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DEVELOPMENT OF GUIDELINES FOR SEISMIC ISOLATION IN ITALY

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ABSTRACT

The first activities on seismic isolation that were performed in Italy concerned the preparation of a proposal for design guidelines for nuclear power plants using the high damping steel-laminated elastomer bearings (HDLRBs). They were jointly initiated by ENEA-RIN and GE Nuclear Energy in 1988, with the co-operation of ISMES and the support of experts of ENEA-DISP and Bechtel National Inc..

The features of the guidelines proposal were outlined at the First Post-SMiRT Conference Seminar on Seismic Base Isolation of Nuclear Power Facilities (San Francisco, 1989). The full text of the document was published in the Journal "Energia Nucleare" in 1990, in a tentative form, to allow for a broad review. A summary of the main items - together with some first results of R&D studies performed in support to guidelines development - was also reported in a paper which was recently published by the Journal "Nuclear Technology" (February 1992).

A first revision of the document is being prepared and will be soon published: it accounts for both comments received - for instance, by the American Society of Civil Engineers (ASCE), ENEA-DISP and the Malaysian Rubber Producers' Association (MRPRA) - and the first results of R&D studies in progress in Italy and the USA.

These activities have recently been extended - as part of a cooperation with the Italian Standard Authority (UNI) - to other anti-seismic devices, for application to civil buildings and non-nuclear plants. A co-operation of ENEA, ENEL and ISMES has also been started with the National Seismic Service to help it in the assessment of national regulations.

Furthermore, extension of the aforesaid guidelines document to nuclear reactors using bearings different from the HDLRB has been planned, under the sponsorship of the Commission of the European Communities: this work will be performed by ENEA, with the cooperation of ALGA, ISMES, ANSALDO and the Nuclear Engineering Laboratory (LIN) of the Bologna University, and the support of experts of the French CEA.

This paper reports the main features of the aforesaid activities, pointing out the need for R&D to support guidelines development.

1. INTRODUCTION

The Italian Status Report, presented to this Meeting by Martelli & Bettinali [1], has explained the reasons for the considerable efforts that are being devoted by the Italian Agency for the New Technologies, Energy and Ambient (ENEA), the National Utility (ENEL), ISMES, ANSALDO-Ricerche and other members of the National Working Group on Seismic Isolation (GLIS) to the development of guidelines for seismically isolated constructions. We remember that one of the purposes of GLIS is to provide support to the State Institutions that are charged with the approvals of structure designs, for the design verification (Martelli & Bettinali [1]).

The Italian Status Report [1] has also stressed the intercorrelations existing between guidelines development and R&D work (such as the experimental activities reported by Bonacina et al. [2] and the numerical studies presented by Bettinali et al. [3]), and the need for performing both activities in parallel.

This paper presents the main features of guidelines development, pointing out the need for R&D to support it, and mentioning the national and international collaborations that are in progress or planned on this subject. It forms an updated version of the paper published by Martelli et al. [4] in the Journal "Nuclear Technology".

2. FIRST PROPOSAL FOR DESIGN GUIDELINES FOR NUCLEAR REACTORS ISOLATED BY HDLRBs

The first activities on seismic isolation development were initiated in Italy by the ENEA Department of Innovative Reactors (RIN), in 1988. They concern the preparation of a proposal for design guidelines for nuclear plants using High Damping Steel-Laminated Rubber bearings (HDLRB), and are being performed with the cooperation of ISMES and GE Nuclear Energy and the support of experts of the ENEA Directorate for Nuclear Safety and Health Protection (DISP) and Bechtel National Inc.. The reasons for the choice of these isolators have been outlined by Martelli & Bettinali [1].

The aforesaid guidelines document was prepared taking into account the most recent information on seismic analysis of nuclear reactors in general and the state-of-the-art of engineering design of isolated structures. It mainly deals with items different from non-isolated systems. Focus is on requirements, analysis methods, qualification procedures and monitoring of isolation devices and systems. Proposals for design requirements and analysis methods for isolated structures, systems and components are also included.

