# Dynamic Experiments Performed in Italy on Seismically Isolated Structure Mock-ups in the Framework of the R&D Studies for the Innovative Nuclear Reactors

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## ABSTRACT

Snap-back experiments were performed on both a 9,500 kN rigid mass supported by six high damping steel-laminated elastomer isolators and an actual isolated building with similar bearings; they are also in progress - together with forced excitation experiments - for a 394 kN rigid mass supported by four 1/4 scale bearings. Test results have already demonstrated the adequacy of seismic isolation and have provided data useful for the comparison with single bearing test results and the validation of numerical models for the analysis of isolated structures.

## 1 INTRODUCTION

In a separate paper (Martelli et al. 1991) we have explained the reasons for the numerical and experimental work that was undertaken by ENEA and ISMES to support seismic isolation development, in view of its possible application to nuclear plants. We have also mentioned that experiments include the analysis of isolated structures mock-ups and actual buildings, in addition to the individual bearings tests described in that paper.

## 2 TESTS OF ISOLATED STRUCTURES

The ongoing experiments of isolated structure mock-ups (Forni et al. 1991) make use of rigid masses that are supported by high damping steel-laminated elastomer bearings, previously characterized in the individual isolators tests. Full-scale isolators are equal to the 500 mm bearings that are used for the five buildings of the Administration Center of the SIP Telephone Company at Ancona (this is the first application of seismic isolation in Italy). The main test purpose is to evaluate the actual global behaviour of isolation systems, and thus, to which extent the results of individual bearing tests can be used to predict the isolated structure behaviour.

In August 1990, snap-back experiments were performed on a 9,500 kN mock-up (Fig. 1), formed by the inertial mass of the ISMES multi-excitation laboratory, which was supported by six

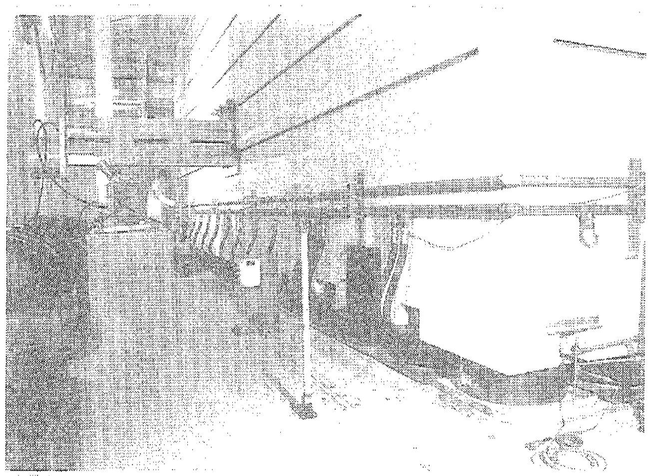

Fig. 1 View of the 9,500 kN inertial mass of the ISMES multiexcitation laboratory, supported by six 500 mm diameter isolators (reinforced concrete ; base = 10 m x 10 m ; height 4 m).

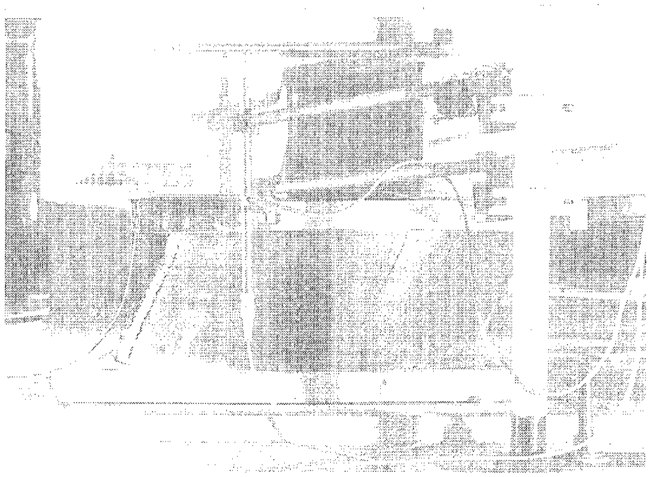

Fig. 2 Isolator supporting the 9500 kN rigid mass , deformed before release in a snap-back test.

