacina et al. 1994). Very close co-operation among partners with different application objectives has been justified by the great potential of SI for both civil and industrial structures, and among the latter, for both nuclear and non-nuclear plants (Forni et al. 1993).

Studies relevant to nuclear and other industrial applications of SI began in Italy in 1988, and include experiments, numerical modelling and development of design guidelines. This paper focuses on the recent developments concerning the first item, while those related to the last two items are presented separately by Forni et al. (1995) and by Martelli et al. (1995).

2 EXPERIMENTS IN PROGRESS

Forni et al. (1993) described the experimental campaigns which had been carried out in Italy for SI development prior the 12th SMiRT Conference. These concerned the use of High Damping Rubber Bearing (HDRB) as isolator, and comprised laboratory tests on rubber specimens, individual isolators, isolated structure mock-ups, and actual isolated buildings (in-situ tests).

The above activities have been jointly continued by ENEA, ENEL, ALGA (which is the manufacturer of HDRBs in Italy), ISMES, the Nuclear Engineering Laboratory (LIN) of the University of Bologna and ANSALDO Ricerche. Again, experiments have been mainly based on the HDRBs, although some tests have also been performed and a new research project already defined concerning other SI and energy dissipation systems. With respect to previous studies, however, the analysis of the effects of different parameters affecting the HDRB behaviour, and their combinations, has been considerably extended: in particular, various types of attachment systems between bearings and steel end-plates (recess, bolts, central dowel, combined use of central dowel and bolts, and direct bonding), rubber compounds and shape factors (S) have been considered. The most relevant recent activities which have already been completed or are in progress concern: (a) uniaxial, equibiaxial and shear tests on high damping rubber specimens; (b) static and dynamic tests of single isolators; (c) shake table tests of a half-scale isolated mock-up of electric equipment. In order to allow for such tests special purpose testing equipment was designed and fabricated (Forni et al. 1995). Further tests will begin soon.

3 TESTS ON RUBBER SPECIMENS

Uniaxial (tension and compression) and equibiaxial tests of rubber specimens have been performed at ENEL for both a rather hard rubber compound used in the U.S. Advanced Liquid Metal Reactor (ALMR) Project (shear modulus G = 1.4 MPa) and new medium hardness (G = 0.8 MPa) and soft (G = 0.4 MPa) compounds. Tests concerning the ALMR rubber have been carried out in the framework of a co-operation with GE Nuclear Energy. Special equipment designed by ENEA and ENEL and manufactured by ENEL has been used for equibiaxial tests. Shear tests have also been carried out at ENEL for specimens of the aforementioned rubber compounds, again using a new testing equipment, which was designed by ENEA and manufactured by LIN.

Figure 1 shows examples of test results. Tests data were used by Forni et al. (1995) to validate and calibrate hyperelastic models of the rubbers considered, then adopted in the detailed analysis of related HDRBs. Evaluation of temperature and ageing effects will soon begin at ALGA and ANSALDO-Ricerche.

4 TESTS ON ISOLATORS

The experimental campaigns in progress for the HDRBs are being jointly carried out by ENEA, ENEL, LIN and ISMES using both SISTEM (Seismic ISolation TEst Machine) - after this equipment was improved by ENEA to allow for easier testing of different size isolators and for real time visualization of the measured data (Figure 2) - and the new CAT (Creep and Aging Tests) machine (Figure 3). These experiments concern HDRBs characterized by: (a) various sizes (125 mm, 250 mm, 500 mm and 600 mm diameters); (b) both medium hardness and soft compounds mentioned in Sect. 3; (c) shape factors S = 12, S = 16 and S = 24; (d) all the attachment systems mentioned in Sect. 2. Some bearings (including the 600 mm diameter HDRBs with soft compound and S = 16) were tested in support of the evaluation of SI benefits for electric equipment, while the other experiments belong to a more recent project for the optimization of HDRBs.