Although particular attention is paid to the case of LMRs (due to their sensitivity to earthquakes), guidelines also aim at fully covering other types of nuclear reactors that are isolated by means of HDLRBs.

The features of the guidelines proposal were outlined by Martelli et al. [5] at the First Post-SMiRT Conference Seminar on Seismic Base Isolation of Nuclear Power Facilities (San Francisco, 1989). The full text of the document was published by Martelli et al. [6] in the Journal "Energia Nucleare" in 1990, in a tentative form, to allow for a broad review. A summary of the main items - together with some first results of R&D studies performed in support to guidelines development - was also reported by Martelli et al. [4]

in a paper which was recently published by the Journal "Nuclear Technology" (February 1992).

It will be shown below that some safety factors to be used in the design, some test parameters and some details of qualification procedures are not defined, yet (these are indicated as TBD, i.e. "To Be Determined"). Indeed, the exact definition of these items requires specific R&D work, such as that described by Bonacina et al. [2] and Bettinali et al. [3]. Furthermore, some other items - such as, for instance, low frequency effects - need to be better precised.

Some remarks on the different sections of the proposed guidelines are reported below. The most important items are better specified by Figs. 1 to 4. There, reference is made to the published document of Martelli et al. [6] for details, and to well-known U.S. reports, such as those of the Nuclear Regulatory Commission (NUREG Reports).

2.1 Definition of Ground Motions

Reference is made to existing codes for Safe Shutdown Earthquake (SSE) and Operational Basis Earthquake (OBE). It is specified that special attention must be paid to the low-frequency range (0.1 - 1 Hz), because of the effects on isolated structures. This implies the use of site specific ground motions and the corresponding response spectra (Fig. 1).

2.2 Design Requirements and Analysis Methods for Isolated Buildings and Isolation Support Structures (Fig. 1)

It is stressed that design of isolated structures must rely on displacement. The methods to be used for determining the reference displacement are prescribed.

Requirements are provided for the structural elements located above and below the isolation interface; it is specified that they shall be rigid in the horizontal plane. Safety factors are also provided against overturning of the supported structure, together with requirements to avoid isolator uplift.

The features and safety functions of ultimate horizontal and vertical restraint systems (fail-safe systems) are pointed out. It is clarified when the horizontal system is required.

The methods to be adopted for defining the gaps that shall be present between isolated and non isolated structures or independently isolated structures are also provided. These gaps shall be equal to relative displacements times a safety factor. The exact value of this factor is still TBD: it has to be determined by experimental tests as a function of the strength reserve of isolators and SSE return period.

Finally, rules are given for the inspectability and replacement capability of isolators, soil-structure interaction analysis, and design analysis methods. As to the last item, prescriptions concern the use of time-histories, applicability of simplified methods, and need and features of parametric calculations to be performed by varying soil, isolation and structure stiffnesses. We note that the use of simplified methods is only permitted in particular cases and requires precise justification.

Fig. 1. Design guidelines for nuclear reactors isolated by HDLRBs: definition of ground motion; design and analysis methods for isolated building and isolation support structure.