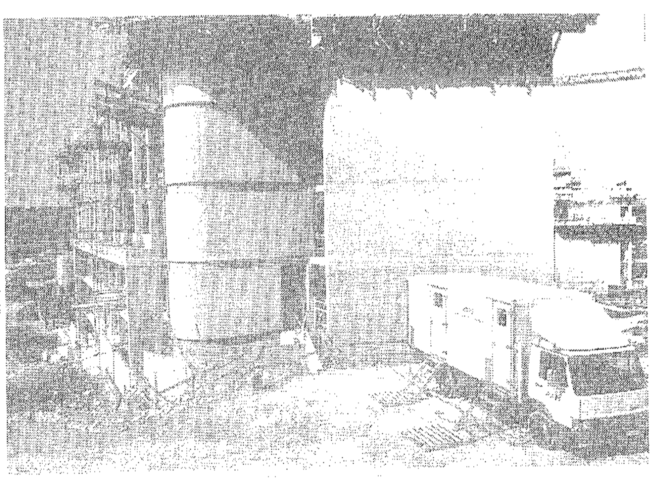

Fig. 3 View of the seven floor SIP building subjected to "in situ" tests (October 1991) . Weight = 6,300 kN at the time of experiment (7,000 kN after construction completion) ; height = 25 m ; number of bearings : 20 with 500 mm diameter , 47 with 600 mm diameter.

full-scale bearings, so as to reproduce the actual design vertical load of SIP isolators. The mass was pushed to the initial displacement (Fig. 2) by means of a hydraulic jack; the use of a dislocatable device made the mass release possible. The aim was also to qualify snap-back mechanisms for "in-situ" tests.

In September and October 1990 forced excitation and snap-back experiments of one of the actual SIP buildings (Fig. 3) were performed by ISMES, mostly on behalf of ENEL (Bettinali et al. 1991). ENEA funded the last snap-back experiment, which aimed at checking the repeatibility of results and obtaining more detailed data on the building response, so as to allow for the validation of numerical models for the analysis of isolated structures. The test technique was similar to that adopted for the 9,500 kN mock-up; building release was obtained by blasting of plastic explosive filling the bolts of snap-back mechanisms.

At present (Febraury 1991), snap-back and forced excitation experiments are in progress on a 394 kN rigid mass supported by four 1/4 scale bearings, mounted on the MASTER six-degrees-of-freedom shake table of ISMES. Forced excitations are both sinusoidal and transient; the latter correspond to actual Italian earthquake recordings for various soil conditions. Effects of excitation amplitude are being studied up to 100 % $\sigma$ ($\sigma$ = shear strain, i.e. horizontal displacement over total rubber height), for both one- and multi-directional simultaneous excitations.

Snap-back and force excitation tests are also foreseen on a 1,600 kN rigid mass supported by four 1/2 bearings and scaled mock-ups of actual isolated structures.

## 3 SOME RESULTS

Snap-back tests were performed at initial displacements ($d_i$) increasing up to 85 mm for the 9,500 kN mock-up (Fig. 4) and 107 mm for the SIP building, i.e. sufficiently close to the design value (144 mm = 100% $\sigma$). A very accurate inspection of the building after test conclusion stressed the full integrity of both the structure and the few brick wall partitions that had already been constructed.

Experiments were repeated at $d_i$ = 70 mm for the building (Fig. 5) and $d_i$ = 65 mm for the mock-up (Fig. 6). For the building, repeatibility of test results was even better than that shown by Fig. 6 for the mock-up (Bettinali et al. 1991).

The motion in the $d_i$ direction lasted a very few seconds for both the bulding and the mock-up (about 3 s), and consisted in three appreciable cycles only. The mock-up response indicates a quasi exclusively horizontal translation mode in that direction after mass release; for the building, some translation in the normal direction was due to the structure asymmetry, while for the mock-up the explanation is that the jack was not exactly applied to the center of gravity, for practical reasons.

Residual displacements of some millimeters were always detected at tests conclusion; these were partly recovered within some hours; their values seem not to be related to those of $d_i$, but they appear dependent on the deformation history and rest intervals to which the isolators were subjected.

