SMiRT-12 / K. Kussmaul (Editor)

K24/2

EXTENSION OF GUIDELINES FOR SEISMICALLY ISOLATED REACTORS

A. Martelli[1], B. Carpani[1], M. Forni[1], G. di Pasquale[2], T. Sano[2], G. Bonacina[3], M. Olivieri[4], A. Marioni[5] and G.F. Cesari[6]

[1]ENEA, Department of Innovative Reactors, Bologna, [2]ENEA, Directorate for Nuclear Safety and Health Protection, Roma, [3]ISMES S.p.A., Bergamo, [4]ANSALDO-Ricerche, Genova, [5]ALGA Sp.A., Milano, [6]University of Bologna (Italy)

ABSTRACT

The preparation of a proposal for design guidelines for seismically isolated nuclear reactors has been initiated with the sponsorship of the Commission of European Community. This work aims at (a) updating an existing document which covers the case of high damping steel-laminated rubber bearings, and (b) extending it to the other isolator types of interest.

1 INTRODUCTION

Forni et al. (1993a) have stressed in a separate paper that considerable efforts have been devoted in Italy for some years to the development and application of seismic isolation for both civil structures and industrial plants, including nuclear reactors. Studies in progress concern both experimental and numerical research, and the preparation of design guidelines for isolated structures. This paper reports on the state of activities on guidelines development, focussing on those for nuclear reactors (research work has been presented by Forni et al., 1993a).

2 EXISTING PROPOSAL FOR DESIGN GUIDELINES FOR NUCLEAR REACTORS

As mentioned by Forni et al. (1993a), the preparation of a proposal for design guidelines for nuclear power plants using high damping steel-laminated elastomer bearings (HDBRs) to provide horizontal isolation (i.e. HDRBs which are very stiff in the vertical direction) began in 1988, in the framework of a cooperation between the ENEA Department of Innovative Reactors (RIN) and GE Nuclear Energy, and with the support of experts of the ENEA Directorate for Nuclear Safety and Health Protection (DISP), ISMES and Bechtel National Inc. The reason for choosing the HDBR was that this isolator type was considered to be one of the most innovative and suitable for application to advanced nuclear reactors, and that it was used in the first applications of seismic isolation to large buildings in Italy (Forni et al., 1993a).

The guidelines document was prepared taking into account the most recent information available at the time on seismic analysis of nuclear reactors in general and the state-of-the-art of engineering design of isolated structures. One of its purposes was to identify items which required further R&D. It mainly dealt with items different from non-isolated systems. Although particular attention was paid to the case of Liquid Metal Reactors (due to their sensitivity to earthquakes), the proposal also aimed at fully covering other types of nuclear reactors that are isolated by means of HDRBs. The proposal consisted of the following sections: (a) definition of ground motions; (b) design requirements and analysis methods for isolated buildings and isolation support structure; (c) design and performance requirements of overall seismic isolation systems; (d) design requirements and analysis methods for isolated structures, systems and components; (e) design requirements and analysis methods for interface components; (f) design requirements for individual isolation devices; (g) qualification of seismic isolation bearing and isolation system; (h) acceptance testing of isolation devices; (i) seismic isolation reliability; (j) seismic safety margin; (k) seismic safety and monitoring systems. In addition, two appendices were included: (A) simplified methods for design of isolation bearings; (B) proposed procedure for establishing design parameters for seismic isolator bearings.

The document was published by Martelli et al. (1990) in a tentative form to allow for a broad review. Its main features were also summarized by Martelli et al. (1992), together with some first information on the R&D studies which had been undertaken at the time to allow for a more complete proposal. In fact, as expected, some safety factors to be used in the design, some test parameters and some details of qualification and analysis procedures were not defined, yet, in the document of Martelli et al. (1990): these were indicated there as TBD, i.e. "To Be Determined", because the exact definition of these items required specific R&D work.

3 GUIDELINES DEVELOPMENT FOR NON-NUCLEAR ISOLATED STRUCTURES

Activities also soon began in Italy to prepare national guidelines concerning the use of seismic isolation and passive energy dissipation systems in civil structures. These activities take advantage of wide-ranging collaborations which had been established, such as those of the Italian Working Group on Seismic Isolation (GLIS, see Forni et al., 1993a). More precisely:

(a) The preparation of a proposal concerning the isolation bearings and passive energy dissipation systems which have been judged of interest for buildings and bridges was undertaken by specific groups established by the Italian Standard Authority (UNI) and was later entrusted to Italian experts by the European Community (CEN TC 167/SC1: Structural Antiseismic Devices). ENEA, ISMES, ANSALDO-Ricerche and other GLIS members are participating in these activities .

