Static and Dynamic Experiments Performed in Italy on Seismic Isolation Bearings in the Framework of the R&D Studies for the Innovative Nuclear Reactors

A. MARTELLI, M. FORNI, B. SPADONI
ENEA-DRI, Bologna, Italy
G. BONACINA
ISMES S. p. A., Bergamo, Italy

ABSTRACT

Static and dynamic tests were performed on high damping steel-laminated elastomer bearings in various scales, in the framework of studies in progress to support seismic isolation development in Italy. Tests allowed for the evaluation of data (bearing vertical and horizontal stiffnesses, damping, creep and scale effects) to be compared to the results of experiments on isolated structure mock-ups and actual isolated buildings.

1 INTRODUCTION

The advantages of seismic isolation for application to the innovative nuclear reactors appear such as to warrant further work to resolve some of the outstanding problems. This is the reason for the large R&D effort that was undertaken ENEA and ISMES to support seismic isolation development.

Present activities are focussing on the high damping steel-laminated elastomer bearings (Fig. 1); they include the preparation of proposals for design guidelines (Martelli et al. 1990), as well as the development of numerical models and experiments, for both individual isolators and isolated structures (Martelli et al. 1991). Tests of isolated structures are reported separately (Bonacina et al. 1991).

2 TESTS OF INDIVIDUAL BEARINGS

Individual bearing experiments were carried out by use of the SISTEM test machine (Fig. 2): SISTEM allows for testing both single isolators and a pair of superposed isolators (Figs. 3 - 5) in various scales, with one-directional (1D) or 2D, simultaneous, static and dynamic horizontal excitations under vertical static load, up to large displacements (Martelli et al. 1991).

Twentyeight (28) isolators are equal to the 500 mm diameter bearings used in the five buildings of the Administration Center of the SIP Telephone Company at Ancona, which are the first example of application of seismic isolation in Italy (Bonacina et al. 1991). Several scaled bearings were also tested (22 were fabricated in 1/2 scale, 20 in 1/3 scale and 40 in 1/4 scale).

Quasi-static experiments were performed to evaluate the static vertical (k_v) and horizontal (k_h) bearing stiffnesses, effects of vertical load variation on k_h, creep deformation due to sustained compression, and failure modes. Sinusoidal 1D horizontal excitation tests were also carried out at fixed frequencies, to evaluate damping and other dynamic effects.

3 SOME RESULTS

Figs. 6 and 7 show the static k_v and k_h values measured for the various bearing scales, the latter at 100% σ (σ = shear strain, i.e. horizontal displacement over total rubber height). The agreement with simplified formulae (Martelli et al. 1990) is satisfactory. Some distortion of theoretical values is due to variations of the shear modulus of elasticity (G). The static k_h data at 50% σ are 10% larger than those of Fig. 7; k_h increased considerably by further decreasing excitation, while it reached a constant value at 100% σ (Fig. 8). Dynamic test data were only slightly affected by the excitation frequency, very close to the static values at 50% σ, and 8% larger at 100% σ.

Equivalent viscous damping (β) decreased by increasing excitation, up to above 100% σ (Figs. 8 and 9). Scale effects on β were small. Dynamic results are higher than the static, but a largely non viscous energy dissipation mechanism is evident. The comparison with the results of the SIP bearings acceptance tests shows some difference due to different rubber characteristics (Martelli et al. 1991).

In the failure test so far performed, some damage started at about 160% σ; however, in spite of severe damage, no collapse nor overturning occurred even at 260% σ (Fig. 5). Increasing displacement above 100% σ led to a slight k_h increase, due to hardening, up to damage beginning (Fig. 8); for larger displacements, k_h started decreasing again, while β increased rapidly, partly because of plastic deformations of steel plates.

Creep deformation due to design vertical load (V_d) was small (7 - 8% of the dead load deflection); effects of vertical load variation on k_h were lower than 10% in the range [0.5 V_d - 1.25 V_d].

4 CONCLUSIONS

Test results have already provided useful information to understand the isolators behaviour and to check and improve design guidelines. Further tests are in progress to complete failure and aging analyses, study the dynamic response at varying frequency and to 2D excitation, and evaluate temperature effects, for both the bearings of Fig. 1 and others with improved restraint conditions (dowelled and bolted) and materials.

REFERENCES

Bonacina, G., Pucci, G., Zola, M., Forni, M., Martelli, A. and Spadoni, B. (1991). Dynamic Experiments Performed in Italy on Seismically Isolated Structure Mock - Ups in the Framework of the R&D Studies for the Innovative Nuclear Reactors, Proceedings of the 11th SMiRT Conference, Tokyo, Japan.

