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Guidelines proposal for seismic isolation of Nuclear Power Plant

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GUIDELINES PROPOSAL FOR SEISMIS ISOLATION OF NUCLEAR POWER PLANT

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Sommario

This report has been issued in the frame of the second research programme of the ENEA and MSE (Economic Development Ministry) agreement and it is one of the deliverables of the Task I " Reactor IRIS – Seismic analyses" of the work-programme 2 " Evolutionary INTD (International Near Term Deployment) Reactors" of the research theme on "Nuovo Nucleare da Fissione" ,

It reports a proposals of guidelines to be used for the seismic isolation of NPPs. In that activity reference was done to the EN15129 European standard.

Note

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INDEX

INTRODUCTION

Nowadays, the designs of nuclear power plants (NPP) of Generation III+ and the future ones of Generation IV are characterized by enhanced safety requirements. In particular, they have to be highly secure and designed to withstand extremely severe external events such as floods, tornadoes, plane crashes, fires and, in particular, **earthquakes**. Their many protective features considerably reduce the impact of external or internal threats through the redundancy, diversity, independence and **reliability** of the safety systems. **Seismic isolation** is considered the most promising technology to protect the modern NPPs in such extreme conditions.

At present, over 10,000 buildings are seismically isolated all over the world; most of them are provided with High Damping Rubber Bearings (HDRBs). Seismic isolation technique is also widely used for bridges and viaducts and for industrial plants. In spite of this, only two nuclear facilities are currently provided with base isolation: 4 PWRs at Cruas (France) isolated with 3600 neoprene pads, and 2 PWRs at Koeberg (South Africa) isolated with 1830 rubber bearings coupled with friction plates. It is worth noting that these isolation systems, designed in the 70's and manufactured in the early 80's, are quite 'rough'; in fact, today's seismic isolators have better characteristics and can provide better performances. In addition to these two old applications, the Jules Horowitz Reactor, now under construction at Cadarache with a seismic isolation system made of rubber bearings, must be cited.

The extremely limited number of existing isolated NPPs is probably due to the relatively low seismic input assumed as design for the Generation II reactors, and also because most of them were water reactors, which are characterized by quite stiff structures and rigid components. Among the advanced designs, only IRIS (International Reactor Innovative and Secure) and 4S (Super Safe, Small and Simple) are provided with base isolation . On the contrary, among the fast reactors, most of the past designs already include the seismic isolation: ALMR (Advanced Liquid Metal Reactor), S-PRISM (GE), DFBR (Demonstration Fast Breeder Reactor), STAR-LM (Secure Transportable Autonomous Reactor-Liquid Metal) and EFR (European Fast Breeder Reactor). Unfortunately, no application of these reactors has been done and there is a dramatic lack of information and experimental results about the behavior of large isolators under severe dynamic conditions. In addition, **no specific standards** exist for NPPs (in reality, Japan has developed a specific guideline [1], but, as far as we know, no English version is available).

The lack of specific standards for the application of seismic isolation to NPPs is one of the main problems that limit the application of this new technologies in nuclear field. Thus, it is extremely important and urgent starting, at least, with a proposal of guidelines specifically addressed to NPPs.

It is worth noting that several standards for isolated civil structures (both buildings and bridges) are already available all over the world (see [2, 3]). In Europe, the European Standard EN15129 on Anti-Seismic Devices [4] was recently definitively approved and will become mandatory in all European countries within 2011. This standard is very complete and cover all the different aspects, from the design to the manufacturing phases, from the qualification tests to the inspection and maintenance procedures, etc.. Thus, we think that EN15129 is the most promising standard to be implemented in order to include nuclear plants, for Europe in general and for Italy in particular. As a matter of fact, Italy is the most seismic European country among those interested in the application of new NPPs.

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PURPOSE

Aim of this document is the elaboration of a proposal to modify EN15129 in order to extend its validity to the seismic isolation of NPPs. Reference will be made to clause 8 of EN15129 (Isolators), with particular regard to section 8.2 (**Elastomeric Isolators**). As a matter of fact, these isolators, in particular the **High Damping Rubber Bearings (HDRBs)** are the most promising ones to be used in present and future NPPs.

