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Performance Based Seismic Design for Lifelines

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Abstract *International Organization for Standards (ISO) is now in progress for establishing design and construction standards based on required limit performance states of every facilities by using reliability risk inspection methods for the seismic safety. Moreover, the European Committee for Standardization (CEN), with an eye to the future-unification European market, is formulating unified standards of design and construction that are very likely to be proposed by ISO standards. In Japan, revisions of Japanese standards, converging into internationally viable technical standards has just started to discussion. Present paper is the state of the arts on performance based seismic design in the world emphasized on the field of lifeline earthquake engineering.*

1. Outline

ISO (International Organization for Standards) is now working on the establishment of PBSD (Performance Based Seismic Design) method based on the required performance with probabilistic reliability procedure for earthquake safety design and construction of various infra facilities. In addition, CEN (European Committee for Standardization), is aiming on the development of design criteria of EU unity under corporation with ISO. Figure 1 shows the distribution of various design codes in the world[1]. In Japan, each Ministries and Agencies have just started to establish unified performance based design standards with harmonizing with ISO and EN after the long history of severe natural disasters. Recently, Bureau of Port in MILT has established a new PBSD for the design and construction of port facilities, as well as the maintenance of facilities , and now under working on utilization. In the future, it is thought that the road, railway and supply-lifeline facilities will be in compliance with performance -type standards[2]. This paper describes the significance of the necessity of worldwide standardization, the outline of PBSD, trend of establishing standards in Japan, the current status of lifeline standards and the trend in PBSD transition.

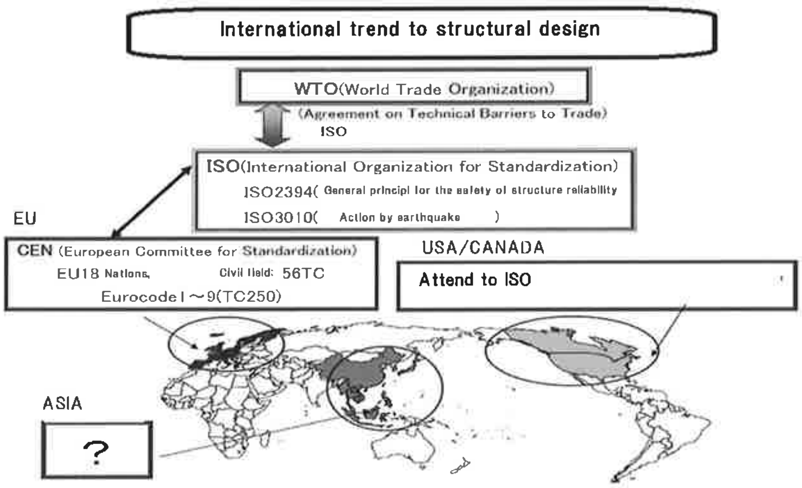

Figure 1 Distribution of different codes in the world[1]

2. Significance of establishing world standard

Table 1 Required basic and other performance[2)]

Required Performance	Main Contents	
Basic required performance	Safety	Guard himan life
	Usability	Usable without in convenience
	Repairbility	Usable with proper repair cost
Other required performance	Performance sustainable for environmental conditions	
	Performance satisfied by facility in construction steps	
	Performance satisfied by facility in service steps	
	Performance satisfied by facility in maitenance steps	

As shown later on the details of ISO, each country has started to be responding to harmonizing to ISO. As the data on the accuracy of reliability analysis, life cycle design, and structure design inputs have been accumulated so far, the trend to PBSD is accelerated to establish the worldwide standard. In addition, due to prudent discussion on the seismic safety of various facilities and the introducing of site-specific seismic inputs were discussed. Basic principle has been established in ISO as the global standard introducing regional features. In addition, due to widely recognizing dynamic analyses, ISO is proposing the dynamic analysis for safety check of the design. The outline of the performance design is considered as follows. In the PBSD, the performance such as facility size, material, design and construction method, safety check of completed facilities are decided according to the standards, but details of the design process are controlled by the designer (code writers). If the required performance is satisfied, the design principle is not the matter. In Table 1, the required performance recently enacting of port facilities is shown. There are basic required performance and other required performance. The former includes safety (life safety, etc.), usability (usable without inconvenience, etc.) and repairability (repairable under appropriate cost, etc.). In the latter cases, the environmental condition, the construction condition, the service condition and the maintenance control condition are shown as the incidental required performance.

