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Some Difference of Concepts between Design Guideline for FBR Base Isolation System and Aseismic Design Guideline of LWR in Japan

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This draft was prepared for the 4th Int. Working Group for Fast Reactor, IAEA. Because of the limitation of the avairable time for the author, neither reference, figure nor table is attached. However, the figures and so on intended to be prepared by the author is conceptual ones, and the most of originals appear in the reports by CRIEPI during this meeting or in the future. Or they were presented in other previous papers by the author, or in JEAG 4601-1984, 1987 or 1991 as mentioned in Section 1.

Abstract

This paper deals with the concept and the relation of "the Base Isolation System and FBR" to the Safety Criteria and the Guideline of the Aseismic Design of LWR in Japan. The Central Research Institute of Electric Power Industries have been working for FBR last several years. The author has been contribute to their works, and this is one of the subjects. He described his own idea obtained through the cooperative work with CRIEPI.

§1 Introduction

It is not clear for the author whether ot not the design guideline should be prepared before to start the design of some actual systems. The draft of the aseismic design guideline for nuclear power plants was prepared in 1960 before to start the design of LWRs, Tsuruga #1, JAPCO, and Fukushima #1, TEPCO. However, the guideline had never prepared until the Guideline of Aseismic Design of NPPs, JEAG-4601-1987 by Japan Electric Association in 1987. Even though the first JEAG-4601 was published in 1970, it was a text book style, and it didn't clearly indicate the design practice. And the Guideline for the Design Basis Earthquakes was issued by the Nuclear Safety Commission in 1981.

In this paper, the author describes the concept and main idea on the design of the base isolation system and the aseismic design of base isolated nuclear power plants including equipment and distribution systems.

First of all, some new items should be added to the safety criteria for light water plants. And it is important how to categorize the base isolation system according to the concept of "Factor of Importance" which has been used for the aseismic design of LWR. The third is the design spectrum. In Japan, Ohsaki spectrum is commonly used for LWRs and other nuclear facilities, however, the region of longer period component, that is, T = 1 sec or longer is considered to be poor comparing to those of the actual ground motions. Ishida, CRIEPI, introduced a modified standard spectrum to their guideline. The author tries to discuss this subject. Add to these three subjects, he is briefly reviewing the difference of the details between the guidelines for FBR and LWR. The guideline for LWR has been prepared by the committee of the Japan Electric Association, which has been chaired by the author for these several years, as JEAG 4601-1987 and 4601-1991.

§2 Design Criteria in General

The design criteria of nuclear power plants are clearly established. As far as those of structural parts of LWR, they are described in the Design Criteria of LWR, which was issued by the Nuclear Safety Commission in 1978 and remodified in 1990. If we try to transfer them to those for FBR, it may be necessary to be modified added to those for LWR as follows:

i) The base isolation system and their elements must be designed, fabricated, and inspected based on the related standards and guidelines. And all materials must be selected from those as listed in the related standards.

ii) The whole system should be designed as the safety functions of the supported structure and the base isolation system must be kept against all kinds of natural events including seismic forces induced by the design basis earthquakes of level S_1 and S_2. Other events, flood, tsunami, strong wind, freezing, snow, ground slide and so on must be considered. For the base isolation system, underground water also must be considered.

iii) As the external events, aircraft crashing, failure of upper stream dam, explosion must be considered. Also, the access of the external persons must be controlled to avoid their action to destroy the base isolation system.

iv) Internal missile must not fail the safety function of the base isolation system. Also the effects of failures of equipment and piping systems including their secondary effects such as fires, flood, chemical attack and mechancial shocks must be considered.

v) The base isolation system must be protected against sodium and chemical product from sodium in the case of sodium leakage or flood. Also the effect of the chemical product in heat exchanger caused by the leakage of water and/or steam from their pipes must be considered.

vi) Against the dangerness of fires, the base isolation system must be designed in consideration with the following three measures: the prevention, detection and extinguishment of fires. Materials of elements of the system should be selected from those which are not burnable or fire proof as well as possible.

For their maintenance, the care must be taken to avoid the fire, such as, on electric power supply system and other fire sources.

vii) Design and treatment of their elements must be done in consideration with their environments, such as temperature, moisture, salt powder and radiation under normal operating condition and abnormal conditions. If the control of their environment is done by air conditioning systems, their design or the effect of their failure must be considered according to the criteria.

viii) The elements must be reliable, and this must be ensured at all times through by design, fabrication, inspection and test.

ix) The base isolation system can be accessable to inspect and to test them during operation and inoperation conditions.

x) They must provide the adequate measure to prevent the failure of control system and instrumentation system by thunder lightening, and to prevent the fire and other unsafe events caused by thunder lightening directly and/or indirectly.

xi) The base isolation system and the distribution system, bridged between the isolated part and unisolated part, must be able to be inspected, maintained and repaired, or to be replaced if necessary.