In the following sections the relevant clauses of EN15129 will be considered; proposals will be done in order to extend their validity to the case of NPPs. Original parts of EN15129 will be reported as pictures within boxes, to avoid possible modifications and confusion with the text of the present document.

It is worth noting that the changes proposed and the other comments and suggestions have been deeply discussed with the experts of seismic engineering in the framework of several technical meetings, especially within the seismic group of the IRIS Project.

GENERAL REQUIREMENTS FOR ISOLATORS (§ 8.1)

8.1 General Requirements

Seismic isolators shall support the gravity load of a structure without excessive creep and resist non-seismic actions such as wind loadings and thermally induced displacements. They shall provide by a low horizontal stiffness or other means the desired low horizontal natural frequency for the isolated structure. They shall be able to accommodate the large horizontal displacements produced by seismic actions whilst still safely supporting the gravity load of the structure and resisting the vertical forces produced by the seismic actions. They shall provide a level of damping sufficient adequately to control the horizontal displacements produced by the seismic actions unless supplementary devices are used to provide the damping.

The types of isolators covered by this clause are:

a) Elastomeric isolators, including those with a plug of lead or high damping polymeric material to enhance the damping

b) Sliders, both curved and flat surface.

NOTE 1 Steel spring isolators are not covered, though it is intended to include them in future versions of this European standard.

Isolators shall be designed and manufactured to accommodate the translation and rotation movements imposed by seismic and other actions whilst supporting the vertical load imposed by gravity, seismic actions and other live loads. They shall function correctly when subject to the anticipated environmental conditions during their projected service life. When isolators are likely to be subjected to exceptional environmental and application conditions, such as immersion in water, exposure to oils or chemicals, or installation in an area constituting a significant fire risk, additional precautions shall be taken (see EN 1337-9) in the light of a precise definition of the conditions.

The general requirements given in clause 8.1 (see above) are quite complete and then fully applicable also to NPPs.

Of course, most of the clauses of EN15129 are applicable to the case of NPPs; thus, in the following, only the clauses when a change or a comment is needed will be reported and discussed.

GENERAL REQUIREMENTS FOR ELASTOMERIC ISOLATORS (§ 8.2)

8.2 Elastomeric Isolators

8.2.1 Requirements

8.2.1.1 General

The clause 8.2 applies to elastomeric isolators, both high damping ($\xi_b(100\%) > 0,06$, where the figure in brackets refers to shear strain) and low damping ($\xi_b(100\%) \leq 0,06$), used with or without complementary devices to extend their range of use.

NOTE High damping rubber bearings are here designated HDRB, and low damping rubber bearings LDRB. The elastomeric isolators may contain holes plugged with lead (such isolators are termed lead rubber bearings [LRB]) or high damping polymeric material (such isolators are here termed polymer plugged rubber bearings [PPRB]) to achieve the desired level of damping.

Elastomeric isolators shall fulfil the general requirements given in 8.1 and the performance requirements given in 8.2.1.2. The materials used in the manufacture of isolators shall conform to the requirements of 8.2.2. Each elastomeric isolator shall be designed according to the procedure and rules given in 8.2.3.

Elastomeric isolators shall conform to the general and functional requirements respectively given in EN 1337-3:2005, 4.1 and 4.2.

The elastomeric isolator design properties to use in the structural analysis shall be the data reported from the tests 8.2.4.1.2.

The upper and lower bound values of the design properties referred to in 4.4.2 shall be determined from the type tests and the following variations:

— production variability ±20% (unless a lower variability has been agreed for the factory production control tests);

— temperature changes reported at T_U and T_L (see 8.2.1.2.4) and where appropriate the change in horizontal stiffness at 100% rubber shear strain in the low temperature crystallisation test (see 8.2.2.1.5);

— ageing change reported in test (see 8.2.1.2.9).

In combining the three a factor of 0,7 shall be used for the production variability and temperature variation, and a factor of 1,0 for the ageing variation. When low temperature crystallisation has to be considered, the change in the stiffness at low temperature shall be the larger of those reported for the cyclic test (8.2.1.2.4) and the crystallisation test (8.2.2.1.5).