Martelli, A., Masoni, P., Di Pasquale, G., Lucarelli, V., Sanò, T., Bonacina, G., Gluekler, E.L. and Tajirian, F.F. (1990). Proposal for Guidelines for Seismically Isolated Nuclear Power Plants (Horizontal Isolation Systems Using High Damping Steel-Laminated Elastomer Bearings), Energia Nucleare, Vol. 1, pp. 67-95.

Martelli, A. , Forni, M., Indirli , M., Masoni, P., Spadoni, B. and Bonacina, G. (1991). Static and Dynamic Tests on High Damping Steel - Laminated Elastomer Bearings, Proceedings of the 9th ASME-PVP Conference, San Diego, California, USA.

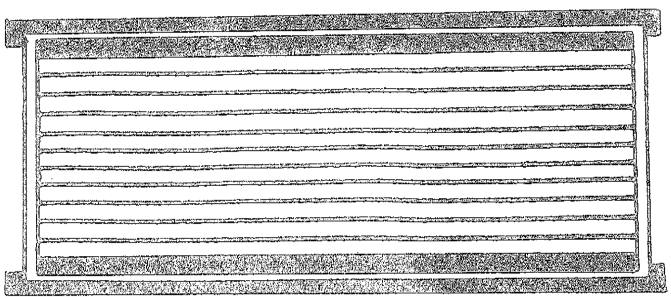

Fig. 1 High damping steel-laminated elastomer bearings used for the SIP buildings at Ancona. Diameter = 500 mm or 600 mm; overall height = 204 mm; total rubber height = 144 mm (eleven inner sheets 12 mm thick and two cover sheets 6 mm thick); total steel height = 60 mm (ten inner plates 3 mm thick and two outer plates 15 mm thick).

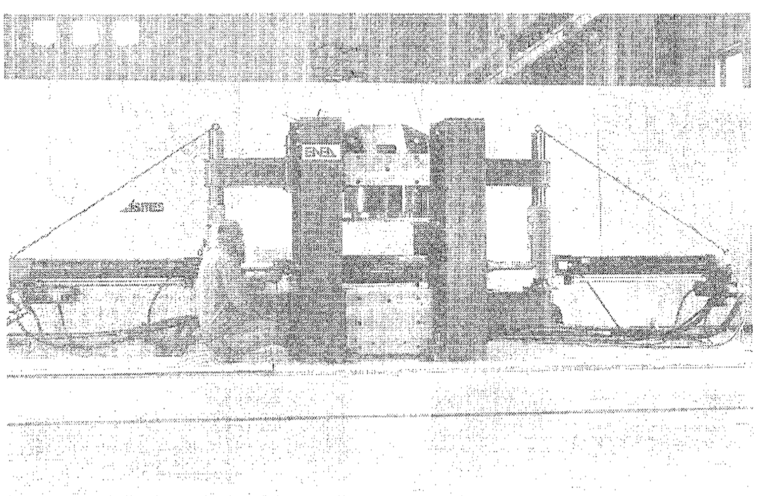

Fig. 2 View of the SISTEM test machine (case of two horizontal actuators in "push-pull" positions).

Fig. 3 Cyclic horizontal excitation test, under static vertical compression load, of a single isolator mounted on the SISTEM test machine (equipped with a roller slide).

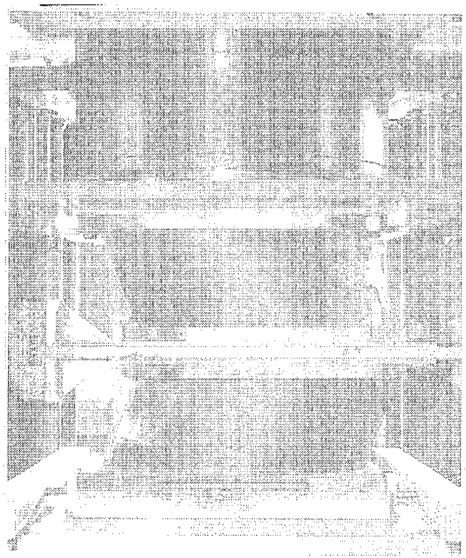

Fig. 4 Cyclic horizontal excitation test , under static vertical compression load, of a pair of superposed bearings mounted on the SISTEM test machine.

