THE WAY OF SETTING THE ASEISMIC DESIGN CODE OF OIL REFINARIES AND PETRO-CHEMICAL INDUSTRIES

by

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SYNOPSIS

This paper dealt with the way of setting the aseismic design code of oil refinaries and petro-chemical industries. The code should be one of the tipical examples of modern open form aseismic design codes as well as the code for nuclear power plants. They are supported by the concept of factor of importance, and their purpose is to ensure the safety operation of such plants for the public and environment during a destructive earthquake. Aseismic design of each items should be based on their modes of failure.

1. Introduction

Since the event of the San Fernando Valley Earthquake in 1971, the effort to establish the codes of aseismic design of various kinds of industrial facilities has been continued in Japan. Those codes are on the aseismic of nuclear power plants.[1] The other code of this type is for oil-refinaries and petro-chemical industries. In 1958, we started the project of the first nuclear power plant in Japan. Since that, the subject "how to establish the procedure of the aseismic design of nuclear power plants" has been discussed.[2] The purpose of them is to avoid hazard to their environments including the public during and after destructive earthquakes. Such a purpose "to ensure the public safety" is also found in the design to keep the functionarities of life lines like electric power system, water supply, energy supply, telephone networks and so on as well as the plants mentioned above.

2. Composition and Form of the Code

The typical composition of aseismic design code can be found in that of nuclear facilities as shown in Fig. 1. Although one of the prominent differences of design procedure between ordinary civil structures and those of these structures is in their safety aspect, however, another difference is in the cost performance. Comparison of the aseismic design techniques of an industrial structure and a building shows that the techniques involved are basically similar. However, the difference has in the number of items for which dynamic design must be made. This means that even a small tower type vessel compares with a large building in the dynamic design required, and as a result, the cost of the basic analysis is comparable in both cases although the actual construction costs will be much greater in the case of the high-rise building. From the foregoing, it can be seen that the cost of aseismic design of a complicated plant would be impossibly high, if dynamic design as the same level of that of high-rise building was necessary for each individual component of the system. It was in response to this problem that the concept of "factor of importance" or "factor of danger" was introduced in the early stages of development of aseismic design of nuclear facilities. We learnt that this was very effective for the design of the nuclear fuel retreatment process as well as that of nuclear power plants.

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There are two ways to describe a code in general. One is a code which provides all details of the regulation which we want to state in it. We can find all informations, at least quoting other codes, to complete the design in the code. The author calls this type of codes as a "closed form" code. Most of classical codes, for example, the Japanese Building Code, belong to this category. On the other hand, a some modern code requires much knowledges in its area to complete the design. The code only states important points including the fundamental philosophy of the design, the way of judging at branch points, restriction on structural design, lists of parameters and other data which we need in the design. Although the designer in this case should know the details of the engineering of the area, however, he obtains much freedom for his design. This type of codes may be called as an "open form" code. The typical example is ASME, Boiler and Pressure Vessel Code, Section III. To apply this code to actual design, we need deep knowledge on the stress analysis of pressure vessels and pipings. The modern aseismic design code should be an open form code, however, we need a group of experts to operate such an open form code and to examine reports based on the code.

3. Mode of Failure and Mechanism of Failure[3)]

In order to effectively design earthquake resistant structures, the factors involved in structural failures under destructive earthquake conditions must be collected and be completely understood. In particular, the weak points in a structure must be recognized. And from the arrangement of these weak points, the "mode of failure" is determined. Then we can establish design procedures for various items in the plant concered. Assessing the weak points in a structure can be a difficult problem in itself without the experience of actual damages. However, it is essential to correctly determine the weak points in complex structures of industrial facilities so that appropriate data is available for effective aseismic design.

The characteristics of earthquakes and the dynamic response of structures to them must be considered in relation to the "mode of failure". We summarize the varriety of the ways of responding and failing of structures as "mechanism of failure". Knowledge on "Mechanism of failure" gives us a definit procedure of the analysis for each item in plants. Usually aseismic designs are based on an acceleration response curve. However, some structures which have the long natural periods like a tall tower-type vessel should be based on displacement response. For this we need record of ground motions which contain long period ground motion (T_g =1∿10sec) rich enough. The behavior of free surface of liquid in a vessel, known as a sloshing phenomenon, is also that in the same category. The design of structures which involve free surface of liquid in it is one of the key points to prevent the potential hazard expected in oil refinaries and petro-chemical industries. The author discusses it in another paper.[4)] The author will discuss "mechanism of failure" in the relation to "mode of failure" in the following sentenses.