The ratio between the upper and lower bound design property values for all elastomeric isolators shall be less than 1,8.

General requirements given in clause 8.2.1.1 (see above) are applicable to NPPs with the following modification:

- product variability ± 15%

This proposal is aimed to reduce the variability range of the characteristics of the isolators, with particular regard to the horizontal stiffness. This will lead to a more precise definition of the real isolation frequency, which will be closer to the design value. As a matter of fact, the isolation frequency is the most critical parameter of the design of an isolated structure and particular attention must be paid to its definition.

COMMENT: no significant variation of temperature is expected under a NPP, in particular there is no crystallization risk (see also § 8.2.1.2.4).

HORIZONTAL CHARACTERISTICS ON RUBBER SHEAR STRAIN (§ 8.2.1.2.2)

8.2.1.2.2 Dependence of horizontal characteristics on rubber shear strain

The horizontal characteristics under cyclic loading shall be measured at the following rubber shear strains: ± 5 %, ± 10 %, ± 20 %, ± 50 % and ± 100 % under the test conditions and using the procedures given in the relevant subclauses of 8.2.4.1. The horizontal characteristics shall be expressed in terms of effective horizontal stiffness, K_b, and equivalent damping factor, ξ_b, except that LRB and PPRB may be characterised in terms of second branch (or post-yield) stiffness, K_2, and characteristic strength, Q_1 (this is defined as the force at which the force –displacement loop intersects the force axis). If the tests are carried out at a frequency other than 0,5 Hz or the isolation frequency, the horizontal characteristics reported shall be referred to one of those frequencies by correcting for the effect of test frequency according to the procedure given in 8.2.2.1.3.3. If the shear strain, $\varepsilon_{q,E}$, at the design displacement, d_{bd}, is higher than 100 %, tests at additional strain amplitudes shall be added as detailed in Table 7. γ_x is a partial factor for elastomeric isolators (see 8.2.1.2.7). The tests may all be performed on the same isolator, in which case they shall be conducted in order of increasing strain amplitude and only at the strains specified in this subclause. The cyclic displacement shall be applied about zero shear displacement: no offset displacement shall be applied.

Table 7— Cyclic test rubber strain amplitudes

Strains in %

Design rubber shear strain, $\varepsilon_{q,E}$	Additional test strains
$100 < \varepsilon_{q,E} \leq 150$	150 or $\gamma_x \varepsilon_{q,E}$
$150 < \varepsilon_{q,E} \leq 200$	150, 200
$200 < \varepsilon_{q,E} \leq 250$	150, 200, 250

The requirements are that:

— the values of K_b and ξ_b (or K_2 and Q_1) for the third cycle are reported for all the rubber shear strains tested;

— if the design rubber shear strain is not included in the test strains listed, the values of K_b and ξ_b (or K_2 and Q_1) for the third cycle at the design rubber shear strain shall both be determined from the test results by linear interpolation;

— the test frequency and reference frequency, if applicable, be reported;

— the values of K_b and ξ_b (or K_2 and Q_1) for the third cycle at the design rubber shear strain shall both be within ± 20 % of the design value;

— the value K_b at 5 % shear strain (or Q_1) shall be sufficient to provide adequate restraint, as determined by the structural engineer, against wind loading.

A cyclic test to determine K_b and ξ_b (or K_2 and Q_1), performed at the shear strain amplitude listed in this subclause that is closest to the rubber shear strain, $\varepsilon_{q,E}$, at the design displacement, d_{bd}, should be performed as a factory production control test with the requirement that the values of K_b and ξ_b (or K_2 and Q_1) for the third cycle shall both be within ± 20 % of the design value corrected, if necessary, for the difference between the test and design shear strain.

It is strongly recommended that, in a NPP, the deformation of the elastomeric isolator at the design displacement **do not exceed 100% shear strain** (see also § 8.2.3.4.1). This will provide a higher safety margin against failure in case of an unexpected earthquake (beyond design). The first damage usually occurs at 300% shear strain for the hardest compounds (G modulus higher than 1.1 MPa) and at 350-400% for the softer ones, thus the isolators can have a safety factor well higher than 3. It is worth noting that most of the seismic loads are supported by the isolators, while the isolated structures and the components inside remains in the elastic field; thus, a high safety factor for a so critical component is not only auspicious, but mandatory.

