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Reevaluation of Design Basis Earthquake for Critical Industrial Facilities

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Abstract

This paper will deal with how to establish the concept of the design basis earthquake for critical industrial facilities such as nuclear power plants. The author once discussed this subject at 7 WCEE. At that time, the author assumed that the strongest effective PGA would be 0.7G, and compared to the values of accelerations to a structure obtained by various codes in Japan and other countries. The maximum PGA observed by an instrument at the Southern Hyogo-pref. earthquake-1995, so-called Kobe earthquake exceeded the previous assumption of the author, even though the evaluation results of the previous paper were pessimistic. According to the experience of Kobe event, the author will point out the necessity of the third earthquake S_s adding to S_1 and S_2, previous DBE.

Key words

Design Basis Earthquake, Nuclear Power Plant, Kobe Earthquake, New Dedign Basis (Margin Check) Earthquake, Concept of Severe Earthquake, Rare Event.

1 Introduction

The Southern-Hyogo Prefecture earthquake-1995, so-called Kobe earthquake is a really unexpected event as the engineering viewpoint. Of course, we expect such an event as a rare event for the design basis earthquake of nuclear power plants. We consider that in average, S_2, limit earthquake motion, defined by the Guideline for the Seismic Design of Nuclear Power Plants in Japan, NSC, in 1981, covers this event. Some unexpected phenomena were observed; energy concentration to particular zone; not only high peak acceleration, but also high peak velocity and large displacement; strong corelation of horizontal and vertical ground motions; very short duration to peak ground motions from starting of P-phase wave. Reasons of some of them are clear in the viewpoint of seismology. Even though, it is very difficult to predict it for the design in advance. Also, the return period of this event is not clear. It is the point in this paper how to consider such problems for seismic safety design of nuclear power plants. And it is the extension of the previous paper presented at TWCEE(SHIBATA, 1980)

It is very important issue to keep the seismic safety how to manage such an unusual event as observed in Kobe earthquake. The same type or more unknown phenomena may occure near to nuclear power plants, not only in Japan, but also any place in the world. For this, the author likes to define a margin checking or marginal earthquake, which has similar concept of the previous S_2 earthquake in Japan. It might be called S_s which has a concept as a severe accident. It is very rare event, but for the seismic safety of NPPs we should consider it. This article will try to discuss how it should be, and whether or not it can be defined as a practice.

2 FACT ON THE SOUTHERN HYOGO-PREFECTURE EARTHQUAKE

2.1 Fault, Ground Motion and Intensity

The slips of related fault have been studied by seismologists, and various kind of new facts have been being found. One of the features is high velocity ground motion. Following issues on their feature of ground motions which were made immediately after the event, now some of them are clear, for example : i) How strong the effective PGA? ii) Is the recorded maximum ground velocity reliable? iii) Which faults did cause main shocks? The short duration of ground motion of this event is very unique as Japanese earthquake. And initial several peaks were significant to cause structural damages as shown in Table 2. Main shock consits of three shocks, and the waves were focused into the eastern part of the City(Kikuchi,1995) (Figs.2(a) and 2(b)). Distribution of peak ground accelerations is shown in various papers. And their attenation curves are shown in Fig.3. Through the activities of the seismologists after the event, we feel the necessity of the establishment of the engineering seismology for estimation of local ground motions, that is, micro-zoning, but it must include the evaluation of the effect of fault movement as the seismologists have been discussed since Kobe event.

2.2 Time-history and Damage

The time history, that is, the parttems of ground motion of this event are very unique, and it has been proved by seismologists that there are exact reasons to induce such ground motions. The features of this event are quite different from other destructive earthquakes which have been recorded in Japan since 1880's instrumentally. The most serious destructive earthquakes, which were recorded in the past, are inter-plate type huge earthquakes and their epi-centers were in the ocean and their epicenter distances are usually more than 100 km. Durations of such earthquakes were over one minute in general. They induced resonance type failure to structures and this S-phase was followed by the surface wave period. Main points are as follows :

i) Very short duration from initiation of ground motion to main peaks ; approximately 2 sec as shown in Table 2.

ii) Similar wave form of acceleration to displacement.