3. History and problems of EN, ISO and USA standards

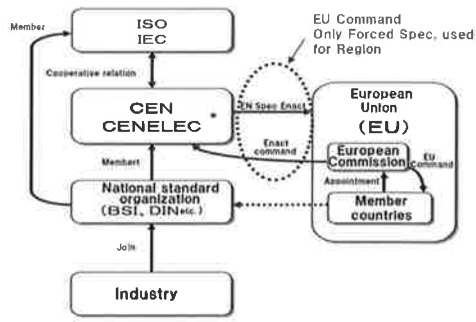

Figure 2 Relations of ISO, EN and Others[1)]

Figure 2 shows related organizations with ISO and EURO establishments. EU (European Union) decides criteria of EN (European Standards) rules. IEC (International Electro-technical Committee) is a major organization of ISO standards. European Electricity Standards Committee) and EESC (European Committee for Standard) and CENELEC (Comite European de Normalisation Electrotechnique) are actually involved in EN. Incidentally, CENELEC is an organization that unifies the entire EU involved in communicating and the electricity. BSI and DIN in Figure.2 are standardized organizations in the UK and Germany. As can be seen in Figure 2 , EN and ISO mutually agree and cooperate to participate in the implementation and enactment of standards in the EU industries. As to the relationship between EN and existing criteria in each country, the NA (National Annex) can be added on the technological progress and international conflict resolution in the country, and consider a unique numeric prescribed coefficients before or after the EN articles. These are Nationally Determined Parameter (NDP) and NCCI (Non-Contradictory) are called as the complementary information. Table 2 and Table3 show the history of the EURO code and the relationship with European and American country standards.

Table 2 History of EN[3)]

Age	Main Organization	Fund	Documents
1970's	EU Technical Group	Product Business Field	Design Guideline
1982-1984	EU Committee	EU Committee	Draft of EURO Code
1985-1986	Standard Organization in each country	Each country organization	Result of calibration and check of rule words
1987-1989	EU Committee	EU Committee	Correction of the Draft
1990	CEN	EU Committee	ENV
1992	Standard Organization in each country	Each country organization	Result of calibration and check of rule words
1998	CEN	EU Committee	pr EN
2001	CEN		pr EN
2005	CEN		Stop of Specification in each country

Table 3 Contents of Standards in each country[3)]

Country	UK	France	USA	CANADA
Standard	EURO		AASHTO/LRFD	CHBDC
Organization	CEN		FHWA	CSA
Director	Government Private technician	Government	Government, Academician, Private technician	Government, Academician, Private technician
Fund	CEN/EC		FHWA/AASHTO	Each State
Supportor	Voluntary		FHWA/AASHTO	Voluntary Base
Complete year	2005		1994	2000
Period	30		7	7

Next, I will describe the significance of the organization of ISO, its history and current issues. In the 1950's , ISO had the purpose of excluding malicious products and securing quality, but since after the latter half of 1950's, securing of cheap products in mass production was the goal. However, in the 1970's , the main objective was targeting safe and secure products. Then, international standards became necessary. The agreements of WTO (World Trade Organization) and TBT(Technical Barriers to Trade) became effective worldwide, and the world standardization of the products has been promoted. The concept of global standardization in WTO / TBT is to ensure mutual trust between producers and consumers by confirming appropriate, high quality products by the standardization ensuring effective and reasonable product distribution. As a result, we could aim to expand the global market . This concept is applied not only to industrial products but also to the design and construction of structures .