As regards the first tests Bonacina et al. (1994) showed that HDRBs provided with

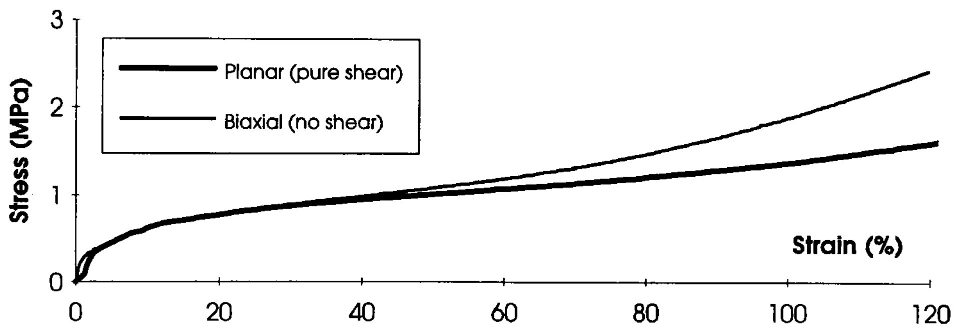

Figure 1. Results of equibiaxial and shear tests of rubber specimens (G = 0.8 MPa).

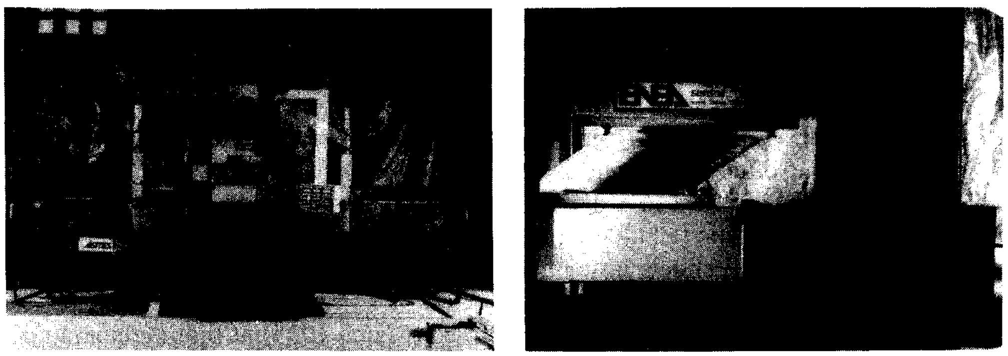

Figure 2. Compression and compression & shear tests on the SISTEM modified version.