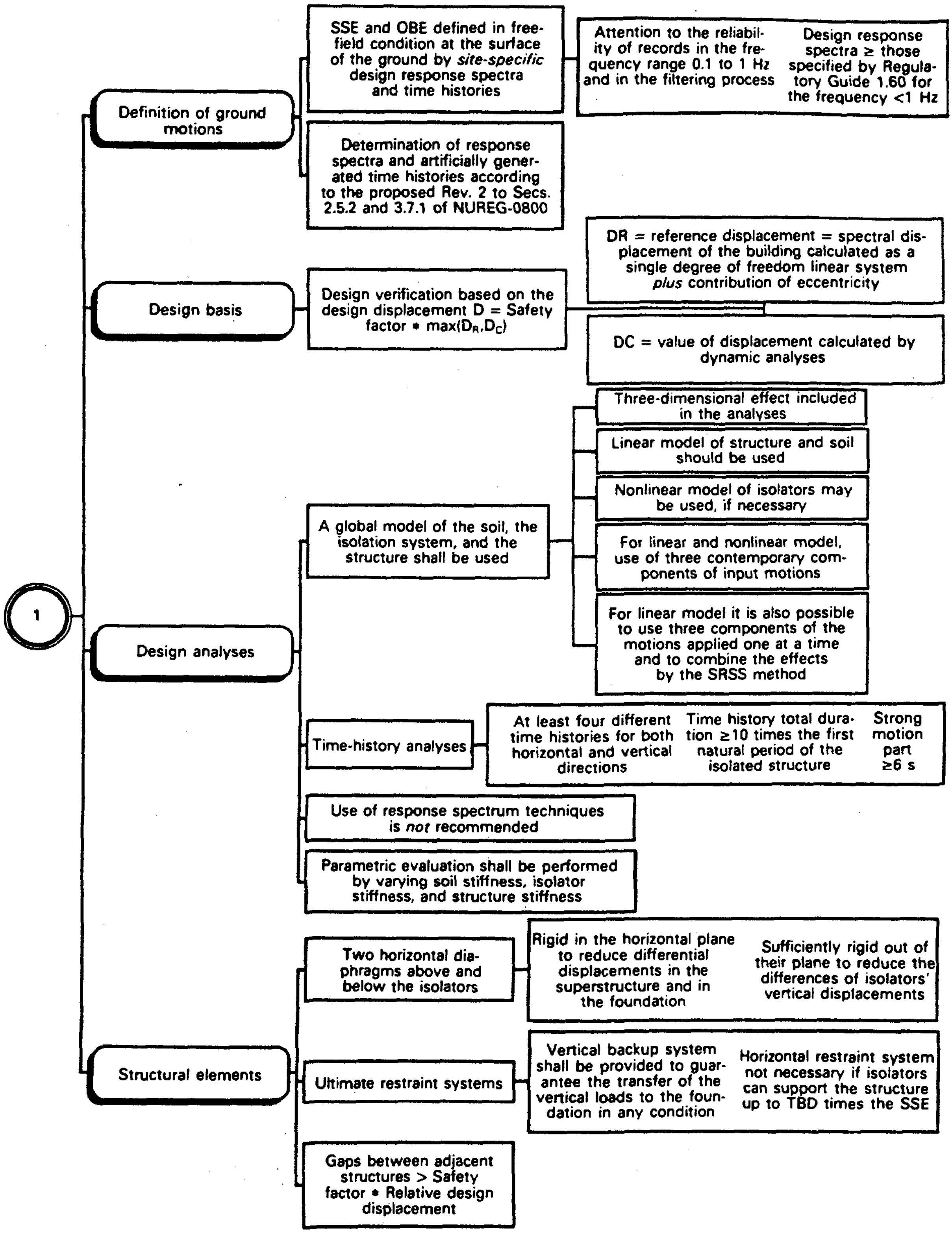
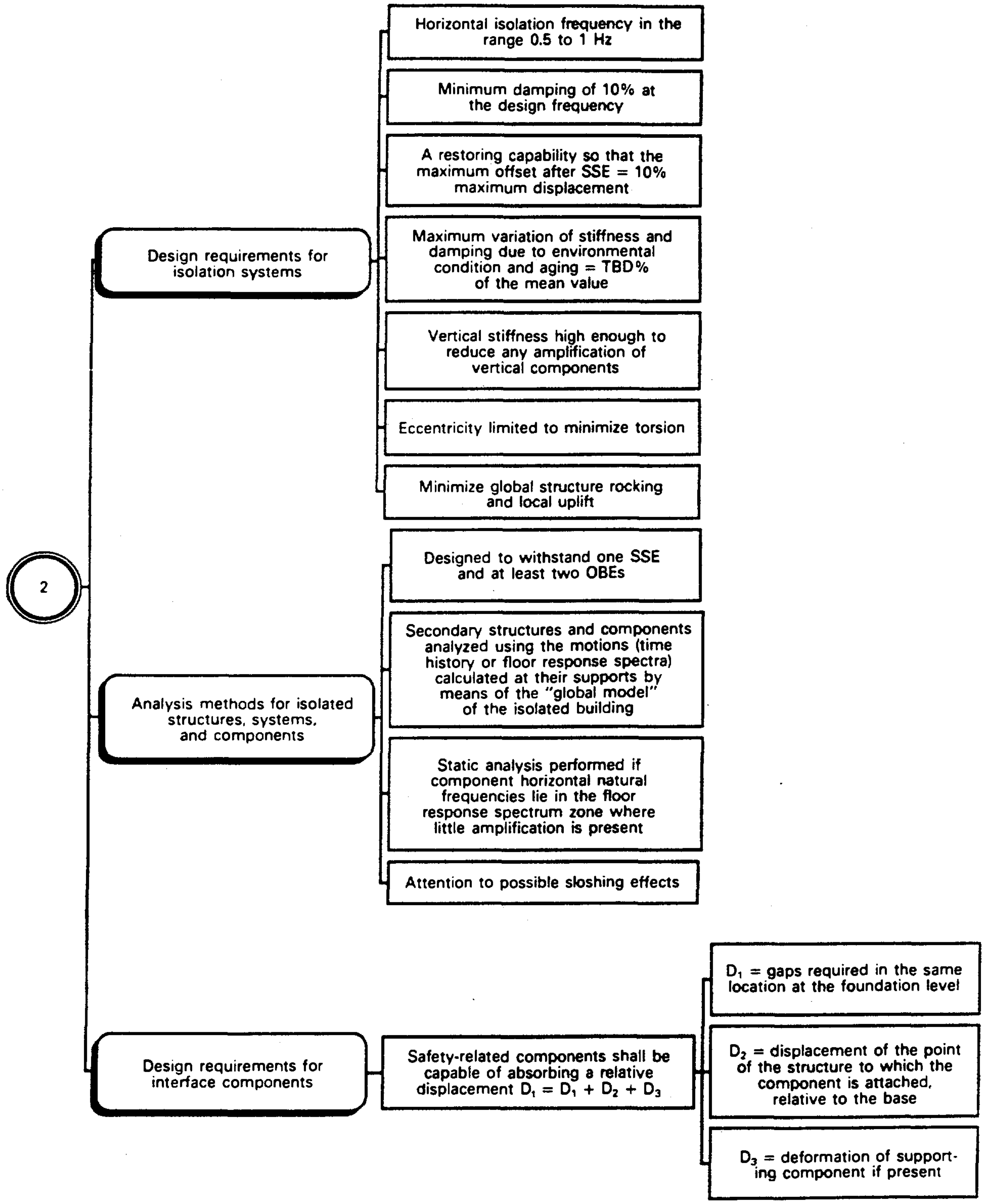