Failure due to Acceleration Effect This effect is worked on systems whose natural periods are far shorter than the dominant period of the ground motion. Acceleration effect is expressed as a static seismic load on a structure, which is determined by multiplying the seismic co-efficient, that is, the acceleration of ground motion, by the structure weight. These structure may fail at the weakest point in the quasi-static force balance. This corresponds to the situation where β_s in eq. (1)(See section 4) is almost equal to unity, and the structure in this ca is being categorized in "rigid structure". However, even rigid structu es may behave differently, in responding to a sharp earthquake which is travelling through a hard rock layer from the shallow source. A brittel structure may fail as the result of such a shock, whereas the structure having enough ductility usually suffer little damage in the same situation. Many equipment which are made of cast iron parts have the possibility to suffer this type of damage as well as porcelain structures seen in an electric power system. Criteria of this mode of failure mainly depends on the maximum velocity of the ground. The design maximum velocity in high seismicity area might be at least 40 cm/sec.

Horizontal acceleration may cause massive industrial facilities such as non-anchored storage tanks, small conventional package boilers or electric transformers to slip sideways. According to a some experiment by small models, sloshing phenomena of liquid in a vessel cause such slipping under the existense of vertical ground motions. Non-anchored structures without liquid have the possibility of slipping sideways also, however, the values of vertical acceleration and horizontal velocity of ground required to cause such slipping are far higher than the case of those with liquid.

Failure due to Acceleration Response A single-mass-and-spring system such as a simple tower type vessel is the fundamental type of models for the dynamic analysis. From the response spectrum curve, the design curves for the modified seismic co-efficient method can be obtained. The reliability of response analysis is not so high, therefore, we need to give some allowance to the mean response curve for design seismic co-efficient curve. The width of allowance should be determined under the consideration on earthquake loading factor and the some natures of earthquake sources which we are concerned with. For the design of small equipment in supporting structure, the concept of floor response curve is usually used. By assuming that the reaction force from equipment to supporting structure would be negligible, the concept of floor response curve might stand. However, uncertainty of the response such a system is higher than a simple structure. Acceleration resonance can be more damaging to a two-mass system by whipping of an appendage portion. Under conditions of acceleration resonance, failure occures mainly in the spring section such as legs, bracings, frames, skirts of vessels and so on. In some cases, because of the high acceleration of the mounting point, attached equipment may also fail.

Failure due to Resonance with Long Period Ground Motion As already mentioned, sloshing phenomenon is depending on how the ground motions contain long period components. For the design under the consideration of ordinary destructive earthquakes, the possibility of resonating to two or three waves of the coincident period of ground motions may be the severest condition except the case where the dominant period of actual ground motion coincide with the fundamental period of sloshing of a storage tank. Hydraulic force caused by sloshing phenomenon usually large compare to the weight of a storage tank, therefore, various kinds of damages may occure adding to the side slip already mentioned. There is very high possibility of inducing disastrous plant-fire from this failure mode.

Failure due to Forced Displacement by Relative Ground Motion and Liquefaction
Relative displacement along the fault line or caused by floating up of buried structure gives a very huge internal force on under ground pipings and other connecting structures. The section of structure which is small in cross-section and bridges two separate massive systems is particularly vulnerable to movements of larger parts not only in under ground structures, but also in composed tower type structures. The necessary condition for occuring liquefaction are the homogeneity and looseness of wet sand in re-

lation to the ground acceleration. In the area of loose fine sand with a high level water, this phenomenon is more common events than we expect.

Failure due to Other Mechanisms Effect of vertical ground motions is non-linear to most of systems, and there are many problems still unknown. One of other unknown problems is torsional vibration. Torsional ground motions have been observed by the author, and several data are avairable for the analysis.