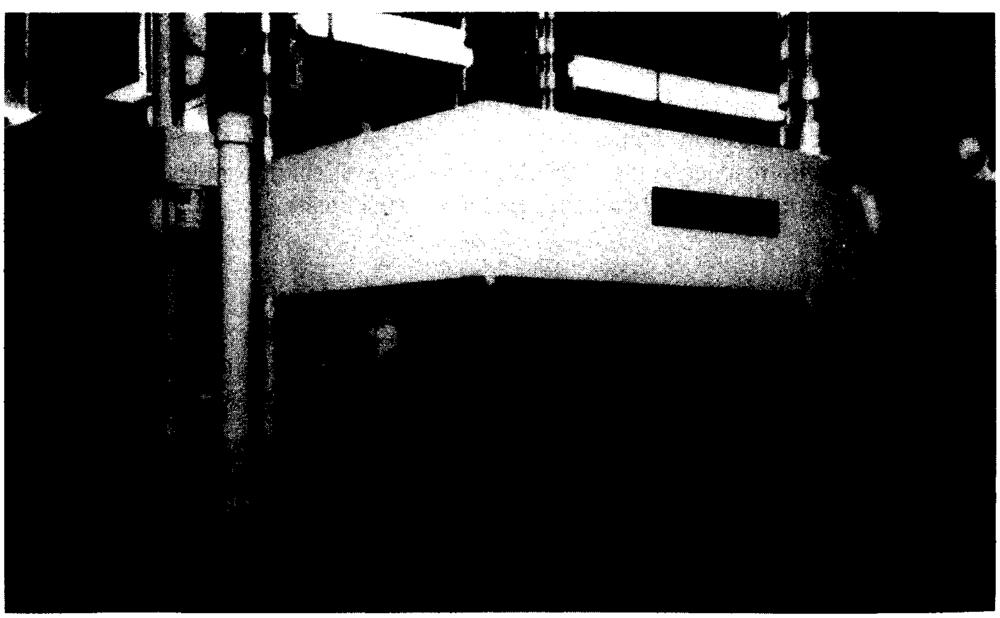

Figure 3. Creep test on full-scale isolators on CAT machine.

central dowel in conjunction with bolts for the attachment system can reach 400% shear strain, in addition to vertical compression load equal to at least 8 times the design value, without failing. Control test performed to 150% shear strain on a 250 mm diameter bearings immediately after the large shear tests showed non-negligible stiffness decrease and damping increase; however, by repeating the same control test 16 months afterwards (prior to shake table experiments of Sect. 5), it was found that damping had recovered its initial value, and that horizontal stiffness was only 7% lower than its original value at 150% shear strain. Thus, the effects of large shear test are to not be attributed to internal damage, but rather to some temporary modification of rubber molecular structure.

The experiments for optimization of HDRBs have been defined based on previous experience of Forni et al. (1993). They comprise, for each relevant combination of the above parameters: (i) quasi-static vertical compression tests for the evaluation of vertical stiffness; (ii) quasi-static shear tests under constant vertical compression load V for the evaluation of static horizontal stiffness at 50%, 100% and 200% shear strain; (iii) quasi-static shear tests at 100% shear strain with different vertical compression loads (from 0.25 V to 2 V) for evaluating the effects of vertical load variation on horizontal stiffness; (iv) dynamic shear tests at various frequencies (0.1, 0.4, and 0.6 Hz), under constant V and at various shear strain values (from 10% to 200%), to evaluate equivalent viscous damping and dynamic effects on the horizontal stiffness; (v) sustained compression tests (from 72 hours at ISMES to some months on the CAT machine at LIN) to evaluate creep effects; (vi) quasi-static failure tests due to compression and shear; (vii) evaluation of temperature and ageing effects on stiffness and damping. These tests are consistent with bearing qualification requirements.

Several experiments have already been performed (March 1995) at room temperature for the 250 mm diameter bearings formed by the medium hardness compound (on which previous experience was deeper), for both shape factors S = 12 and S = 24. Tests for the the evaluation of temperature and ageing effects will begin soon at ANSALDO-Ricerche. Most completed tests concerned bearings with the recess attachment system (for the same reason as above), but some also with that consisting of the central dowel in connection with bolts. Data are already available for the full test series mentioned above. Their processing and implementation in detailed HDRB models are in progress. The good performance of isolators seems to be confirmed, in particular as regards damping which increased (with respect to the HDRBs previously available) from less than 15% to about 20% as desired (Figure 4 shows the results of a shear test).

5 SHAKE TABLE TESTS

Based on the experience achieved in previous tests by Forni et al. (1993), shake table tests have already been performed at ISMES on a rigid mass mock-up of ENEL electric equipment supported by four 250 mm diameter HDRBs designed by ENEA (soft compound, attachment system formed by central dowel and bolts). Three isolators were virgin, while the fourth was that mentioned in Sect. 4 which had been subjected to 400% shear strain. The superstructure, weighting 335 kN, was provided with an eccentric upper part to simulate actual equipment. One-, two- and three directional simultaneous excitations were applied, which corresponded to rigid, medium and relatively soft soil conditions similar to previous tests. The maximum displacement (143 mm, corresponding to 217% shear strain, see Figure 5) was reached for the Calitri record of the 1980 Campano-Lucano (Irpinia) earthquake (relatively soft soil conditions). No damage of