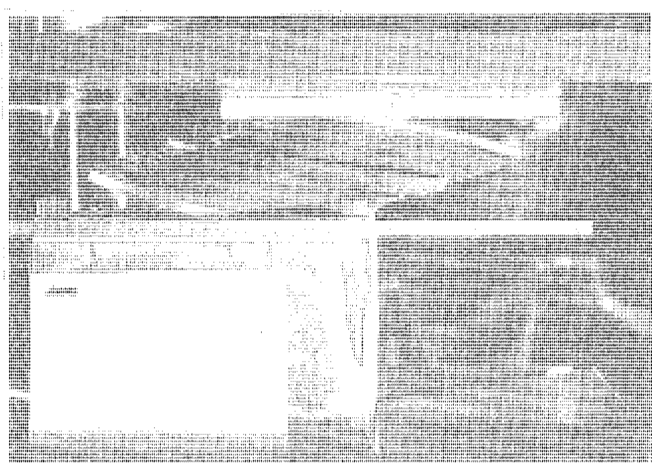

Fig. 5 1/2 scale bearing without lateral rubber cover , displaced at 260 % σ during a quasi-static horizontal failure test under static vertical compression load.

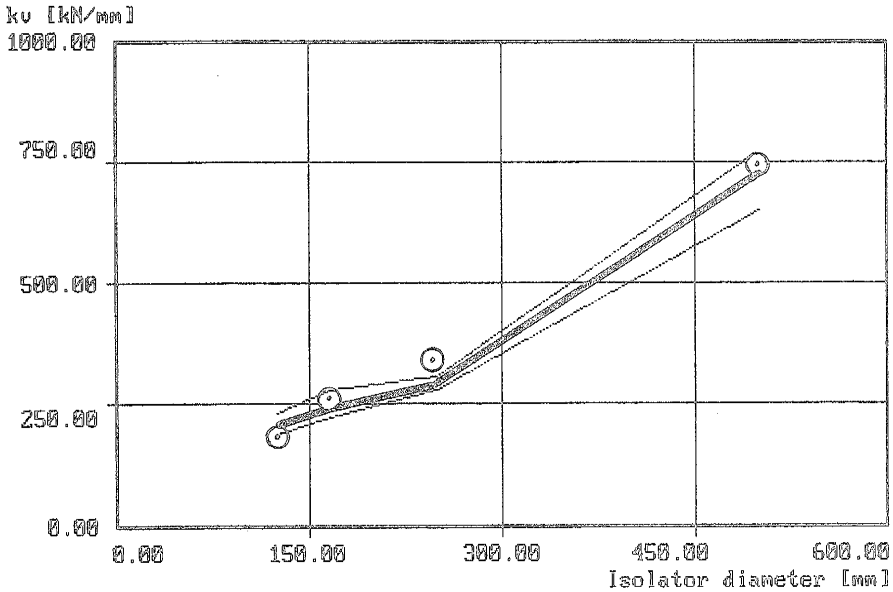

Fig. 6 Static vertical stiffness k_v versus bearing diameter, measured for the various scale bearings (═══ = average values; --- = maximum and minimum values). Comparison with the theoretical data (o).

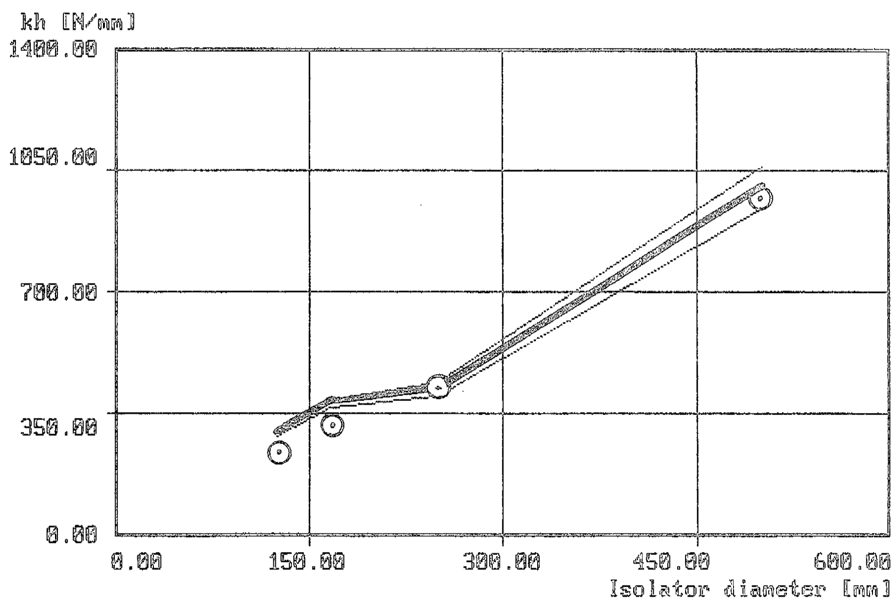

Fig. 7 Static horizontal stiffness k_h versus bearing diameter, measured for the various scale bearings at the vertical design load, in the range [-100% - +100%] σ (═══ = mean values; --- = maximum and minimum values). Comparison with the theoretical data (⊙).