4. Factor of Importance and Design Methods

The term "factor of importance" means the factor of danger of items in a plant classified in accordance with their potential danger. If it is assumed that such a plant has not been aseismically designed, the potential hazard in the case of failure or rupture by a destructive earthquake can be evaluated. There are several ways of classifying items in a plant, here, the part of the four stage systems[5)] is shown:

Class I : Single failure or rupture of the items classified in Class I may cause complete destruction of the public, including private properties, public properties and the whole environment.

Class II : Single rupture or failure of items classified in Class II may cause loss of human life and damage to properties outside the plant area.
and so on.

The maximum design acceleration S_A at the center of gravity of a structure is usually difined in eq. (1) as follows:

$$S_A = \beta_1 \beta_2 \beta_3 K \qquad (1)$$

where S_A : the maximum design ground acceleration in G or seismic co-efficient,
β_1 : co-efficient determined by the factor of importance,
β_2 : local amplification factor of the ground where the structure stands,,
β_3 : response factor of the structure expressed in the seismic model,
K : the maximum basic ground acceleration for the design.

By the factor of importance, not only β_1 , also the practice of design should be controlled. For the higher class items, the higher and more precise technique should be adopted.

In Fig. 2. the comparison of the several typical curves of amplification is shown. The highest curve N-1 is the modified response curve of a zero-damping system to the Pacoima Dam Record in the San Fernando earthquake by Newmark. The lowest curve is the well-known curve drawn from the Uniform Building Code of the U.S.. As to β_3 in this paper, the use of a group of curves including the curve CSB-2 drawn by Kuribayashi as averages of the response curves to 44 earthquakes in Japan are being considered. The maximum basic ground acceleration K is the expected maximum ground acceleration at the site where the plant to be built. It should be greater than that which can be estimated from the data of past destructive earthquakes and seismic disasters in the area around the specific site.

5. Other Considerations

Planning of the structural conception is also important factor to reduce the total damage of the plant. An arrangement of equipment and other facilities is planning to be refined to achieve the best arrangement from the viewpoint of structural design and disaster prevention. The general design criteria, which designate design limitations, shape restrictions to prevent structural damages, are also important.

In general aseismic design of a structure is understood as the design which assures sufficient strength to endure earthquake loads. However, the purpose of the aseismic design of industrial facilities is to ensure the safety of their environments and the public. For this purpose the safety design of the system is important as well as the strength design. The role of safety design including the instrumentation and control system is very important.

The allowable stress for seismic loads has not been established from the philosophy shown in the ASME Section III. The author makes the propose that the allowable stress for seismic loads S^* be $S^* = 1.5S$, where S is the original allowable stress for internal pressure, weight and other long term loadings.

The co-efficient 1.5 should be chosen in accordance with consideration of increasing the probability of the failure by seismic loads. Considering the shake down phenomena, stress intensity during earthquakes can reach the value of $2S_y$. In this case the attention should be paid to prevent brittle fracture in vessels and pipings.

6. Acknowledgements

This paper is due to the results of many surveys, studies and design experiences. The author owes much to the people in these fields in both Japan and the United States. He wishes to express his deep gratitude to these people.

7. Reference

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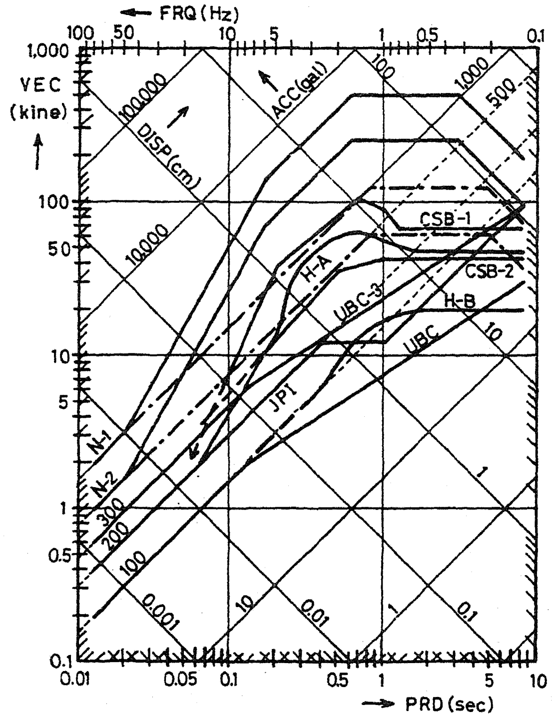
Fig. 2. Major Response Curves and Seismic Coefficient Curves in Japan and the United States