(b) The preparation of a guidelines document to be used by designers of isolated buildings (to get the approval for contruction by the High Council of Public Works) was undertaken by the National Seismic Service, in cooperation with ENEA, ENEL and ISMES (Dolce et al., 1993).

Both documents are being completed (February 1993). Finally, a specific subgroup of GLIS was formed: its tasks are to collect, analyse, comment and if necessary, integrate the available guidelines documents and regulations (Forni et al., 1993b). It is noted that the contribution of ENEA and ISMES to the development of documents concerning civil structures took great advantage from the experience gained through the preparation of the proposal of Martelli et al. (1990). In turn, both guidelines development work and research performed for civil structures have been very useful to clarify items applicable to nuclear reactors also.

4 UPDATE AND EXTENSION OF THE EXISTING PROPOSAL FOR DESIGN GUIDELINES FOR NUCLEAR REACTORS

Martelli et al. (1990 & 1992) stated that their proposal would have been periodically updated to include comments and to reflect the advances of seismic isolation technology developments. A first revision of the document has already been prepared according to comments officially received by ENEA-DISP, the American Society of Civil Engineers and Malaysian Rubber

Producers' Association. This revision has been submitted to GE Nuclear Energy.

Furthermore, work to update and extend this document to nuclear reactors using bearings different from the HDRB and energy dissipation devices has been initiated by ENEA, within studies sponsored by the Commission of the European Community (CEC) in the framework of the Study Contract ETNU-CT-91-0031. Work for the CEC is being performed in cooperation with ALGA, ISMES, ANSALDO-Ricerche and the Nuclear Engineering Laboratory (LIN) of the Bologna University. It consists of the following activities:

(a) Revision of the document based on further comments and updated analysis of the state-of-the-art on design of isolated nuclear and non-nuclear structures in Europe.

(b) Extension of the document to: (b1) other horizontal isolation systems of interest for the European projects (neoprene bearings, sliding devices, etc.); (b2) the other types of horizontal isolation systems of general interest (other elastomeric isolators, including lead plug and low damping rubber bearings, etc.); and (b3) three-directional isolation.

(c) Identification of items to be precised through further R&D and specification of the related necessary work.

These activities take into account the other available proposals and recommendations for design guidelines for isolated structures, and take advantage of the co-operations existing between ENEA and other national and foreign organizations. At the time being (Ferbruary 1993), phase (a) is in progress. Work consists in a careful re-analysis of the document revision, made by ENEA, ISMES and ANSALDO-Ricerche, which accounts - among others - for the results of experiments and numerical analyses described by Forni et al. (1993a). Par. 5 reports the main comments (if any), to the different sections of the proposal published by Martelli et al. (1990), which were later included or suggested. It also points out items which are still TBD.

5 REMARKS ON THE EXISTING PROPOSAL FOR DESIGN GUIDELINES FOR NUCLEAR REACTORS

In general, it was suggested that, because of the large number of referenced documents, the most important information of these shall be included in comments. Also, some references shall be updated; in particular, reference should be made to the Appendix SEAOC-1991 or even to the 1991 Uniform Building Code. Finally, the Appendix of Martelli et al. (1990) shall be re-written according to recent of ISMES and ENEL work.

5.1 Definition of Ground Motions (§ 5)

Probabilistic evaluations of SSE and OBE were suggested, together with specification of OBE requirements similar to those adopted in the USA for some ALWRs (§§ 5.1.1-5.1.2). The requirement that design response spectra in the frequency range to 1 Hz shall be equal at least to that specified by R.G. 1.60 was changed to a suggestion (§ 5.1.3). Specific requirements concerning the features of design time-histories (according to App. D of NUREG/CR 5374) were moved from § 6.8.3 to § 5.1.6 and better precised there. Specification of criteria for the choise of time-histories or spectra was suggested (§§ 5.1.6-5.1.8). The need for a characterization of ground motion rotational components, if necessary, was specified (§ 5.1.8).