This means, that the waves consist of rather simple component distribution like sinusoidal wave, and it makes easy to analyse them from seismological view-points. Table 2 was obtained by as follows : Comparison of NS motions at Kobe Ocean Observatory to the images of the video, recorded at 10 sec ahead at the NHK office in the area, which shows the process of events. According to the author's experince, it is clear that the shaking tests of human by this motion on the table demonstrate the strong effect to human body as well as to structures. The large amplitude of displacement in a short duration(Table 1) may cause many unique features of this event, especially, many deaths. It should be mentioned that such a type of ground motions may be expected more in low seismicity area rather than high seismicity area, even though the probability of occurence might be low.

2.3 Response Spectrum and Particle Motions, Role of Vertical Component

They have been discussed, but their direct effect has not been known exactly yet. Some features are as follows : i) Dominant in longer period range, $1 \sim 1.5$ sec in the response spectrum (in Fig.4). ii) Corelation of horizontal motions and vertical motions is recognized strongly. iii) Video-recordings at super-markets have a certain role for seismological study. As far as the second item, we feel the strong necessity of more study.

3 TWO LEVELS OF DESIGN BASIS EARTHQUAKE AND KOBE EVENT

3.1 Design Basis Earthquakes in Japan

After the event, the Nuclear Safety Commission organized a task group, chaired by Professor Kojima. This TG consisted of nine specialists including the author. They examined the following points to clarify that the Guideline for (examining) the Seismic Design of Nuclear Power Plants,issued by NSC in 1981, which has been used for the regulatory purpose, is adequate : that is i) If a nuclear power plant is constructed according to the Guideline in Kobe Area, the design would be reasonable ? ii) How S_2 ground motions would be strong ? iii) How the response spectrum of S_2 would be conservative ? Nine meetings and one field survey were made. The following part of this chapter is a summary of the report (NSC, 1995). Two levels of "Design Basis Earthquakes" have been employed in Japan since almost beginnings, 1960's. In the Guideline, S_1 and S_2 are defined as follow : S_1; the strongest earthquakes, and S_2; the limit earthquakes. The second one may be interpreted as the upper-bound earthquake. S_1 earthquake may be the historical maximum earthquake in the site region. The historical records on destructive earthquakes have been kept since 5¢, and those since 9 $\sim$ 10¢ can be listed in the seismic catalogue. S_2 earthquake is the upper-bound earthquake, whose magnitude M can be estimated in region by region. According to the practice in Japan, the annual probability of occurence of a certain earthquake doesn't follow the stochastic relation in the stronger level, and there is the limitation as explained in Fig.5, and this value can be estimated by the seismotechtonic structure of the region (Omote map in Fig.6). However, level of intensity may be more diverged rather than the curve in Fig.5.

3.2 Comparison of Design Basis Earthquakes to the Kobe Earthquake

According to the requirement of the Guideline, S_2 in this region should be as follows : $M = 7\frac{3}{4}$ and $\Delta = 7$ km. If we assume that a nuclear power plant in the area $M_{95} = 7.2$ and $\Delta_{95} = 16$ km as Kobe event based on Japan Meteorogical Agency'data. Those values, officially reported, are formalized as the definition as to concentrate to one focus. According to the survey result by the seismologist the situation is more complicated. The focal distance R_{95} can be defined not so clearly. The above value was decided under consideration of such a situation, and the value based on original definition, it might be more than 50 km. Δ is the epicenter distance, and the focal distance is the distance to the focus of the event. However, the definition of a focus is the point which the initial slip of a fault movement had started. In the case of this event, its depth H_{95} is estimated as 14 km. The S_2 earthquake in the Guideline is defined in two ways : the maximum earthquake which might occure at the point estimated by seismological survey on active fault distribution, and that ; $M = 6.5$ underneath of the site, that is $\Delta = 7$ km, $H = 7$ km. In this case, the former definction is applicable for more effective DBE.