Figure 3 is an organization related to standardization in the United States as NIST (National Institute on Standards and Technology), ANSI (American National Standard Institute), ASTM (American Society for Testing and Materials) NTTAA (National Technology Transfer and Advancement Act). Although the United States has its own standardization and standards, ANSI is also a member of ISO and has strong relationships with world standards while having cooperation with EN. In particular, ASTM was founded in 1898 and is the world largest standardization organization. He has 34,000 members in 140 countries worldwide . Up to now, 12,350 standards have been established. ASTM is also strongly involved in the American Society of Civil Engineers, involving the American Society of Mechanical Engineers and the Institute of Electrical and Electronics Engineers .

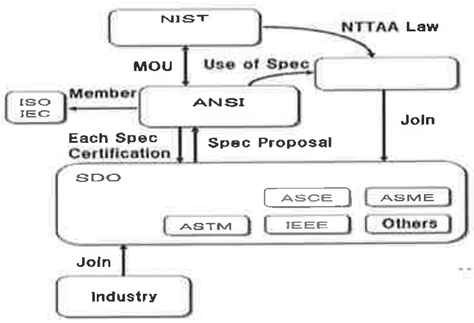

Figure 3 Standardization related organization in USA[1)]

4. Trend of standardization in Japan and PBSD

4.1 Modification of Japanese standards compatible to world global standardization:

IPPP (Intellectual Property Promotion Plan) has been determined by Japan National Governments in May 2010. Here, seven fields with outstanding technology are selected as specific international strategy fields. In addition, in June 2012, as a system to promote the international standardization of the IEC, has established as a top standard system.

Moreover, a new market-creation-type standardization system is constructed in July 2014. Based on the proposal of "General principle on reliability of structures" in ISO 2394 code, the MLIT (Ministry of Land, Infrastructure, Transport and Tourism) started to considered for the change of basic idea of design concept of various facilities. Performance specification type design standards are beginning to be studied also in the Japan Society of Civil Engineers and the Japan Gas Association in accordance with ISO -2394 standards under principle of the reliability probability theory and dynamic analysis, against to the design principle based on the allowable stress method with safety factor.

In Japan, the structural design standard for road, railway, harbor have been established under the jurisdiction of the MLIT (Ministry of Land, Infrastructure and Transport), for water by MHLW (the Ministry of Health, Labor and Welfare), for gas by METI (the Ministry of Economy, Trade and Industry), for communication by MIC (the Ministry of Internal Affairs and Communications). Among them, MILT became the first place to introduce performance regulation type standards into the design of especially to port facilities.

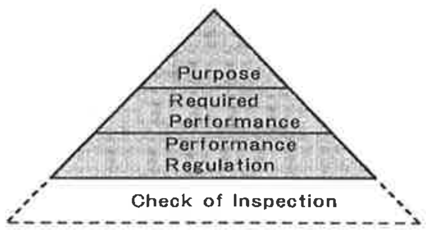

Fig.4 Basic principle for port facility[2)]

4.2 Performance based design of port facilities

Figure 4 shows the basic concept in designing port facilities. Purpose of designing performance of the port facility is to define required rules and checking system of required performance design. As shown in Figure 4, performance checking system is a pyramid type and upper level has priority of judgment. Regarding the inspection, then, emphasis is placed on confirming the deformation of the port facility such as the limit value of damage probability for piers and breakwaters. In Figure5, required performance of usability, repairability and safety are performances following to the action (load) determined by ISO. It is necessary to ensure usability with respect to persistent action with variable action, and the priority for usability, repairability and human life safety are given in accidental action. Major changes compared with conventional port facility design are summarized as follows.

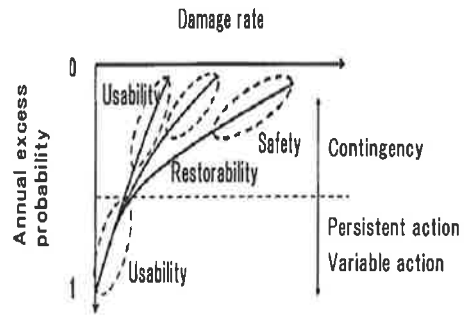

Fig.5 Performance for port facility[2)]

①Once performance is secured, the detailed process of design is left to the judgment of the designer(code writer).