The **type tests** shall include additional amplitudes, up to failure or instability, to evaluate the ultimate displacement capacity to support the vertical load (see § 8.2.1.2.7).

EFFECTS OF TEMPERATURE (§ 8.2.1.2.4)

8.2.1.2.4 Dependence of horizontal characteristics on temperature

The changes in horizontal characteristics K_b and ξ_b (or K_b and Q_d) between the upper and lower service temperatures, T_u and T_l respectively, shall be determined by tests under the conditions and using the procedures given in the relevant parts of 8.2.4.1. The horizontal characteristics shall be measured at a rubber shear strain amplitude of ± 100 % over a range of temperatures extending from at least T_u to at least T_l. A test at 23 °C shall be included. The tests shall be performed in order of decreasing temperature. It is recommended that tests at the following temperatures are included if they are within the range of service conditions.

40 °C, 23 °C, 0 °C, - 10 °C, - 20 °C

The values of K_b and ξ_b (or K_b and Q_d) for the third cycle shall be reported for each test temperature. The values at the lowest temperature shall not differ by more than + 80 % or – 20 % from the corresponding values at 23 °C, and the values at the highest temperature shall not differ by more than ± 20 % from those at 23 °C.

For HDRB and LDRB, the tests may be performed on isolators scaled without restriction, or may be substituted by the tests required in 8.2.2.1.3.4 on the elastomer used in its manufacture.

COMMENT: as already mentioned, no significant variation of temperature is expected under an isolated NPP, thus the test at low temperature (typical of bridges applications) could be avoided.

HORIZONTAL DISPLACEMENT CAPACITY (§ 8.2.1.2.7)

8.2.1.2.7 Horizontal displacement capacity

The horizontal displacement capacity of an isolator shall be checked up to a displacement of $\gamma_b d_{Ed}$ or a load of $\gamma_b V_{Ed}$ whichever is reached first (where V_{Ed} is the horizontal load corresponding to d_{Ed}) under the axial loads $N_{Ed,max}$ and $N_{Ed,min}$.

γ_b is a partial factor for elastomeric isolators, and its value shall be taken as 1,15.

The value of $N_{Ed,min}$ shall not be a tension force producing a stress greater than 2G, where G is the shear modulus measured at 100 % strain (see 8.2.2.1.3.2).

NOTE 1 The value of the minimum vertical load may be tensile. The imposition of tensile stresses above the level specified here is avoided as cavitation of the rubber occurs at relatively low tensile hydrostatic stresses. A tensile stress of up to 2G is normally sustained without significant cavitation occurring. Special connections between the isolator and the structure that remove the possibility of the vertical load on the isolator becoming tensile can be used.

The test shall be carried out under a ramp input. The other test conditions shall conform to those given in the relevant parts of 8.2.4.1.

The requirements are that the load shall be monotonically increasing up to the maximum displacement and that the isolator shall not show any significant signs of failure at the end of the test. The visual evidence of failure referred to shall include:

— signs of bond failure;

— surface cracks or imperfections over 2 mm wide or deep.

The isolator connections to the load platens shall not show any signs of failure or yielding.

NOTE 2 See EN 1337-3:2005, 4.3.3 for further guidance regarding visual evidence of failure in the isolator.

If $N_{Ed,max}$ differs from $N_{Ed,min}$ by less than 20 % and the minimum load is compressive, only one test at the mean of the two loads needs to be performed; the same requirements shall be met.

The seismic isolator shall never lose the capacity to support the vertical load in any condition, **even for beyond design earthquakes**. To this aim, based on the results of the failure test reported in (§ 8.2.1.2.2), a maximum displacement must be defined and an horizontal fail-safe system (a sort of containment ring) shall be positioned at this distance from the base of the isolated building. In case of extremely violent earthquakes, the hammering between the base of the building and the containment ring is preferable to the collapse of the whole isolation system. The hammering should be preferable damped by the use of shock absorbers.