5.2 Requirements & Methods for Isolated Buildings & Isolation Support Structures (§ 6)

Account for accidental eccentricity due rotational ground motion component was suggested to determine Reference Displacement (§ 6.1.2). Requirements concerning the calculation of the Design Displacement were modified, suggesting the use of 90% the Reference Displacement in the second criterion of § 6.1.4 (comments to such a reduction were later suggested). Requirements concerning the definition of gaps were also modified, suggesting the use of 80% the sum of the absolute values of structures' Reference Displacements, in the second criterion of § 6.5.1; it was also specified there that gaps shall remain free in every design condition (e.g. flood). The maximum damping ratio which can be assumed at SSE was modified to 15% (§ 6.7.2). It was suggested to refer to foundation rigidity instead of foundation flexibility, in § 6.7.5. The use of SRSS method, to combine results of separate one-directional analyses, was replaced by the Absolute Sum method, and requirements concerning the contribution of rotational components of the input motion where introduced in § 6.8.1. A further modification of § 6.8.3, so as to include the possibility of using a single set of input time-histories, was suggested (by moving there the contents of § 8.5 and the last sentence of § 8.4).

Some TBD values remain as to features of fail-safe systems and safety factor for gaps between separately isolated adjacent structures. Furthermore, a new TBD value was introduced concerning which contribution of rotational effects makes it necessary to account for this effect.

5.3 Requirements for Overall Seismic Isolation Systems (§ 7)

Modification of § 7.1.1 (by simply referring to § 6.1.4) was suggested. The minimum value of isolation frequency range to be chosen was lowered from 0.5 Hz to 0.33 Hz (§ 7.2.1.1). It was suggested to specify, in § 7.2.1.2, that vertical stiffness shall be sufficiently high to avoid not only vertical amplification, but also rocking. The value of 10% was specified as to the minimum equivalent viscous damping ratio which shall correspond to design displacement (§ 7.2.2.1); however, a careful evaluation of this item was later suggested. The need for investigating the effects of so called "minor earthquakes" was stressed (§ 7.2.5.3).

TBD values remain for safety factors applicable to horizontal displacement and maximum design vertical load to be used for the design of isolation system (the first being equal to that to be used for gaps), as well as to permissible variations of isolation system stiffness and damping.

5.4 Requirements & Methods for Isolated Structures Systems & Components (§ 8)

Reference to the NUREG/CR-1161 Report, as to simplified rules to evaluate sloshing motion, was included as comment to § 8.7.

5.5 Requirements for Individual Isolation Devices (§ 10)

The need that vertical load capacity shall account for buckling effects was stressed (§ 10.2). Safety factors were specified for the maximum horizontal displacement (2), and vertical load and horizontal displacement at which the isolator shall be designed to be stable (both 1.7) (§§ 10.3.1-10.3.2). The requirement that safety factors shall account for roll-over - if relevant - was introduced (§ 10.3.3). As to § 10.4.4, it was recalled that large temperature effects were measured below 0 C by Forni et al. (1993a). The reduction to three, of the number of cycles for the evaluation of damping, was suggested (§ 10.6). A criterion to evaluate fatigue life was proposed, the very large number of cycles at large shear strain before failure in US tests was stressed, and a requirement such as that foreseen in the IEC-980/1989 document was suggested (§ 10.7.2). The requirement that environmental conditions shall also include various chemical and biological attacks was specified, and tests for the evaluation of aging due to thermal and radiation effects were suggested, together with the specification of engineering solutions to reduce the risk connected to fire attack (§ 10.8). The need for defining the temperature at which creep effects shall be evaluated was stressed (§ 10.9). Finally, requirements that degradation due to aging shall not reduce safety factors below specified values, and that isolators shall survive the faulted condition at the end of their design life were introduced (new §§ 10.10.1 and 10.10.2).

Several TBD values remained, for instance for environmental effects, tests to be performed to evaluate the maximum offset, uplift and rocking, disengagement of dowelled bearings and tests to be performed on the rubber compound (although the latter were suggested).