②A method for checking the usability, the repairability, the safety performance should be clearly stated.

③ We should design based on the stochastic design method.

④ For each port facility, 3 kinds of actions should considered and also site conditions as the seismic characteristics, wave propagation characteristics and construction site ground conditions should considered.

⑤Emphasis on construction and management methods should put into consideration.

⑥It is necessary to confirm the suitability with the design system currently used

5. Action guideline related to performance based design at JSCE committee

At TC98 (Technical Committee 98) in ISO-SC2 (Science Committee2), " the reliability of the structure " gives basic principle of dealing with serviceability, sustainability, evaluation of existing structures. ISO2394 is no mentioning in details of design procedure, but gives the design concept of ultimate limit state, design check method and terminology and symbols. Also, according to ISO 2394 , the description of content, transparency, consistency with other criteria are illustrated, but it does not concern the non-tariff system on trade and commerce.

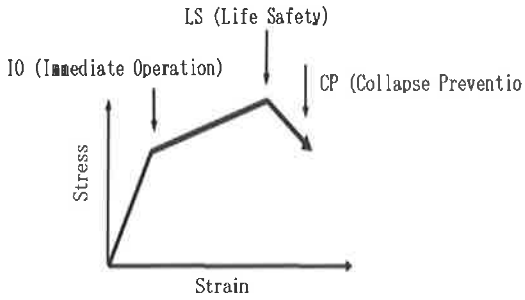

Figure 6 Stress-strain relation and performance

Based on ISO 2394 , JSCE is working on formulating guidelines on design inputs for civil engineering structures. In general, input levels used for seismic design of civil engineering structures always have uncertainty. The safety investigation process of the facilities is classified into 4 methods, ① safety factor, ② partial safety factor, ③ load factor, ④ resistance coefficient and so on. The design method is roughly divided into (1) an allowable stress intensity method and (2) a plasticity (limit state) method. Although the safety factor used for the former differs depending on the type of structure due to occurred stresses , the latter is the same regardless of the structural type in the material ultimate state if materials has the same characteristics. The correspondence between material properties and design method is shown in Figure 6. On the other hand, there are following three levels of reliability analytical methods.

Level I Ultimate state design method

Level II Reliability index $\beta \leqq$ target reliability index β_T

Level III Fracture probability $P_f \leqq$ allowable fracture probability P_{fa}

Different level of the probability is used for performance design depending on required accuracy by the designer who performs the performance inspection.

The ISO-TC98-SC3 has 13 working groups show the effects of specified each action in each WG. In ISO , the input of structural analysis is called action. Conventionally, it is called a load in Japan, but the load acts in the vertical direction, and loads in the horizontal direction was not always considered in EN so far. Within the EU area, the occurrence of earthquakes is in rare cases and in most cases there is no consideration of seismic forces. Due to the cooperative works in the EN regulations with the earthquake countries, "action" is now taking into account both external forces. In the present action guidelines in JSCE , emphasis is placed on the following 3 types of actions are defined as well as the ISO. Those are constant action (Persistent Action), change action (Fluctuation Action) and rare action (Accident Action). The various type action are independent on the structure types and is an independent on various hazard events even under multi-hazards is introduced to clarify the required performance, considering the action factor. In addition to emphasizing combinations of actions, impairing factors during the service period of the facility is involved. Also, actions caused by environmental change are proposed to introduce from the viewpoint of sustainability of facilities. The basic principle on action, required performance, dynamic analysis, probability check is prescribed, but the details of the design method are based on judgment of the designer . The following judgment is to code writers. ①Select actions considering action factors, action effects in specific region, ②Select the required performance levels, ③Select response analysis method including dynamic analysis, ④Check of the safety considering function continuation, early restorability, human life and environment, ⑤ Select inspection check method, ⑥ Clarify tasks for maintaining and managing of facilities related to the design. Figure 7 shows the flow of working items in the guideline. The following issues are discussed in comparison with the conventional design method in Japan.