The first response frequency (f) varied considerably during

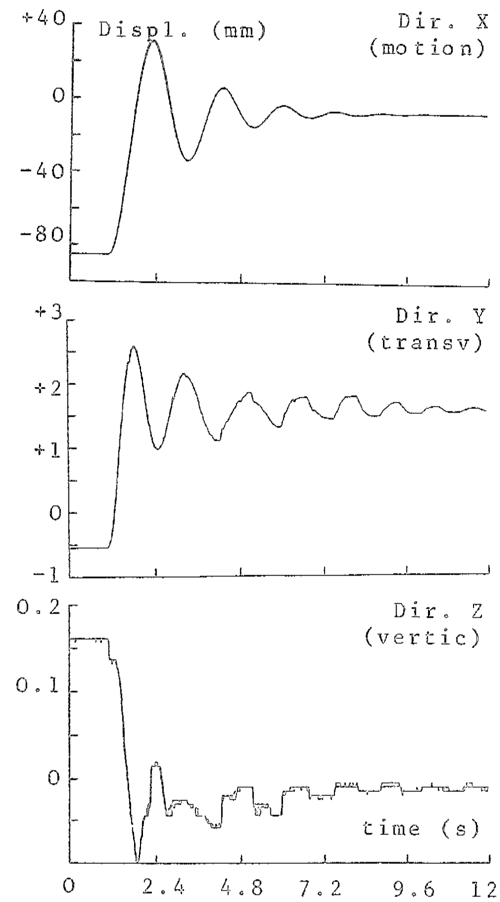


Fig. 4 Displacement time - histories of the isolated 9,500 kN rigid mass, recorded during the test at 85 mm initial deformation.

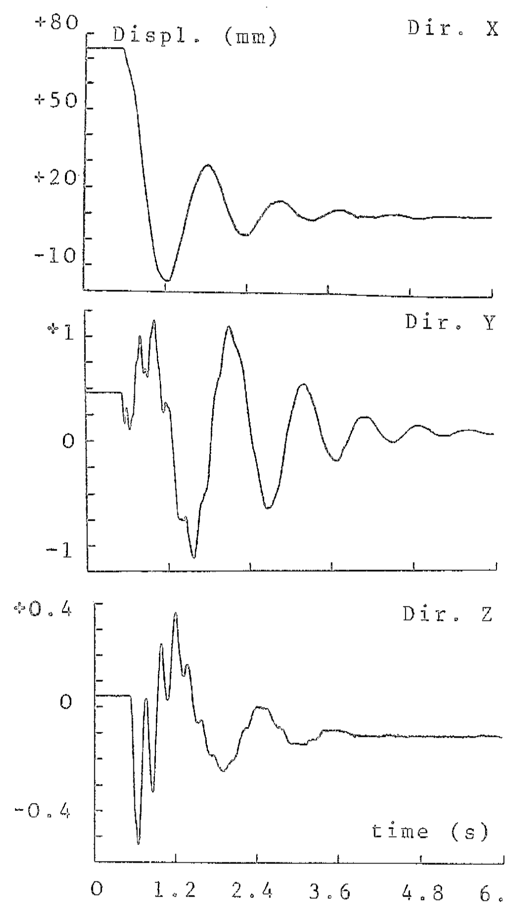


Fig. 5 Displacement time - histories measured on the SIP building base slab during the second snap - back test at 70 mm initial deformation.

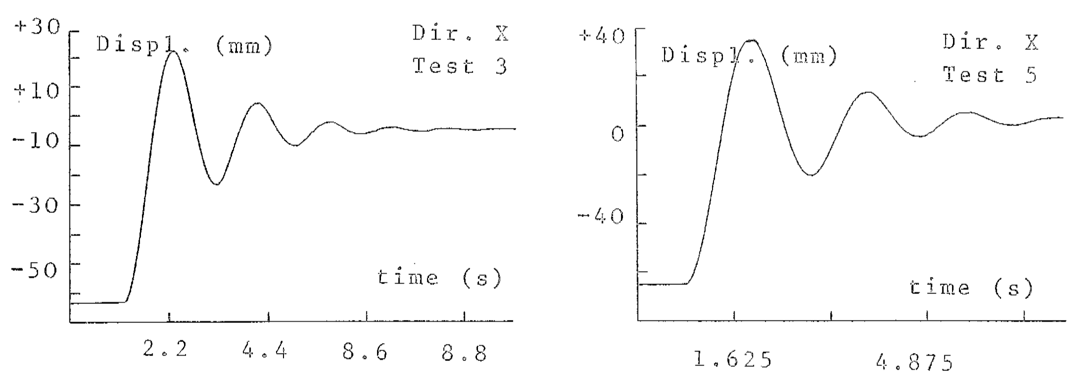


Fig. 6 Comparison between displacement time-histories of the isolated 9,500 kN rigid mass, recorded in the motion direction during the two tests at 65 mm initial deformation.

motion, as a function of displacement amplitude: for the mock-up, f was between 0.44 Hz at the largest displacements and 0.74 Hz when the mass was near to stopping; for the building, these f values were 0.75 Hz and 1.2 Hz, due to the lower mass per isolator and presence of mostly larger isolators (Fig. 3). This behaviour is consistent with the non-linear correlation that exists between bearing elastic forces and displacements (Martelli et al. 1991).