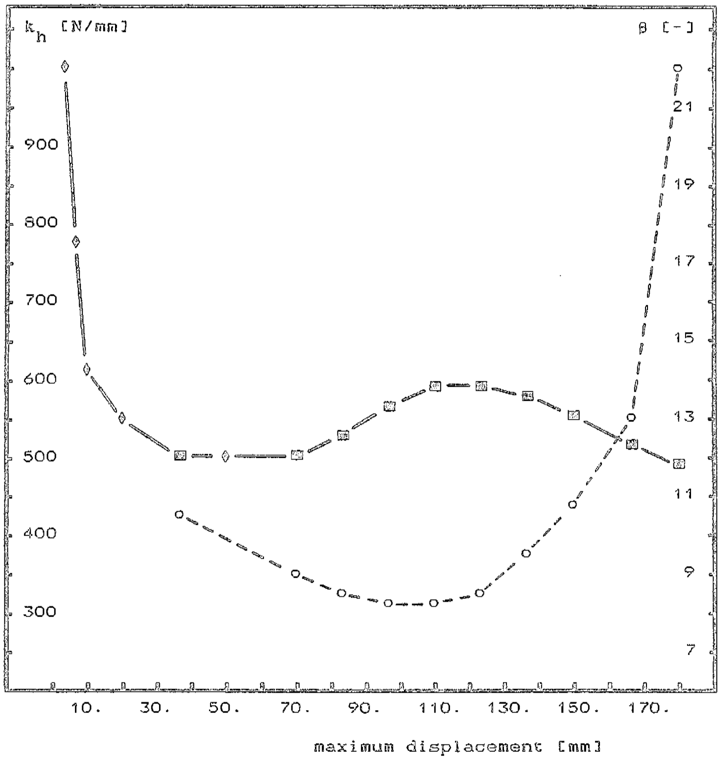

Fig. 8 Horizontal stiffness (▩) and fraction [%] of critical equivalent viscous damping β (o) measured in the static failure test of the bearing of Fig. 5 , versus applied displacement (◊ = stiffness measured in previous tests).

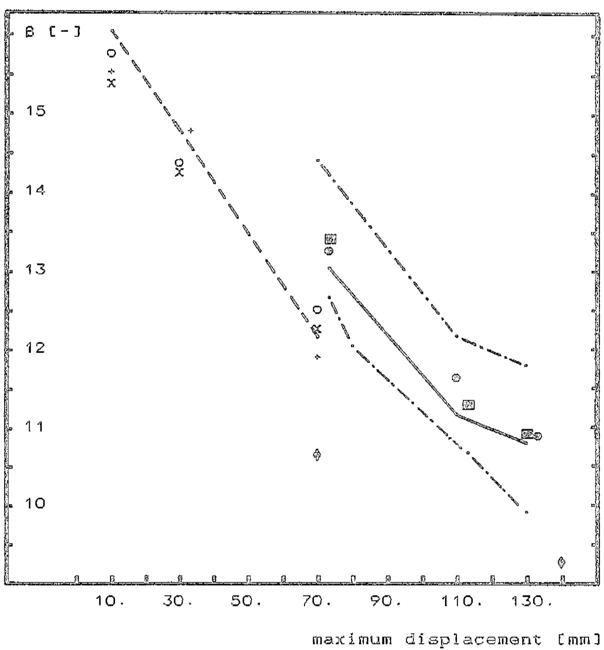

Fig. 9 Fraction [%] of critical equivalent viscous damping, β, measured for the full-scale scale bearings in the dynamic tests at fixed frequency, versus applied displacement (average values: ⊚ = 0.3 Hz, ══ = 0.6 Hz, ▩ = 0.9 Hz; maximum and minimum values: -·-). Comparison with average static data (◊) and results of a dynamic test of two superposed SIP bearings (x = 0.1 Hz, o = 0.3 Hz, --- = 0.6 Hz, + = 0.8 Hz).