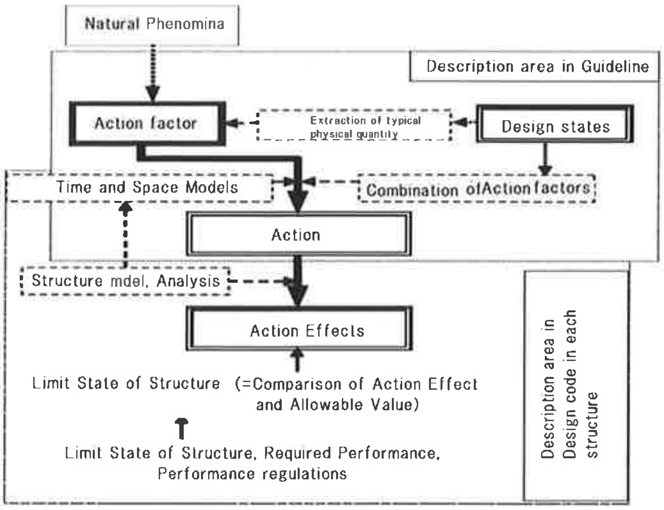

Figure 7 Flow of Action Guideline in JSCE[4)]

① The action is decided by taking action factors and then, action effects are into consideration. But the relationship with the conventional loads should be considered handling of the relation with the loads considered in the existing facility

② In Japan, seismic design under level 1 and level 2 ground motions are the basic concept. However, in EN, ASTM etc , the action is decided under the return period. To clarify the Level 1 and Level 2, an earthquake resistant performance matrix is being to be proposed. However, handling of the relation between seismic motion levels and earthquake occurrence frequency should be considered in probabilistic ways.

③ ASTM, EN and etc. are using acceleration design spectra in principle for above ground structures, and then velocity spectra are calculated by the acceleration spectrum under an appropriate period for buried structures. Meanwhile, Japanese codes are acceleration spectra for above ground structure and independent velocity spectra for underground facilities is presently used.

④ It is practical to determine the action fluctuation loads in consideration of regional specific characteristics and regional geological active faults. Construction and practical application of the system to compute the probability seismic motions acceleration or velocity are preferable as a design actions by giving longitude / latitude like as in the USGS standard.

⑤ Practical feasibility of considering huge earthquake action should be considered as contingent (accident) actions.

⑥ The action combination of action phenomena such as fault displacement, liquefaction, hillside collapse, tsunami, and etc. is in hand in code writers.

6. Current status and trend of seismic design of buried lifelines

The concept of response displacement method was proposed for the first time in the ASCE Journal on the US- BART tunnel design in 1969. Following its design procedure, Japanese oil petroleum technical standards was regulated in 1974. After that, basic concept of seismic design of buried pipelines have not been changed for these 45 years. After the 1995 Kobe earthquake, required performance of buried pipelines has been introduced in the several guidelines for buried pipelines. On the other hand, regarding the seismic inputs required performance of the buried pipelines as the basis of the design, the Level 1 and Level 2 earthquake ground motions are given depending on the importance of facilities as Rank A1 and Rank A2 as shown in Table 4 . The response calculation method is also different depending on continuous and segmented pipelines. In this guideline, calculation method of pipe stress is within the range of allowable stress level. The guideline has proposed the limit state design method for the pipe joints. On the other hand, the design regulations of gas conduits with medium / low pressure has presented a unique concept. Absorption capacity of gas pipe joint for ground displacement, slippage of pipeline, design method of curved or T-shape deformed pipe, etc. have been regulated. However, above guidelines do not harmonized with the basic policy of ISO guidelines. Persistent action and fluctuating action are the main factors, and accidental action should be considered qualitatively with appropriate counter measures. The velocity response spectrum calculated by Level 2 seismic ground motions are shown in Figure.8. Not so much difference is existing in water, sewer and gas systems. It is given in the velocity spectrum that becomes the maximum constant value in about 0.7 to 1.0 second. It is basically a nationwide uniform spectrum using by multiplication of the region coefficient. It is not combinated with acceleration spectra for above ground structure design. Rank 1 is a trunk line facility such as water transmission pipes and Rank 2 is other facilities. Safety checking method is deterministic one and no concept for probabilistic reliability procedures. The relation between the safety checking method and the required performance is not clear. Present guidelines show that pipe stress is within elastic range and joint response is in the limit value. The essential function of the water supply is to supply water even just after the earthquake occurrence for the purpose of fire fighting, injured person's life and out patients. All actions for the design should be based on probability distribution level and the response calculation of probability distribution is not taken into consideration and the performance check is not based on probabilistic concept. Insufficient data on various actions could not be introduced in terms of probabilistic design. In addition, it is more difficult situation to check the performance by the accidental action. The more researches and development is expected.