For similar reasons it is impossible to define an unique damping value for each entire test. The assumption of equivalent viscous damping ($\beta_v$) and use of the logarithmic decrement technique led to $\beta_v$ values that vary from 17% of the critical (at the largest cycle) to 20% for the mock-up, and between 16% and 20% for the building. These values are rather larger than those obtained in the single bearing tests, due the strong increase of $\beta_v$ with decreasing displacement during each test and maybe, a hysteretic nature of energy dissipation (Forni et al. 1991).

The numerical analysis of free-vibration test data performed with ABAQUS and other programs that are only able to account for $\beta_v$ independent of displacement showed that horizontal stiffnesses ($k_h$) are consistent with those related to single bearing tests, if the dependence of $k_h$ on displacement is correctly taken into account (Fig. 7). Moreover, the response measured in each test was well calculated by use of a constant $\beta_v$ value that was only slightly larger than the average test data, and by translating the force-displacement curve from the origine along the abscissae axis, of a quantity equal to the residual displacement, so as to account for the non-zero center of the motion cycles that is due to creep and other phenomena (Fig.7).

It is noted that the agreement with β values measured in the single bearing tests was much better by use of a simple program accounting for the dependence of both $k_h$ and $\beta_v$ on displacement (Fig. 7) or by means numerical methods based on hysteretic damping (Sanò & Di Pasquale 1991). Anyway, the first results being obtained for the isolated 394 kN rigid mass seem to indicate that the applicability of the model with constant $\beta_v$ improves in the case of forced excitations, because also single bearing tests had been performed by use of forced cyclic loading.

## 4 CONCLUSIONS

Experiments of the isolated 9,500 kN mock-up allowed for the qualification of the snap-back mechanisms used later in the "in situ" tests of the SIP building. The latter clearly demonstrated the adequacy of seismic isolation to guarantee the integrity of the structures and their contents.

Test results have already provided excellent data for the characterization of isolation systems, comparison with the single bearing experimental results and validation of numerical models for the analysis of isolated structures. Such data stressed the adequacy of single bearing tests to determine the bearing characteristics (especially stiffness) to be used in this analysis, provided that the dependence on displacement is taken into account in the calculations. As to damping, its largely non-viscous nature seemed confirmed, together with the interest in verifying the applicability of a hysteretic model.

Anaway, constant $\beta_v$ values might be better applicable to the analysis of forced excitation test data, according to some first results of tests in progress on a 394 kN mock-up. This and other items will be also verified by testing an isolated 1,600 kN rigid mass and scaled mock-ups of actual isolated structures.

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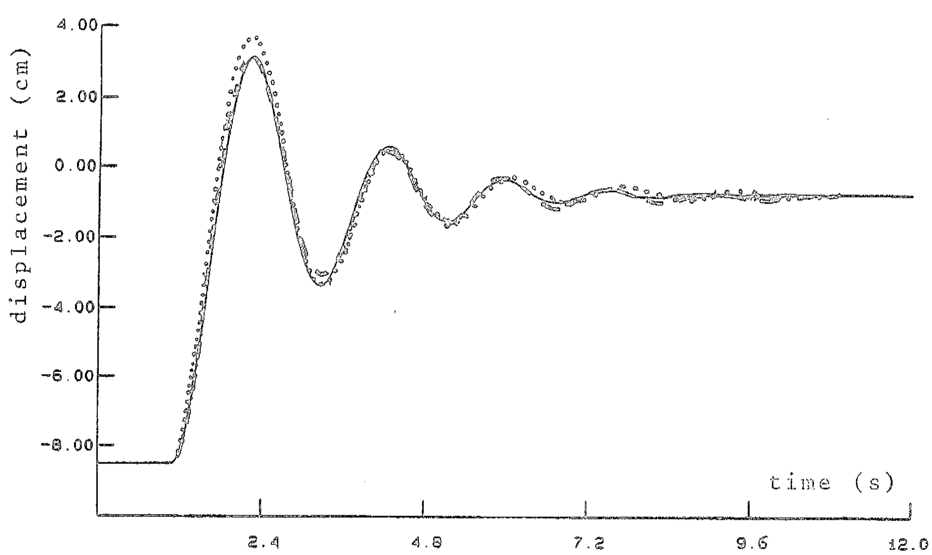


Fig. 7 Comparison between the horizontal displacements of the 9,500 kN mass measured during the test at 85 mm initial deformation (═══) and those computed with both ABAQUS at $\beta_v$ = 20% (---) and the $\beta_v$ values obtained in single bearing tests (···).