ISOLATOR DESIGN (§ 8.2.3)

8.2.3 Design

8.2.3.1 General

Elastomeric isolators, including low damping isolators shall be designed to meet the relevant provisions of

— this subclause corresponding to load combinations including the seismic action;

— subclauses 5.1, 5.2 and 5.3.3 of EN 1337-3:2005 at load combinations not including the seismic action, unless otherwise specified in this subclause.

The parameter A_r, the reduced effective plan area due to the horizontal displacement of the top of the bearing relative to the bottom (see EN 1337-3:2005, equation (9)), shall only take account of non-seismic horizontal displacements.

8.2.3.2 Types and shapes of isolators

The isolator shall consist of alternate layers of elastomer and steel; in each case the layers shall be nominally identical. It shall be moulded under appropriate conditions of heat and pressure, and the steel plates hot-bonded to the elastomer during vulcanization. Two thick end plates shall be hot bonded to the rest of the isolator. The sides of the isolator, possibly excluding the sides of the end plates in the case of isolators located in a recess, shall be covered with a rubber layer at least 4 mm thick. Unless the cover layer provides fire resistance, it shall consist of the same material as that in the bulk of the isolator and be cured at the same time as the main body of the isolator.

The design seismic input of a NPP is quite severe; even in case of beyond design earthquakes, the isolators must continue to support the dead load of the structure up to very large deformations. The **recess attachment system is not suitable** to support large deformation. Thus the only fixing method to be used for NPP is that using **bolts**.

DESIGN SHEAR STRAIN (§ 8.2.3.4.1)

8.2.3.4 Design criteria

8.2.3.4.1 Design Shear Strain

The shear strain, $\varepsilon_{q,max}$, due to the maximum horizontal displacement, d_{bd}, shall be less than 2,5, i.e.:

$$\varepsilon_{q,max} \leq 2,5 \qquad (18)$$

As already mentioned, it is strongly recommended that the deformation of the elastomeric isolator at the design displacement **do not exceed 100% shear strain** ($\varepsilon_{q,max} \leq 1$) to provide an adequate safety margins against failure in case of unexpected earthquakes.

This prescription has consequences in terms of costs of the isolation systems and also in terms of testing, installation and replacement of the isolators. In fact, to satisfy this requirement, the isolator turns out to be quite higher and, to keep the same horizontal stiffness, also larger in diameter, that means more expensive and encumbering. The latter, also means that the isolators shall have larger concrete pedestals; this reduces the room available for inspection and replacements. Also the testing will be more expensive. However, there is also a positive consequence: the larger cross section of the isolator allows a better distribution of the dead load over the rubber layers (lower stresses). Thus, the isolator have higher safety margins to support unexpected vertical loads that can be due to the failure of a partial number of isolators, soil settlements, etc.

ISOLATOR TYPE TEST (§ 8.2.4.1.2)

8.2.4.1.2 Type Testing

The type tests listed in Table 11 shall be performed on the minimum number of samples specified in 8.2.4.1.4, according to the methods specified in 8.2.4.1.5. For low damping bridge isolators subjected to small seismic actions, only the tests marked with an asterisk in Table 11 are required as type tests by this European Standard; the type tests in EN 1337-3 shall be performed for such isolators.

For those tests required to be performed on an isolator, it shall be full-scale, except the tests on LRB and PPRB to determine the influence of frequency, temperature and repeated cycling on the horizontal characteristics may use isolators scaled according to the following rules:

— isolators of plan dimension ≤ 500 mm shall be tested full-scale;

— for larger isolators, linear dimensions may be reduced by factor up to maximum of 2. All dimensions shall be scaled by same factor. Minimum allowed plan dimension for bearing after scaling is 500 mm.

The following modifications to an isolator shall require a new set of type tests:

a) different elastomer compound;

b) variation of the shape factor of the elastomer layers of more than 10 % with respect to that of a device already tested;

c) increase of any external dimension of the isolator or of the plan dimension of the internal reinforcing plates of more than 10 %;

d) decrease of any external dimension of the isolator or of the plan dimension of the internal reinforcing plates of more than 50 %;

e) a different type of attachment system is used;

f) different moulding conditions are used.