Even though, the eleven new items have been raised, there might be some unknown problems as well as the methods of analysis, design and fabricating the system itself. We must study on the practical model and method for hazard analyses of the whole system and its elements. For example, it is not clear for us the effects of the following natural or external events: i)aircraft crash, ii)wild fire, iii)thunder-lightning, iv)chemical explosion and v)flood. The direct effect of those is mainly fire. The flood may bring rock, sand and soil surrounding the system and bury it. These events are not considered enough in the criteria above, but it is clear that there are some difference between an ordinary designed NPP and the base-isolated NPP. However, it should be noticed that those differences don't come from the differences between FBR and LWR.

§3 Factor of Importance

In Japan, all items in NPP are categorized according to the factor of importance for their seismic design. This concept was originated by Housner or USAEC in late 50's, but now popular. Three or four categories have been applied to those in Japan since the second plant, that is the first LWR. Supporting structures are divided into two categories, that is, a direct supporting structure and an indirect structure. A typical direct supporting structure is a support for the primary coolant pipings. We usually call "a piping system", and this includes not only pipings themselves, but also hangers, snubbers, rods and supporting structures up to anchoring devices. Those, which consist of the system, are categorized as the same categories as As class of the primary coolant piping system.

A typical indirect supporting system is the main reactor building. Many important items are involved in this building. As a rule, the main reactor building is not necessary to categorize in this sense, but it is recommended that it is categorized as the same category to the highest category of involved equipment and/or piping systems in the building. But, according to the situation, it may be deducted to the lower category, if the condition in the view point of the safety may allow it.

Back to the base isolation system, it is considered to be an indirect supporting structure, except that for locally supporting a component like a computer. In the case of a floor isolation system, it is also categorized as an indirect supporting structure in principle. If we defined all panels and racks as one control system, and they are supported by one base isolation floor, we may say them as "a system", and the base isolation system would be a direct supporting system. But this definition usually may bring a confusion, because items supported by this floor are those categorized to various categories.

The use of a base isolation system, which is discussed and planned to be used at this moment, is only for the main reactor building, and some computers and control devices including operators. Those are categorized As class or at least A class. In such cases, the base isolation system should be A class or As class. However, there is a discussion whether or not super-structure, especially, the main building is stronger than the system, as discussed later. In the sense of the categorization, both should be equally strong to the design basis earthquake.

§4 Design Basis Earthquake

The guideline for the aseismic design of nuclear power plants was issued officially by the Nuclear Safety Commission in 1981. According to this, the Ohsaki spectrum has been emploied to define the design basis earthquake in principle. This chart of response spectrum was prepared by Ohsaki and others based on approximately fifty strong motion records originally, and modified in some extent later. However, it is rather poor in the region of longer period range, that is, longer than 1 second. Ishida, CRIEPI, tried to strengthen this region based on the knowledge of engineering seismology in some extent. In two cases, we observed the rich component in longer period region $2 \sim 10$ sec in Japan. One is the case of the huge earthquakes which were M=8 or higher. And, if the local strata condition has eigen periods in this region of the period , then the strong displacement waves were observed in a particular period(s). Typical examples were reported in the Keihin area, in the south of Tokyo, and in the Niigata Tohkoh area, in the east of City of Niigata. Dynamic characteristics of the upper soil layers, which are several thousand meters in this case, mainly governs their eigen periods in the longer period range as we concern in these *regions. Several practical techniques to estimate those* characteristics have been established in the field of engineering seismology. The author considers that there is no new problem to define the response spectrum in this region anymore. However it should be mentioned that there were some misunderstanding on the evaluation of the effect in this range because of the dynamic characteristics of accerographs which had been widely used in 1970's, and some engineers have the tendency that they evaluate too low, maybe only one tenth of the actual value. The author establish the following relation for the MITI Notice #515 on the "Seismic Design Guideline of the High Pressur Facilities" is 1981:

$$\left.\begin{aligned} D_g &= 60 \text{ cm} \quad T > 7.5 \text{ sec} \\ V_g &= 50 \text{ kine } T \leq 7.5 \text{ sec} \end{aligned}\right\} \qquad (1)$$

where D_g is the design basis ground displacement, and V_g is the deseing basis ground velocity.

§5 Design Principle of the Whole System

Hereafter, the author discusses mainly on a main reactor building supported by multi-rubber pad system. Therefore, a main building, a base isolation system and equipment and piping systems are the three main items concerned. The details of each will be discussed in later.

Most significant discussion is how to make the balance of the strength of the main building and the base isolation system. According our design practice, most of design engineers try to design that the building is stronger than the base isolation system. For the S_2 earthquake, the probability of failure of the base isolation system is lower than that of of the main building in $10^{-5} \sim 10^{-8}$ estimated, by the group of CRIEPI. The fragility curve of the base isolation curve is not steeper compare to that of the main building. This means that against the far severe earthquake, the main building may be weaker than the base isolation system.