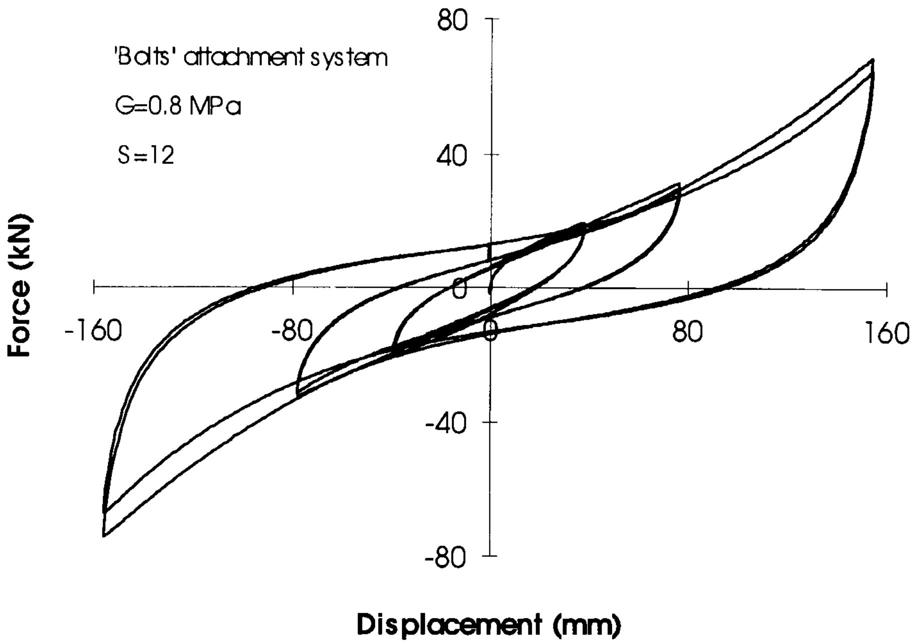

Figure 4. Results of a 200% shear test on a half-scale HDRB.