5.6 Qualification of Seismic Isolator Bearings (§ 11)

It was suggested to cancel the possibility of analytical qualification of single isolators, to consider that isolator qualification shall not be limited to seismic effects, and to include reference to IEC standards (e.g. IEC 780-1984 and IEC-980-1989) in comments to §§ 11.1.1-11.1.3 and to IEEE Std 323-1983 in § 11.1.3. The requirement that the manufacturing process of isolation bearings shall be qualified was introduced (§ 11.1.5). It was suggested to extend the use of tests on scaled bearings according to the US seismic bearing qualification program presented at the 1992 IAEA Meeting on Seismic Isolation Technology (§ 11.2), and also, to use § 11.2.1 for general requirements, thus adding that qualification is necessary every time that isolators with new features are developed and defining acceptance criteria according to Dolce et al. (1993); it was also stressed that § 11.2.1 shall require the repetition of the same tests on four aged bearings, as those performed before in their virgin conditions. It was suggested to only outline, as requirements of § 11.2.2, tests to be performed (according to Dolce et al. 1993) and to include proposed details of tests procedures as comments (detailed definition shall be carried out in the framework of test procedures and specifications). Environmental effects such as temperature were introduced among those to be considered and it was suggested to repeat qualification tests after artificial aging globally accounting for environmental conditions (§ 11.2.3). It was suggested to refer to Dolce et al. (1993) for tests concerning the evaluation of vertical load variation on horizontal parameters (§ 11.2.5). Some questions arose on the difficulty, in some cases, of performing shake table tests on scaled isolated structure mock-ups (§ 11.3.1), and real need for multifrequencial simultaneous three-directional excitations (§ 11.3.2). The recommendation of performing forced excitation tests - if feasible - on isolated structures, in the case that snap-back tests cannot be performed, was added in § 11.3.3; further recommendations concerned the use of snap-back tests on scaled mock-ups if those on actual structures are not feasible; however, it was later suggested to only make a generic recommendation that in-situ tests should be performed, in the requirements of § 11.3.3, and to cite the different techniques as comments.

5.7 Acceptance Testing of Isolation Devices (§ 12)

It was suggested: to require the measurement of vertical stiffness for all bearings (§ 12.1.1); to include tolerance classes for some geometrical sizes as a comment to § 12.2.1; to replace - where feasible - the destructive controls required on isolators in § 12.2.3 by controls during the assembly phase (those foreseen by Martelli et al. 1990 are very costly, due to the limited number of bearings per batch); to move, to comments, the detailed description of compression tests and combined compression and shear tests (§ 12.2.3 and § 12.2.5), and not to suggest any procedure (only the important topics shall be outlined). A TBD fraction of the isolator heigh measured during qualification tests (which if exceeded determines isolator rejection) was introduced in §

12.2.4 concerning sustained compression tests; however, it was later suggested to cancel the entire section (because undesirable effects may be detected during qualification or measurement of vertical stiffness), or at least, to limit tests to 20% of the isolators (to be selected using statistical criteria). It was finally suggested to comment, in § 12.2.6, that tensile tests are required only if tension is foreseen in the design (it is noted that TBD values remain as to such tests).

5.8 Seismic Isolation Reliability (§ 13)

Reference to finite-element analysis as to the evaluation of phenomena affecting the bearing reliability was cancelled, together with the entire § 13.4.2, concerning submission of the in-service inspection program to the Licensing Authorities (otherwise, reference to these Authorities should be also made for other items). It was specified in § 10.4.3 that OBE is the "significant earthquake" after which tests shall be performed on a larger numbers of bearings (this number, however, remains TBD, together with the number of bearings to be usually tested and time interval for more detailed controls).

5.9 Seismic Safety Margin Assessment (§ 14)

Comments to § 14.1.1 were moved to prescriptions. However, it was later commented that the entire § 14 is too detailed, thus it was suggested to shorten it considerably, by making reference to the documents describing PRA and SME procedures and limiting requirements to specific items caused by the adoption of seismic isolation (definition of seismic input, isolation effects on the response to beyond SSE earthquakes, evaluation of the seismic capability/fragility of the isolation system itself).

6 CONCLUSIONS

This paper has summarized activities in progress in Italy on the development of design guidelines for isolated structures, focussing on those concerning nuclear reactors. Information has been provided on work in progress to update and extend the proposal of Martelli et al. (1990). Advancements will be reported by Forni et al. (1993b).

REFERENCES

Dolce, M., et al. 1993. *Linee Guida per il Progetto di Edifici con Isolamento Sismico*. Roma, Italy: Servizio Sismico Nazionale della Presidenza del Consiglio dei Ministri (in Italian).

Forni, M., et al. 1993a. *Most Recent Experimental and Numerical Studies Performed in Italy on Seismic Isolation*. Proceedings of the 12th SMiRT Conference. Amsterdam: Elsevier.

Forni, M., et al. 1993b. *Most Recent Developments on Seismic Isolation of Nuclear Facilities in Italy*. Proceedings of the Post 12th SMiRT Conference Seminar on Isolation, Energy Dissipation and Control of Vibrations of Structures. Ascoli Piceno, Italy: CREA.

Martelli, A., et al. 1990. *Proposal for Guidelines for Seismically Isolated Nuclear Power Plants - Horizontal Isolation Systems Using High Damping Steel-Laminated Elastomer Bearings*. Energia Nucleare. 1: 67-95.

Martelli, A., et al. 1992. *Development of Design Guidelines for Seismically Isolated Nuclear Reactors and R&D Work Performed by ENEA*. Nuclear Technology. 97: 153-169.