This relation is ideal, because the capability of supporting the super-structure may be remained after the failure of the base isolation system, especially rubber pads, according to the authors opinion. However, there is another result that the fragility curve of the multi-pad system would be very steep because of the zipping failure effect, which observed in anchor bolt failure in the fields of previous earthquakes. The model above mentioned is the simpler than multi-pad system, but it should be mentioned of that the degree of the steeper fragility curve depends on the result of the quality control of pads and other elements such as anchoring devices. The study on the fragility curve of these items should be continued to establish the design concept. However, the capability of supporting the loads from supper- structure of the failed pads should be carefully studied to solve this problem. Some results of the mid-scale testing in Japan beautifully showed the possibility to realize this concept.

The design against the shock of breakage of pad and other elements, and also that of the over deflection would be not necessary, according to the author's opinion. There are two design principles. In the case of two elements series, one design concept or the design criteria of the stronger element should be governed by the strength of the weaker one. It is typically applied to a case of a design of a nozzle and vessel.

As a concept of the design of the base isolation system, the base isolation system is stronger than the super-structure, because the function of supporting the main building is significant. This is one idea. However, the supporting function could be remaining after some failures of its elements, then the base isolation system may be weaker than the super-structure at the design level S_2 or higher like 1.5 S_2. It should be noticed that the relation "weaker" or "stronger" is not absolute in this discussion. It means that their fragility curves may cross around this design levels. Now it is clear that the concept, like a nozzle and vessel, is not employed in the case of the design of the base isolation system. One of the reasons is that their strengths are relative, and the other reason is the remaining functional capacity. And also, it comes from the design basis earthquake S_2, that is, the upper bound earthquake. In Japan, the probability of exceeding S_2 earthquake is zero in principle.

§6 Design of Base Isolation System

The design of rubber parts is the most significant part. It is based on the CRIEPI's research. Two levels should be considered, that is, for S_1 earthquake and S_2 earthquake. Two design limits are considered relatively to two levels of the design basis earthquakes. The relation of shear strain to resistant force is linear and these stress hardening type one. The first point for S_1 should be stayed in the linear range, and the second point for S_2 should be stayed in the stress hardening range, but lower than its ultimate strength. The margin may be decided based on the variation coefficient of their ultimate strengths. However, it should be noticed such relation is also function of its vertical load and the pattern of the stress hardening curve, which may change in the relation to vertical loadings, and the vertical loading is also variable by the rocking type response of the super-structure. In general, the margin would be 1.5 ∿ 2.0 against statical vertical load, however, more precise analysis may be necessary.

The draft of CRIEPI's guideline is more concervative compare to the author's one. They take the design limit for S_2 is at the first point for its elastic limit. And that for S_2 is lower than this elastic limit with enough margin. The author feels the necessity of further discussion on this problem.

For the detailed design of the whole system and the base isolation system, it is recommended to use the response simulation. For this simulation, the lumped mass model may be employed by expressing each story of the building as one mass-spring system as well as the base isolation system. However, for the design of the base isolation system, their elements, multi-pad model may be necessary to evaluate their vertical load change caused by the rocking response of the super-structure. It is also significant for the probabilistic failure analysis of pads, and the gradient of the fragility curve is affected by the way of modelling of pads.

The nonlinear characteristics of pads are one of keys to predict the behavior of the whole system. Two points should be considered, one is how to express the relation of the reaction force to the horizontal displacement. There are several models are proposed by several research groups. The results may be not significant compare to the uncertainty of ground motions for future earthquakes. However, to the difinit input motions, there are some differences including the effect of induced higher harmonic motions. The second one is the effect of vertical dynamic load caused by the rocking of the super-structure. This is significant for the failure analysis. The most adequate type of models is different from the type of base isolation pad and the combination of damping device.

Base-plate and anchor bolts are also very important for the function of the base isolation system. The author believes that their design criteria near to those of the class I vessel or piping should be applied. At least their allowable stress limit should be lower than those of ordinary structural elements.

The criteria of steel plates in a pad have not been discussed in detail. For S_1, it should be remained in elastic limit. But for S_2, it is not clear whether or not it still should be remained in elastic limit. If it deforms plastically, the pad can't work normally anymore, and their replacement is required. It, maybe, depends on an individual situation of the plant.

A damping device is divided to three types mainly, that is, elasto-plastic deformation of metalic material, hydraulic damper and fliction damper. The design criteria of latter two types are clear, that is, they should be normal even for S_2. The criteria of metalic type should be considered in two points. On its fatigue failure, it should be discussed whether or not several after shocks of S_1 level after one S_2 shock should be taken into account. And also the same type of the evaluation for S_o

earthquakes. The level of S_o earthquake is around 90 ∿ 120 gal defined at the free field of supporting soil or rock. This concept of fatigue analysis may be applied to other elements.