Table 4 Peformance for Level 1 and Level 2[5)]

Seismic Performance	Seismic Performance I	Seismic Performance II
For Level 2 Ground Motion	-	Rank A1 , Rank A2
Inspection Standard for Continuous Pipe	Check in Elastic Range Pipe stress ≦Yield Stress Pipe Strain ≦Allowable Strain	Check in Plastic Range Pipe Strain ≦Allowable Strain
Inspection Standard for Segmented Pipe	Check in Elastic Range Pipe stress ≦Allowable Stress Joint Amount of Expansion / Contraction≦Max Amount for Design Inspection	Check in Elastic Range Pipe stress ≦Allowable Stress Joint Amount of Expansion / Contraction ≦ Max Amount for Design Inspection

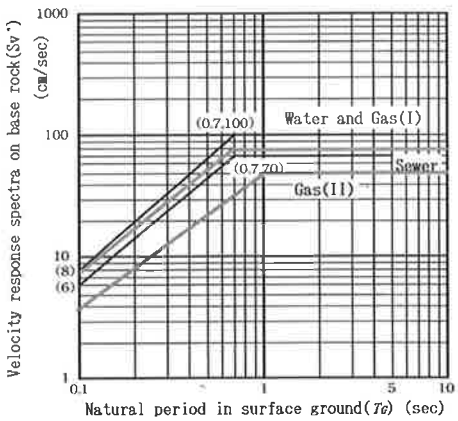

Figure 8 Design velocity spectra

7. Current status of performance based design of nuclear facilities

Seismic design of nuclear facilities is basically performance based design by reliability theory. After the accident of Fukushima Nuclear Power Plant, the seismic design of the facility has changed drastically. Basic concepts after the Fukushima accident is the effects of the tsunami and the prevention of diffusion of radioactive materials. Action force of S_S class has been taken into consideration instead of conventional S_1 and S_2 . Also, it focuses on the safety of core vessel facilities within reactor coolant and pressure boundary (RCPB). When there is an accident in the nuclear reactor (A-class facility), all equipments in RCPB classified in B-class should be payed important rolls to guard reactor. The other facilities are classified as C-class equipments. NPP 2006 standards give probability estimation of PSA (Probabilistic Safety Assessment, Figures 9). By the concept of residual risk for non-functional damage of the reactor had still function loss probability per year as 10^{-4}. For damage CV (Core Vessel) has risk of annual 10^{-5} as shown in the guidelines. Before the Fukushima accident, this residual risk has never been widely explained to the society. This risk probability, even when compared to the probability that one person may be killed by traffic accidents over a year, is by no means a little lower value. Regarding the action force, the A-class facility is combined with the operating force using the Ss spectra to be the limit state design method considering deformation performance. For B- and C- class nuclear facility equipments, it is the allowable stress design by operating force and S_d spectrum (equivalent elastic design spectrum). On the other hand, NPP design regulation are requesting examination of safety performance against earthquake accompanying phenomena like as landslide in the vicinity of nuclear facilities and tsunami attack hazards. Furthermore, the influence of neighboring volcanic explosion safety should considered due to huge linked earthquakes. This concept corresponds to the accident actions specified in the ISO standard. These events should take into consideration by probabilistict manner.