Fig. 2. Design guidelines for nuclear reactors isolated by HDLRBs: design and performance requirements for overall seismic isolation systems; design requirements and analysis methods for isolated structures, systems and components; design requirements and analysis methods for interface components.



2.3 Design and Performance Requirements for Overall Seismic Isolation Systems (Fig. 2)

The horizontal displacement to be used for the design of the isolation system is defined. The safety factor to be adopted for assessing its value shall be equal to that (TBD) related to gaps. The design case for vertical loads is also defined, and requirements are provided with regard to horizontal and vertical stiffnesses, damping, self-centering, wind and small earthquake resistance.

2.4 Design Requirements and Analysis Methods for Isolated Structures, Systems and Components

Rules are provided as to how to determine Floor Response Spectra (FRS) and to analyse systems and components located inside isolated structures (Fig. 2). For the FRS determination, parametric time-history analyses are required, by varying the stiffness parameters of both the structure and isolators. For the design of components, simplified static analysis is usually permitted.

Analysis of sloshing and other low frequency effects requires specific R&D to be better precised.

2.5 Design Requirements and Analysis Methods for Interface Components

Displacements to be accomodated by the components and systems that cross the isolation interface are defined as functions of gap values and structure flexibility (Fig. 2). Effects to be accounted for in the analysis are stressed, and the need for adequate qualification, especially for piping expansion joints, is pointed out. This may require tests, to be performed in the correct pressure and temperature conditions.