The allowable stress of plastic part of the metal has not been established as well as lead for damping device. Their fatigue analysis is important as mentioned, but it is difficult to be defined by the concept of plant conditions like "Plant Condition D". At least the margin to its ultimate strength and also its fatigue process should be considered. Also the characteristic of hardening and the condition of its brittle failure should be considered. If we use ordinary material in an industrial standard, usually there is no detailed definition for its behavior in higher level strain as using for damping device.

It is necessary to design the energy absorbing portion and other portions separately and the latter should be designed as a supporting structure. The allowable stress of their portions should be the same to that of ordinary structural element. This is the same to the concept of other elasto-plastic damping devices for nuclear pipings. Also, the inspection method of the energy absorbing portion should be established. The author feels the necessity of the inspection on its grain size level including impurity of matrix.

§7 Design of Building Structure

The basic method of the structural design of the super-structure is not different from that of un-isolated building. As the author discussed in Section 5, there are several choices in the relation of the strength of the super-structure to that of the base isolation system. The author recommends the strength of the super-structure is stronger than that of the base isolation system on the basis of detailed design.

It should be mentioned that the horizontal force induced by the response has longer period components of motions compare to that of ordinary ground motions. It depends on the designed eigen-period of the whole system, however, the force will work on super-structure and so on as a static force in general. This effect is more significant to equipment and piping systems, especially a main reactor vessel. Also, the effects of higher modes of the whole system should be evaluated, especially to a light damped, flexible structure.

The relation of a pad arrangement to the wall arrangement and the load distribution should be evaluated by an adequate method. The detailed design practice of the basement slab of the super-structure, and also that of the lower basement mat have not been established. In a case of softer foundation soil, V_s=1,000 m/sec or lower, it should be considered to the design of the lower basement mat like Winkley model, according to the author's opinion. Because the equivalent shear velocity of the ordinary reactor building may be 1,000 ∿ 1,500 m/sec.

Design criteria and the way of analysis of a supported super-structure are not different to an ordinary unisolated nuclear building. Based on the level of input acceleration or velocity at the upper level of the base isolation system induced by the design basis earthquakes S_2 or S_1 or S_0, buildings and others should be designed. Their allowable limits may be the same to those of unisolated nuclear structure, the author recommends. However, there are some discussions, and the most elegant evaluation may be a comparison on their fragility curves in various earthquake levels.

§8 Design of Equipment and Distribution System

As their structural design, it is not much difference to those in unisolated buildings, except force works longer duration like a static force. In the design of a shell or a rod, the buckling should be examined carefully. If the after-buckling behavior is considered for the design, this fact is more significant.

Connecting distribution systems should be designed as enduring to the differential movement of the both systems. For this, again, there is the same type of discussion to the previous one, that is, whether or not the design displacement is the maximum limit of the displacement of the system, or the response to S_2 earthquake with an adequate margin. In principle, the author believes that it should be designed based on the response induced by the design basis earthquake. On the other hand, the categorization of induced stress of the system, especially of that for a piping system, should be the primary stress. The reason is clear, that is, the strain (stress) caused by their differential motion is almost static one, and for the tensile strain, it is easy to exceed the elongation limit of the material.

§9 Quality Control and Inspection

The quality control of rubber pads has not established well. At this moment, we try to test at the time of receiving them. However, on tire of automobiles and aircrafts, the techniques of the quality control is most advanced. Therefore, manufacturers of rubber pads may overcome these difficulties easily in the near future. The evaluation of degrading of rubber material is also established and the acceleration test is commonly done. Even though the standard surveillance test should be established for the system, it may be no farther difficult problem. They will meet to the safety requirement of nuclear power plants soon.

§10 Concluding Remarks

There is no much difference between the design guidelines of LWR and FBR. The main difficulty of the design of FBR is the sloshing phenomenon. The base isolation system can not work for it, and in some cases, the system may amplify it. We need further research how to overcome the sloshing phenomenon.

Within, one or two years, we are going to complete the final draft, it may be applicable to both LWR and FBR. And it is not so much difference of criteria for base isolation floor. The actual systems will be used more often and earlier than base isolated reactor buildings. Already, an example is built in the field of nuclear facilities.

The concepts, which the author described above, have been obtained through the discussions in the meetings with CRIEPI and Japan Atomic Power Company. And also the informal research group sponsored by Mitsubishi Heavy Industry Co.. The author expresses his gratitude to the related members of these committees, especially Mr. M. Motegi, CRIEPI, who has been discussing this subject with the author.

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"§11 Reference" and Tables and Figures have not been prepared.