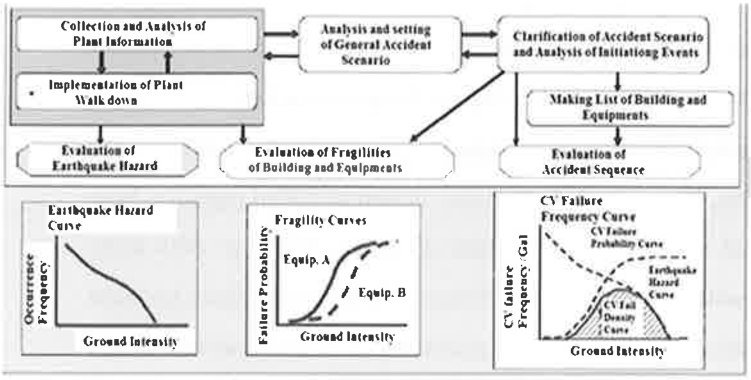

Figure 9 Reliability analysis for NPP[6)]

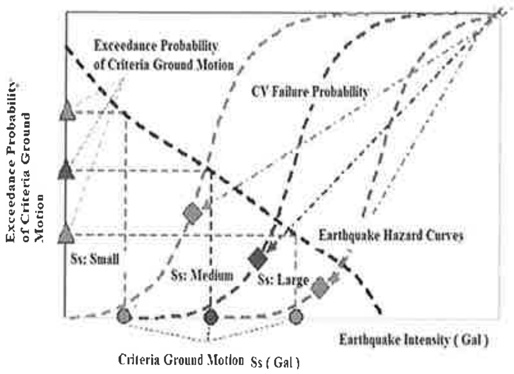

Figure 10 Distribution curves for earthquake[6)] occurrence and NPP damage

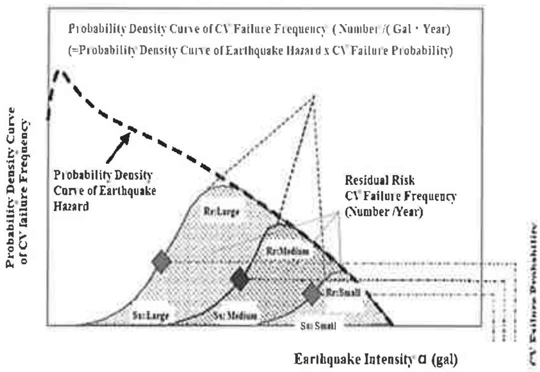

Figure 11 Damage probability density curve to obtain residual risk[6)]

Figures 10 and Figure 11 show how to obtain the residual risk probability when the variable seismic action seismic works. Large excess probability and Ss spectrum of the reference ground motion in Figure. 10 (Large), medium (medium) or small (Small) level earthquake occurrence is selected and corresponding seismic intensity of CV damage probability is determined. The total area of the range of the same intensity enclosed in the probability density curve shown in Figure 11 gives the residual risk probability. Obtained residual risk is discussed for the safety check in PBSD.

Figure 12 shows examples of the ground motion spectra Ss. In the past, spectrum (input acceleration 395 gal) was considering seismic motion at the time of the 1923 Great Kanto earthquake. However, earthquake motion considering geological faults affecting nuclear reactor facilities is set, and it is almost 700 gal level recently. However, if necessary, past 400,000-year history of geological fault movement should be taken into account. Now in Japan, re-running of reactor facilities is discussed. Average 700gal input action is viewed up to 1,000 gal under the judgment of performance requirements in margin.

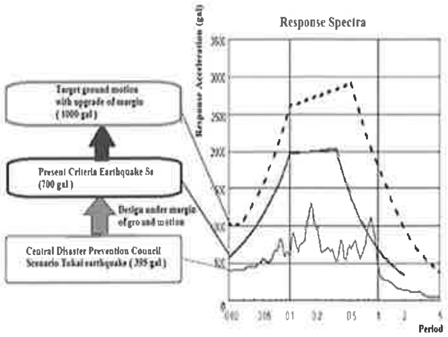

Figure 12 Design spectra for NPP[7)]

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