2.6 Design Requirements for Individual Isolation Devices

Requirements are provided with regard to the vertical load capacity and design load, the maximum horizontal displacement capacity and design displacement and stability, the determination of vertical and horizontal stiffnesses and buckling load, the assessment of stiffness - strain relationship and damping (Fig. 3). In particular, it is specified that the isolator characteristics (stiffness, damping and buckling load) to be used in the design shall be based on specific test data or validated finite-element methods. Simplified formulas - such as those provided in appendix to the document - may be used if demonstrated adequate.

As to R&D needs in support to these prescriptions, we note that experimental tests were judged necessary to determine the (TBD) safety factors related to the vertical load, buckling, and combined effects of vertical load and horizontal deformation. To allow for the assessment of the total rubber thickness of bearings, experimental work was also judged necessary for the exact definition of the (TBD) value of shear strain (horizontal displacement divided by the total rubber thickness) that shall correspond to the SSE.

Further requirements concern the effects of cycling and related degradation, environmental effects, creep effects, aging effects, self-centering capability, uplift and rocking, and design tolerances

(Fig. 3). For the exact definition of some of these requirements, R& D work was again judged necessary: tests were needed to fix the TBD values of the parameters related to envinronmental effects (temperature, radiation, ozone attack, fire), to determine the isolator life -time, and to define the maximum offset permitted for each isolator after an earthquake. With regard to the latter item, appropriate test features had also to be identified.

2.7 Qualification of Seismic Isolator Bearings

Static and dynamic tests identified as necessary for the qualification of single bearings and isolation system are reported. These are consistent with the ongoing experimental campaign of ENEA-RIN reported by Bonacina et al. [2], which also aims at confirming the adequacy of the test series and defining the exact values of some test parameters (see also Fig. 4).

2.8 Acceptance Testing of Isolation Devices

Tests required to provide the quality control of bearings are outlined. These also include checks on the external geometry, some distructive controls, and tests to confirm the isolator characteristics, performance and integrity.

The criteria that determine the number of isolators to be tested are given, together with those to be adopted for rejecting bearings - in the case that controls are out of tolerances - and those to be used for bearing identification.

2.9 Seismic Isolation Reliability

Requirements concern the Quality Assurance (QA) program, bearing life-time and in-service inspection. Use of three-dimensional (3D) finite-element (f.e.) models is specified to identify, assess and if necessary, correct isolator weaknesses (Fig. 4).

2.10 Seismic Safety Margin Assessment

Methods to be used to ensure an adequate level of seismic safety and to identify if necessary, feed-backs on the design are provided. The process consists of the following steps: (a) selection of the earthquake assessment level; (b) technical QA (design organization, design methods, codes and standards, etc.); and (c) safety margin assessment.

The safety margin assessment derives from that proposed for the existing commercial Light Water Reactors as a simplification of Probabilistic Risk Assessment (Fig. 4). For those plants, however, construction details are well known, while for future isolated plants there is a lack of construction and operational experience. This makes it necessary to carry out the assessment for isolated plants at both design and construction stages: the first step allows for a check of plant design and if necessary, feed-backs to improve it, while actual margins may only be provided by the second step.

The process makes use of the best available plant information at the time of the analysis. It permits detailed analysis to be avoided for the safety-related components and systems for which previous experience or collective opinion of appropriate experts

Fig. 3. Design guidelines for nuclear reactors isolated by HDLRBs: design requirements for individual isolation devices.