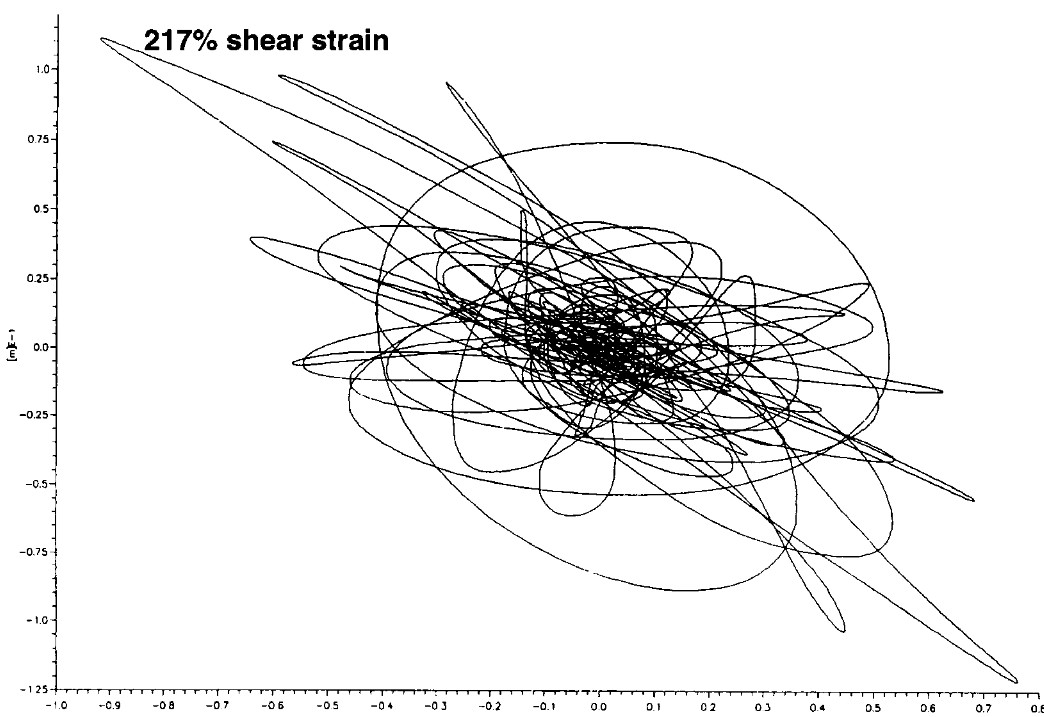

Figure 5. Displacement measured for the isolated electric equipment mock-up (3-directional simultaneous application of the 0 db Calitri record).

bearings was detected at test conclusion, not even on the fourth aforesaid isolator.

Further shake table tests, on a more representative structure mock-up supported by optimized HDRBs, will begin at ISMES as soon as the experiments concerning single bearings are completed. In addition, shake table tests have been planned for isolated nuclear structures at the Casaccia Laboratories of ENEA, partly in the framework of a cooperation with GE (i.e. using the ALMR bearings, which were partly manufactured by ALGA). These tests will concern reactor vessels like that of PRISM, but spent fuel storage pools may be also considered in the future. Finally, a first set of experiments of large structures based on HDRBs, to be performed at JRC Ispra using the pseudodynamic method, has been defined (Renda et al. 1995).

6 CONCLUSIONS

The experiments described above are considerably extending the knowledge previously acquired in Italy on the behaviour of HDRBs and will contribute to the optimization of such bearings. The results already obtained confirm the capability of SI for considerably enhancing the seismic protection of civil and industrial structures, including nuclear plants, and provided relevant input for the design guidelines development of Martelli et al. (1995). Some more details and some extensions of the work will be presented by Marioni et al. (1995) at Post-SMiRT Seminar No. 1.

REFERENCES

Bonacina, G., Bettinali, F. & A. Martelli 1995. State-of-the-art of work in progress on seismic isolation technique for civil structures and industrial plants. *Proc. 10th European Conf. on Earthquake Engineering, Vienna, 28 August - 2 September 1994.*

Forni, M., Martelli, A., Spadoni, B., Vernoni, G., Bettinali, F., Marioni, A., Bonacina, G., Mazzieri, C. & F. Vestroni 1993. Most recent experimental and numerical studies performed in Italy on seismic isolation. *Proc. 12th Int. SMiRT Conf., Stuttgart, 15-20 August 1993.* K2: 225-236. Amsterdam: North Holland.

Forni, M., Martelli, A., Dusi, A. & G. Castellano 1995. F.E. models of steel-laminated rubber bearings for seismic isolation of nuclear facilities. *Proc. 13th Int. SMiRT Conf., Porto Alegre, 13-18 August 1995.* Rotterdam: Balkema.

Marioni, A., Martelli, A., Forni, M., Bonacina, G., Bettinali, F. & C. Mazzieri 1995. Progress in applications and experimental studies for isolated structures in Italy. *Proc. Post-SMiRT Conf. Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Structures, Santiago, 21-23 August 1995.*

Martelli, A., Forni, M., Bergamo, G., Bonacina, B., Cesari, G.F., Di Pasquale, G. & M. Olivieri 1995. Proposal for design guidelines for isolated nuclear facilities. *Proc. 13th Int. SMiRT Conf., Porto Alegre, 13-18 August 1995.* Rotterdam: Balkema.

Renda, V., Martelli, A., Verzelletti, G. & L. Papa 1995. Research activities and programmes on seismic isolation at the Joint Research Center of the European Commission. *Proc. Post-SMiRT Conf. Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Structures, Santiago, 21-23 August 1995.*