3.3 Response Spectrum of the Event and Vertical Ground Motion

Even though there are many records of strong seismograph in the area, those of rock site are limited, because the site of a nuclear power plant in Japan must be rock site. Therefore, the record observed in the tunnel at the campus of Kobe University was only met to this requirement. The design basis spectra in the Guideline, which are called as Ohsaki spectra based on approximately 40 ground motion records in rock site observed in the world wide, are the standard spectrum which is recommended in the supplimental explanation of the Guideline. According to the response spectrum, in the lower frequency region, the response spectra of them are dominated compare to the design basis response spectra which are used for the design (Fig.7). The comparison of this standard spectra to the response spectra of ground motions in the area was made, and the standard spectra are more conservative than the spectra of the event at the Kobe University except in the lower frequency region than 0.6 sec. Eigen-periods of significant structures, piping systems and equipment are generally shorter than this value. This means that the standard spectra for the design are adequate in the view point of the margin. It seems to be that many evidences of domination of vertical ground motions of this event. One of the reason comes from nonlinear characteristies of soil layer for transmission of S-wave, and linear for that of P-wave. The ratio of peak value of vertical ground acceleration to that of horizontal one was less than a half, 1/2, in general. Also, that of peak velocity and spectral intensity are the same situation. This means that the ratio used for the design is also adequate. Even though, we could find many facts of behaviors showing the vertical ground motion were dominated as mentioned above, and the author believes that it might be induced by their corelation. Study on the corelation of both vertical and horizontal motions shall be necessary. The analyses of key structures and items in a typical power plant based on the spectra had been made as a reference, and we could not find any critical issue. The report on the new basic proposal prepared by the Central Commission of Disaster Prevention pointed out that all kind of structures, not only nuclear facilities, must be designed in two levels, such as the concept of S_1 and S_2. The draft of the special committee, the Science Council of Japan recommended that the equalization of the concept of seismic codes, whose number is approximately 40 kinds in Japan, shall be made. In 1981, only the concept of zoning had been established except for nuclear power plants, however, now there are opinions that the activity of local active or capable fault must be considered in the codes of others, like a civil engineering structure. Also the continuous effort to improve the seismo-techtonic map like Omote map is necessary. The author likes to point out that the necessity of introducing a new margin check earthquake or design basis earthquake, which might be called "severe earthquake S_s" as discussed in the following chapters.

4 NECESSITY OF INTRODUCING NEW EARTHQUAKE S_s FOR DESIGN MARGIN CHECHING

As already mentioned, there are several ways to define two levels of design basis earthquakes as S_1 and S_2. The most popular concept of two level DBE is observed in the Building Code. The first level, lower one, is for the design of conventional structures to decide its configuration and cross section of structures, and the second level, higher one, is to evaluate its ductility or capacity of its strengh beyond elastic region.

For a rare event like Kobe earthquake, it is a big issue how to set the measure. In the new principal program for the disaster prevention, the loss of human life must be prevented against such a rare event which is not expected in general. In a seismic safety of nuclear power plants, this principle may correspond to S_2 requirement. A rare event, which may occure once per 10^5 year or more, is another requirement. S_2 in Japan is an event 5×10^4 year event in principle. The Kobe event is a really rare event in the area as shown in Fig.1, however, the discussion is still remained how its return period is. Also on which parameters should be focused for this discussion, its peak ground acceleration, peak velocity, magnitude, short duration, coleration between horizontal and vertical motion and so on. High peak ground acceleration is observed through the world last several years. One of the reasons, it comes from the improvement of accuracy of recording device and their distribution density. However, in the case of the Kobe event, also the peak ground velocity, and its amplitude of displacement are high and large, and the duration is short, this means, high energy concentration to the severely damaged area (Kikuchi, 1995). The reason of this is estimated as a Dopular effect of the wave propagation and the slip development along the fault. Such a phenomenon was observed at Lowrence Livermore National Laboratory in 1981, and two fussion faclities like Shiva were damaged as well as storages of wine at Wente winary next to LLNL.