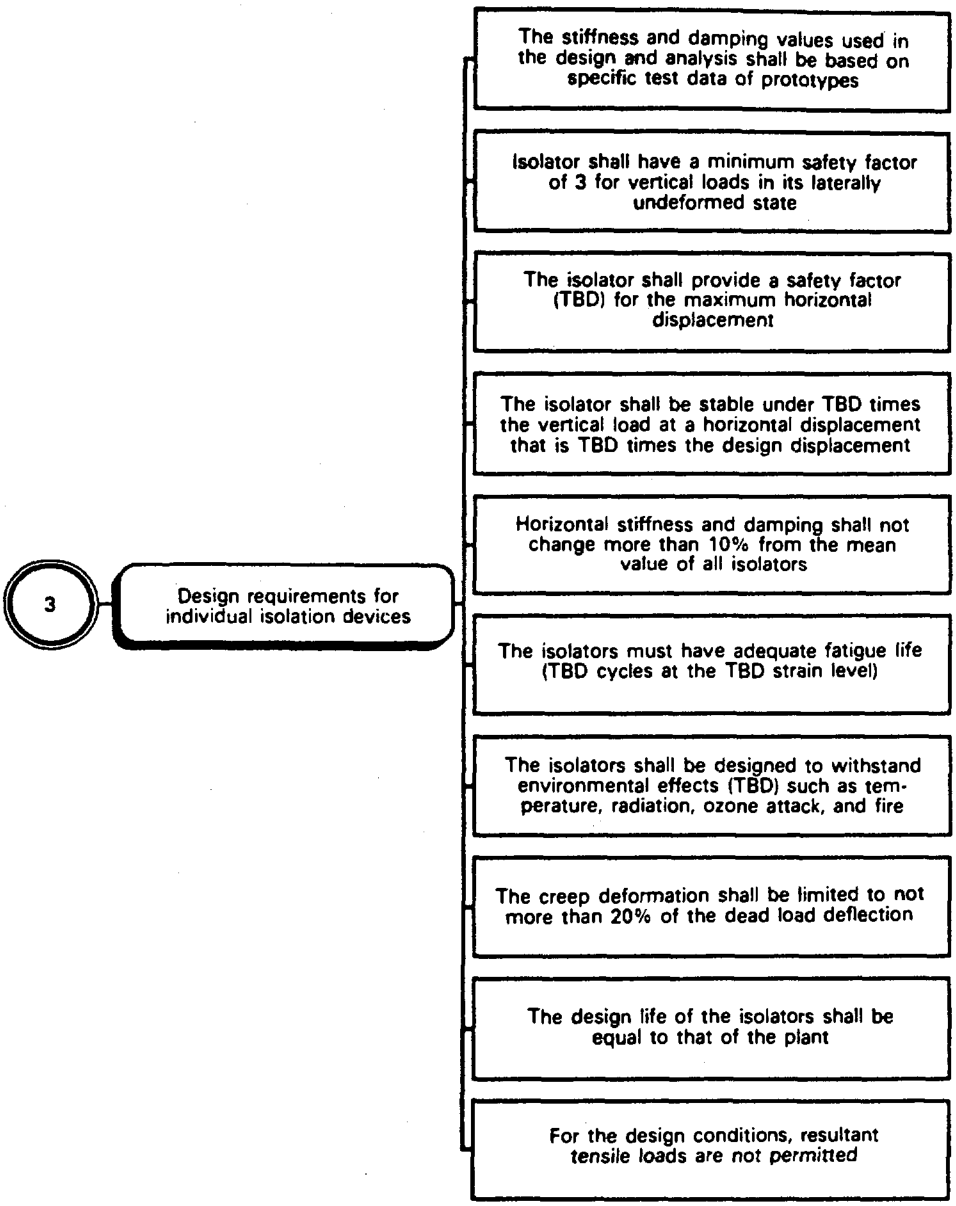