NPPs are characterized by huge masses and severe seismic inputs. Thus, quite large isolators must be used. In civil buildings, the standards usually allow the scale reduction up to 50% of linear dimensions. However, the manufacturing process of seismic isolators, in particular rubber bearings, can be quite different in case of large sizes (e.g. vulcanization of the rubber in the most internal part of the isolator). For this reason, for nuclear application, the **type test shall be done on full-scale prototypes**. It is worth noting that the type test are carried out on a quite limited number of isolators and that the type tests are valid for similar isolators (see above). Unfortunately, only few labs all over the world, have the capability to test large isolator in dynamic conditions.

The type tests required by clause 8.2.4.1.2 are listed in the second column of the following table.

In addition to the above tests, the execution of a series of **tri-axial tests with real seismic excitations** (increasing up to failure) is strongly recommended. In fact, not only rubber bearings, but also other type of isolators (e.g. sliders with curved surfaces) can have a quite different behavior when loaded at high velocity in the two horizontal directions simultaneously, under the vertical dead + seismic loads.

Of course, this kind of test is not usually performed (and also not required) for the reason stressed above: only two labs in the world have a suitable equipment. However, this cannot considered a limit for the applications to NPPs.

Table 11 — Isolator testing and requirements

Test	Type test requirements	Factory production control test requirements
Capacity in compression under zero lateral displacement	Support N_{Sd} . No defects visible. See 8.2.1.2.6.	N/A
Compression stiffness	Report value. See 8.2.1.2.8.	Within ±30% of type test value. No defects visible. See 8.2.1.2.8
*Horizontal characteristics K_b and ξ_b (or K_2 and Q_d) under cyclic deformation	Report strain dependence. At design displacement, d_{bd}, values within ±20% of design value. See 8.2.1.2.2	Values within ±20% of required values. See 8.2.1.2.2
*Horizontal stiffness under a one-sided ramp loading (Required if cyclic horizontal stiffness and damping from production control test not measured at shear strain amplitude close to value corresponding to, d_{bd})	Report value at design displacement, d_{bd}. See 8.2.1.2.2	Within ± 20 % of adjusted type test value. See 8.2.1.2.2
Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with frequency	Report variation. Maximum variation ± 20 %. See 8.2.1.2.3	N/A
*Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with temperature	Report variation. Maximum variation within limits set in 8.2.1.2.4	N/A
Dependence of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) on repeated cycling	Dependence within limits specified in 8.2.1.2.5	N/A
*Lateral capacity under maximum and minimum vertical loads	Force-displacement curve increasing up to $\gamma_b d_{bd}$. No defects. See 8.2.1.2.7.	N/A
Change of horizontal characteristics K_b and ξ_b of the isolator (or K_2 only for LRB manufactured using low damping elastomer) due to ageing	Change ≤ 20 %	N/A
Creep test under vertical load[a]	Total Creep rate < 20 % per decade. See 8.2.1.2.10.	N/A
[a]Optional test N/A = Not Applicable	*For low damping bridge isolators subjected to small seismic actions, only the tests marked with * shall apply. See 8.2.1.2.11 for requirements.	

ISOLATOR FACTORY TEST (§ 8.2.4.1.4)

8.2.4.1.4 Sampling frequency

Each type test shall be carried out at least twice, using a different test isolator in each case. If the double shear test arrangement is used for a type test, only one pair of isolators need be tested.

A test isolator may be subjected to several different type tests provided they are performed in the following order:

a) compression stiffness (8.2.1.2.8);

b) dependence of horizontal characteristics on rubber shear strain (8.2.1.2.2), frequency (8.2.1.2.3) temperature (8.2.1.2.4) and repeated cycling (8.2.1.2.5);

c) effect of creep (8.2.1.2.10);

d) capacity in compression under zero lateral displacement (8.2.1.2.6).

Provided the isolator meets the requirement of the preceding tests.

e) horizontal displacement capacity (8.2.1.2.7).

There shall be a summary test report stating the order of the tests on the isolator and the dates and times of each test.