Even the same magnitude earthquake would occure in the same area with the same parameters, the concentration of energy will be differ in each case, that is, the peak ground acceleration might be different as well as the feature of its dynamic characteristics. Therefore, even the magnitude and its epi-center are discussed in the probabilistic view point, also some additional parameters must be discussed, and such a consideration may be reduced dramatically its probability of occurence. The author mentioned the probability of occurence of a certain earthquake like S_1 or S_2 in Fig.5. If its abscissa is chosen in magnitude M, it is still true, however, if it is intensity or peak ground acceleration, it might be more diverged. And, almost no upper-bound of the concentrated energy to a certain area, even the magnitude has its upper-bound region by region as refered in Fig.6. If the velocity of crack developing is equal to the velocity of wave propagation, all energy might be concentrated to a point at the end of its fault zone. The evaluation of the probability of occurence of such a critical case has never discussed. Here, the author can mention that the necessity on the consideration of such a critical case for a severe earthquake as S_s. We don't know how the upper-bound would of intensity be strong. All energy of an event may concentrate at the end of the region of the fault, and the peak ground velocity or the peak ground acceleration may reach to almost unlimited value.

5 HIGH VELOCITY AND LARGE DISPLACEMENT

As indicated in Table 1 the Kobe event showed very high velocity and large displacement as well as high acceleration. This nature was kept not only on the motion at Kobe Ocean Observatory, but also the motions at other points in the seriously damaged area. This means that original ground motions, induced by its fault movement, have those nature. The high value of acceleration was brought by rather longer period peaks, as features of the response curves, which are shown in Fig.3. Usually high peak acceleration is observed at the point of peak(s), whose period is rather shorter, and this leads the conclusion that the high PGA doesn't mean the high destructive effect in general. In the Kobe event is quite different from such events observed often, and its high velocity caused brittle failure on various structures.

Reevaluation of design basis spectrum, like R.G.1.60 has been discussed since the Kobe event. As mentioned in Chapter 3, the response spectrum of the Kobe event is more dominate than the design basis spectrum, so-called Ohsaki spectrum, in longer period range. Also it should be mentioned that the spectrum, obtained by simulatory ground motions from parameters assumed for an event which is considered on an assumed fault ($M = 7.75$, $\Delta = 16$ km), coincides with those of the Kobe event in the longer period region as shown in Fig.7. This means that high velocity and large displacement of the Kobe event are very significant features, and deeply related to its unexpected destructive power.

Back to high values of peak ground acceleration observed in the area, the return period of such an event has been never discussed by now. The figure, Fig.1, was plotted by Watabe originally based on the seismic catalogue. He decided the line OA, which was biased by a record P, which was marked by the event. He temporally concluded that the return period of the Kobe event might be 5500 years However, based on events, which occured last 300 years, upto the event Q, the line OB is more adequate than OA. Of course, its gradient is steeper than CD, the gradient 2 line, and we don't know whether or not its feasible. If we extent the line OB to 500 gal or 800 gal, the return period becomes 10^6 or 10^7 years, respectively. And these number seems to be not feasible. Even the line OA to 800 gal, the return period is more than 20,000 years. A concept of the seismic hazard carve was introduced for Seismic PSA, but it is very difficult to estimate it. One of the reasons is how to locate the point P which indicates the strongest event upto now. We know the shortest period for plotting its return period, that is duration from the time of the point P event to now. On seismic hazard curves for peak velocity or peak amplitude of displacement, the same type of discussion must be made.

The corelation between horizontal ground motions and vertical ground motions is considered through the ratio of peak values only. In the report on the adequecy of the Guideline, only this type of discussion was made. However, the strong corelation of particle motion diagram. This might be related to the feature of ground motions of this event, which discussed in previous part of this chapter. The exact reason has not been known, however, if the ground motions dominated in Kobe event directly comes from the motion of the block near to surface, it might be. It is necessary to study such features of this event related to failure of structures must be studied.

In Fig.3, $\pm 1\sigma$ range is indicated. Fluctuation of data is considered as one of random phenomena. But as discussed, the deviation from the mean value might be caused by the focusing effect of energy. It can be said that σ/m =1.9 in logarithmic scale. If it is true and we try to apply some stochastic criteria to estimate its upper-bound, the value becomes unrealistically large. However, it may be reasonable that the reason of such divergence might come from the focusing effect rather than effects of soil amplification.