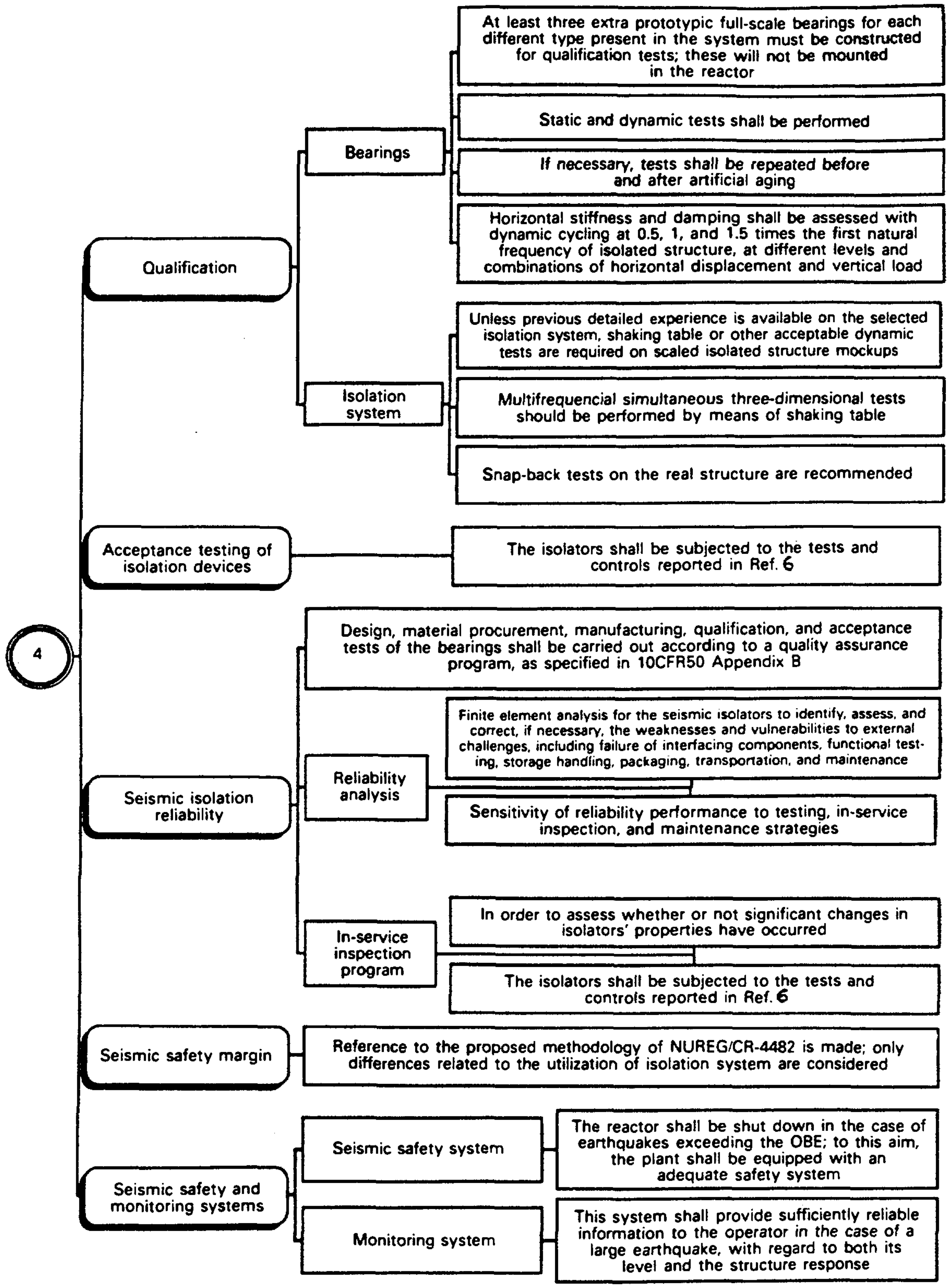