For each type of isolator, the factory production control compression test and compression and shear test (see Table 11) shall be carried out on the first production isolator. Subsequently, at least 20 % of the production isolators of each type, chosen randomly, shall be subjected to both factory production control tests. For projects involving a structure supported by four or fewer isolators, all the production isolators for that structure shall be tested unless otherwise agreed with the Structural Engineer.

COMMENT: clause 8.2.4.1.4 requires that at least 20% of the production isolators for each type, chosen randomly, shall be subjected to factory tests (third column of table 11, previous section).

*For isolators to be installed in NPPs, this quantity should be increased (for the compression test, at least) up to **50%** or even more.*

IN-SERVICE INSPECTION (§ 12)

12 In-service inspection

12.1 General requirements

All the relevant requirements given in EN 1337-10 for the structural bearings shall be applicable to the anti-seismic devices.

12.2 Regular inspection

In the regular inspection all the properties listed in Clause 5 of EN 1337-10:2003 shall be checked with the following addition:

— Oil leakage (for Temporary Dynamic Connection Devices, Velocity Dependant Devices and all devices utilising fluids)

If an oil leakage is detected a Principal Inspection shall be performed.

12.3 Principal inspection

The principal inspection shall be carried out at less frequent intervals than the regular inspection and normally replaces one of them.

The first principal inspection shall be carried out within one year of the structure being put into service.

The principal inspection shall be repeated after any earthquake reaching the level of no failure requirement as defined in 4.1.1 a).

The specific checks for the different types of anti-seismic devices shall be defined by the manufacturer. For sliders and elastomeric bearings the specific checks shall meet at least the requirements given in EN 1337-10.

The records to be made at the Principal Inspection shall be defined by the manufacturer and shall be based on concepts similar to the records required for structural bearings as given in EN 1337-10.

COMMENT: Seismic isolators are, first of all, bearings and they behave as bearings for most of their life (they behave as isolators during earthquakes, only). Thus, for in-service inspection criteria and rules, EN1337 standard shall apply [5]. For NPPs, suggested intervals for regular and principal inspections are 1 and 5 years, respectively. The following table, taken from clause 9 of EN1337, gives the criteria to be followed for in-service inspections.

9 Criteria for in-service inspection

EN 1337-3:2005 (E)

During inspection of items listed in EN 1337-10 the following criteria shall be checked:

- The top and bottom load bearing surfaces shall be in full contact with the plinth (bottom supporting surface) and the soffit (top supporting surface). If there is imperfect contact between the surfaces given above the angle between the soffit and the plinth shall be checked against the design specifications.

- The magnitude of the shear deflection of each bearing shall be checked to ensure that it is within the design specifications.

- A visual inspection shall be made of all the accessible edges. A note shall be made of the size and position of any cracks or splits, or uneven bulges.

- Examine the plinth and soffit for signs of displacement from bearing original position (Black marks may give an indication of movement).

If applicable:

- Examine the sliding surfaces for cleanliness and that the movements are within the design range and report results.

- Examine the protective coating and / or dust protection for signs of deterioration and report results.

CONCLUSIONS

No standard concerning the application of the seismic isolation to nuclear power plants is currently available in Europe and in USA. EN15129 is the most complete standard for the application of seismic isolation to civil structures. Making reference to this document, which will become mandatory in all European countries within 2001, a proposal has been done to extend it validity to the case of nuclear power plants.

The most important difference between a civil structure and a nuclear plant is that the latter must maintain its integrity even after an extremely violent earthquake, beyond the design conditions, to avoid the release of radioactivity. This means that, in case of using seismic isolation technique, the isolators shall be designed with higher safety margins, manufactured and tested with lower tolerances and tested in more severe conditions. Thus, some proposals have been done to modify EN15129. Two of these are particularly important and have relevant consequences on the design, manufacturing and testing of the devices:

1) Limit to 100% of the shear strain the deformation of the isolator at the maximum design displacement;
2) Perform the type tests on full-scale devices, with additional tests in tri-directional dynamic conditions.

Both the above proposed requirements lead to a larger and more expensive isolators, more difficult to be manufactured and tested, but they are necessary to provide seismic isolators capable of satisfying the severe requirements of GENN III+ and GEN IV nuclear power plants.

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