7 CONCLUDING REMARKS AND ACKNOWLEGEMENT

We feel the necessity to fix the value for the value of the severe earthquake motion S_s for the margin checking of nuclear power plants. It is significant especially degraded, aged ones. Even though, it is very difficult to estimate its value by a stochastic approach. It is more practical to estimate the value from seismological approach on its fault mechanism with assumptions several significant parameters of fault and its movements. Those values might be decided by observed results on the related fault with some data of previous historical data plus assumptions. It is more important to examine the seismic safety of nuclear power plants under the severe earthquake S_s as a practice than to hesitate it because of unaccurate value of related parameters.

The disscusion above is the author's personal opinion. However, he has proposed this concept for a part of subjects of a new task group of PWG3 of NEA, under OECD, CSNI(Committee on the Safety of Nuclear Installation) to their secretary. He greatly appreciates their descusion on future development of this concept.

8 REFERENCES

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Peak-values of Ground Motion

Component	NS	EW	UD
Acc. gal	818	618	332
Vel. kine	90.4	75.0	40.3
Disp. cm	21.0	19.8	11.2

Table 1 Peak Values of Acceleration, Velocity and Displacement of Kobe Ocean Observatory Records JMA (Prepared by BRI)

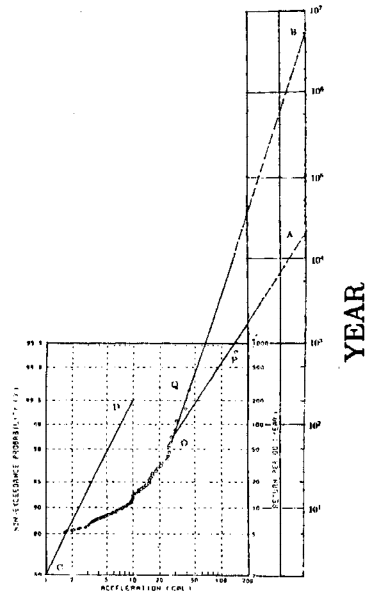

Fig.1 Return Period Estimated from Historical Earthquake Record (Original : prepared by Watabe, modified by SHIBATA)

Digital Memory Device for 10 second-ahead recording Video

i = small articles (books) on the desk are slightly moving.

↓

a = large motions of articles are observed.

↓

b = overturn of file-cabinet.

↓

c = TVset is droping from a rack.

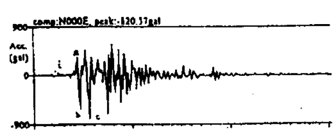

Table 2 Sequence of Failures Observed in Kobe Branch, Nippon Broad Casting Corp. by Video.

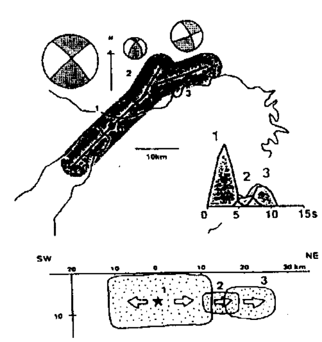

Fig.2(a) Fault Movements of Kobe Earthquake (Prepared by Kikuchi)

D.B.Earthq.	Design Basis Seismic Coef. (Static)	Dynamic ZPGA gal	Related Item	Plant Cond.	Post Earthq. Inspection
S_2 (Margin check) Upper bound	0.9	240~500(480) ~ (600) (=1.5S_1)	A_s (A_2)	FC (D/4)	Level 3
S_1 (Design basis) Historical Max.	0.6	180~300 ~(600)	A (A_1)	EC (C/1)	Level 2
S_0 (Operational) once per 2 ~ 10 years	—	50~60	all	UC & NC (B/2 & A/1)	Level 1
S_B	0.3	90~200 (=1/2 S_1)	B		
S_C	0.2	90~100 (=1/3 S_1)	C	(conventional level) equivalent to Building Code	

Table 3 Design Basis Earthquakes in Japan and their Values

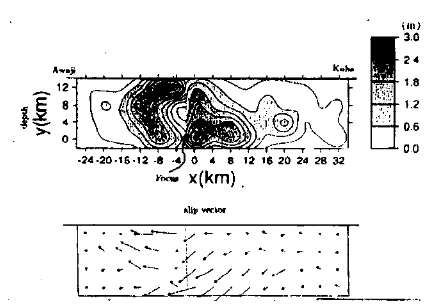

Fig.2(b) Slip Distribution on Sliping Surpace (Prepared by ERI, Univ. of Tokyo)