Fig. 4. Design guidelines for nuclear reactors isolated by HDLRBs: qualification of seismic isolation bearings; acceptance testing of isolation devices; seismic isolation reliability; seismic safety margin assessment; seismic monitoring.



shows that there is a high confidence of low probability of failure at an earthquake level larger than that selected.

2.11 Seismic Monitoring

The need and required features of a detailed seismic monitoring system, capable of recording earthquake motions during time in the free-field and on the structure, partly in short time, are stressed (Fig. 4). It is pointed out that displacements between the structure base and isolation system support base must be recorded, in addition to accelerations at various elevations.

3. REVISIONS OF THE GUIDELINES DOCUMENT OF REF. [6]

The guidelines document of Martelli et al. [6] will be periodically updated by ENEA and GE, to include comments and to reflect the advances of seismic isolation technology development.

A first revision of the document is being prepared and will be soon published: it accounts for both comments received - for instance, by the American Society of Civil Engineers (ASCE), ENEA-DISP and the Malaysian Rubber Producers' Association (MRPRA) - and the first results of R&D studies in progress in Italy and the USA.

4. EXTENSION OF THE GUIDELINES DOCUMENT OF REF. [6] TO OTHER BEARING TYPES

The extension of the guidelines document of Martelli et al. [6] to nuclear reactors using bearings different from the HDLRB will be also soon initiated, within the studies sponsored by the Commission of the European Communities (CEC). This work will be performed by ENEA, with the cooperation of ALGA, ISMES, ANSALDO and the Nuclear Engineering Laboratory (LIN) of the Bologna University. It will consist in the following activities:

(a) Revision of the document of Ref. [6], based on comments of European organizations and an updated analysis of the state-of-the-art on the 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.

Activities will take into account the other available proposals and recommendations for design guidelines for isolated structures, and will take advantage of the co-operations existing between ENEA and other national and foreign organizations.

5. GUIDELINES DEVELOPMENT FOR NON-NUCLEAR ISOLATED STRUCTURES

Development of guidelines for isolated structures is also in progress in Italy for non-nuclear structures, according to the increasing interest in these applications and the increasing number of civil buildings being isolated in Italy (Martelli & Bettinali

[1]). More precisely:

(a) The preparation of guidelines concerning the isolation bearings and energy dissipation systems that have been judged of interest for buildings and bridges is in progress in the framework of the activities of specific groups established by the Italian Standard Authority (UNI). ENEA, ISMES, ANSALDO-Ricerche and other members of GLIS participate in these activities.

(b) A co-operation of ENEA, ENEL and ISMES was started with the National Seismic Service to help it in the assessment of national regulations (the design of constructions is regulated by law in Italy). The preparation of two guidelines documents (the first for bearings, the second for isolated buildings) is already in progress: these should be used by the designers of isolated buildings in the transition period preceding the promulgation of the necessary law, to get the approval of the High Council of Public Works which shall examine each plan for an isolated building in that period.

(c) A specific subgroup of GLIS was very recently formed, with the task of collecting, analysing, commenting and if necessary, integrating the available guidelines documents and regulations (Martelli & Bettinali [1]). The aim of this subgroup is not to further duplicate works in progress in different frameworks, but to compare and homogenize these works.

6. COLLABORATIONS

The importance of national collaborations for the development of guidelines for isolated structures are made evident by the previous sections. As to the existing international collaborations, it is worthwhile stressing that with the USA (especially with GE - see Sects. 2 and 3) and that with Japan. In the first meeting concerning the Project on Seismic Isolation in the framework of the Agreement of Scientific and Techological Co-operation between Japan and Italy, held in August 1991 at Tadotsu, it was agreed that the Japanese experts will provide comments to the proposal of Martelli et al. [6], and documents of common interest will be exchanged.

Furthermore, the work to be performed with the CEC sponsorship will strengthen cooperations between Italy and other European countries: in particular, a collaboration between ENEA-RIN and the Department of Mechanical and Thermal Studies (DEMT) of the French Commissariat à l'Energie Atomique (CEA) is foreseen.

7. CONCLUSIONS

Work in progress in Italy for the development of design guidelines for seismically isolated structures has been outlined. In particular, the main features of a proposal concerning nuclear reactors, isolated by high damping steel-laminated elastomer bearings, have been recalled. Items that needed R&D work to be precised have been stressed. It has been mentioned that a first revision of the aforesaid document is in progress, to include comments received and to account for the results of the ongoing R&D work, and that this work is being performed in cooperation with GE Nuclear Energy.

Extensions of the guidelines document to other bearing types, in the framework of a project sponsored by the CEC, have been cited, together with a collaboration with Japan and the work in progress in Italy for non-nuclear applications, as part of the activities of the

Working Group on Seismic Isolation (GLIS) and to support the Italian Standard Authority and the National Seismic Service for the assessment of national rules.

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