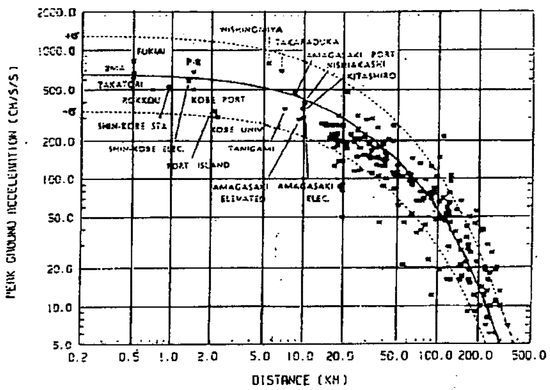

Fig.3 Attenuation Curve of P.G.A. of Kobe Earthquake (NSC, TG. Report)

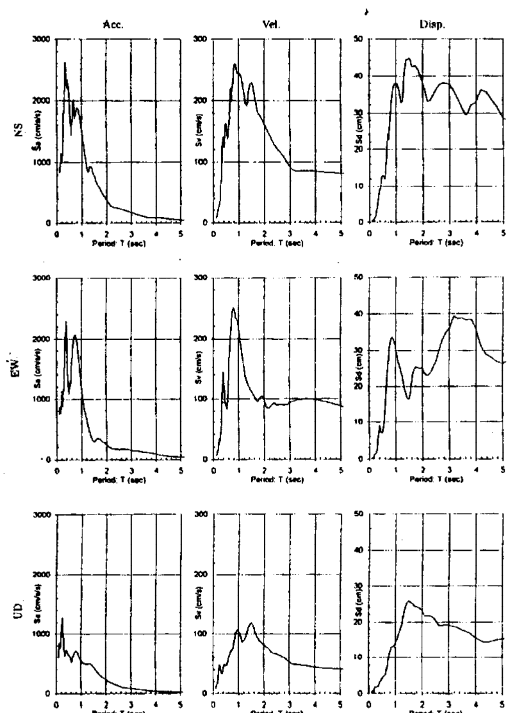

Fig.4 Response Spectrum of Record at Kobe Ocean Obsevatory, JMA (Prepared by ERI)

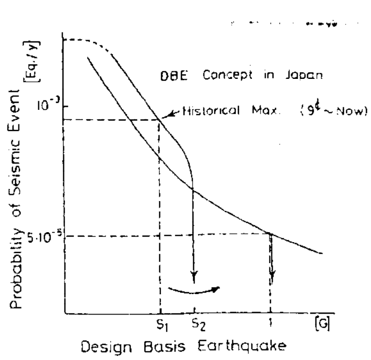

Fig.5 Relation of S_1 and S_2 Design Basis Earthquakes To Probability of Occurrence of Seismic Event

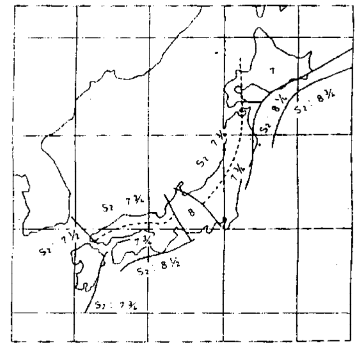

Fig.6 Map of Distribution of Maximum Potential Earthquake in Japan, Omote Map

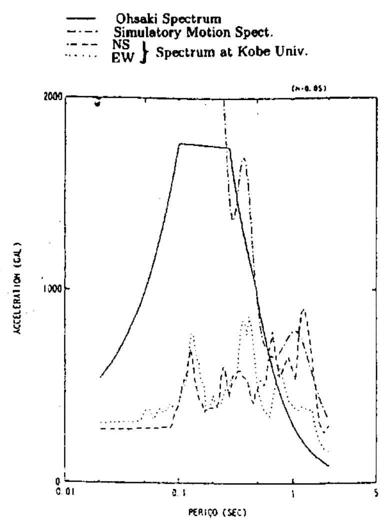

Fig.7 Comparison of Responspectrum of Record at Kobe University *vs* NSC TG. Report