N : by Newmark
H : by Housner
CSB : by Kuribayashi
JPI : Japan Petroleum Inst.
UBC : Uniform Building Code



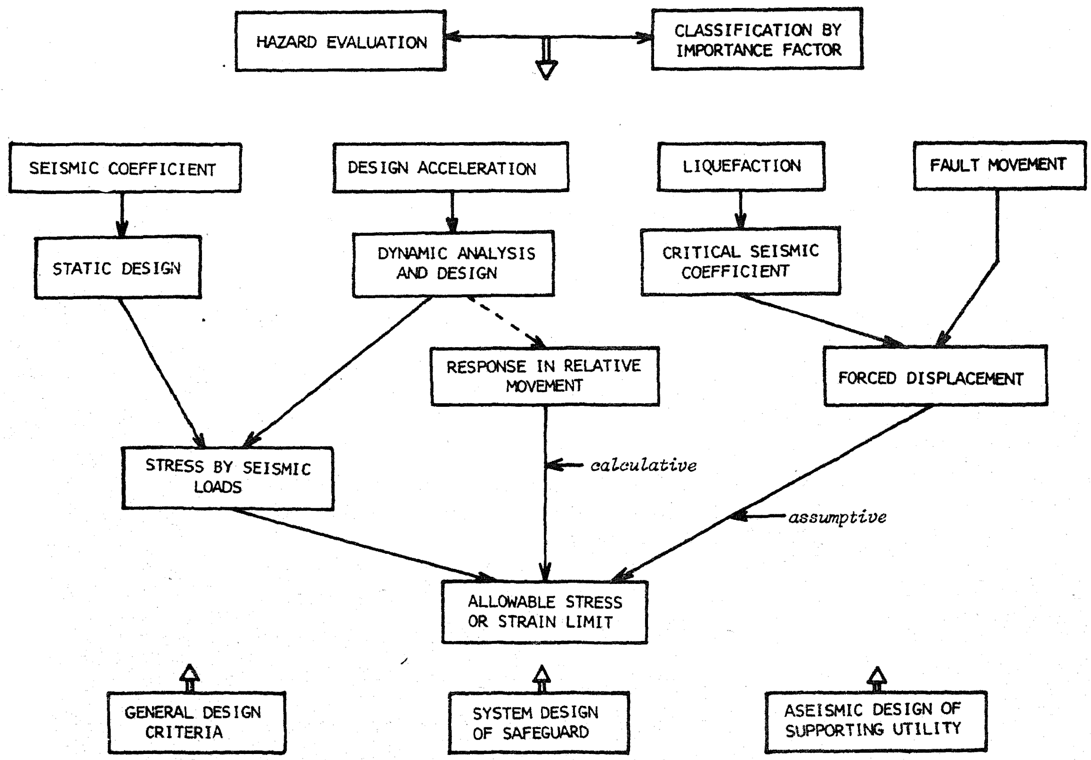


Fig. 1. Flow Chart of Aseismic Design of Nuclear Facilities

DISCUSSION

H.N. Gandhi (India)

Prof. H. Shibata deserves appreciations for presenting very important paper which is based on many studies and design experience. The paper presented by him is on the subject "THE WAY OF SETTING THE ASEISMICDESIGN CODE OF OIL REFINERIES AND PETROCHEMICAL INDUSTRIES" is very important for aseismic design of oil refineries and petro-chemical industries. Generally, oil refineries are having a low pressure systems and hence, the hazard are normally in the form of fire, whereas for petrochemical and fertilizer industries, very often high pressure system is essential and hence hazard due to explosion is very much compared to the hazard in oil refineries. Therefore, the common code for aseismic design of oil refineries and petrochemical industries may lead to over design or under design, considering different degrees of hazard due to fire and explosion. In this connection it is noted that the "FACTOR OF IMPORTANCE" has to be choosen for specific design as mentioned by the author. The author has classified potential hazard under two classes viz. Class-I and Class-II. The details of these classification is not mentioned. It is, therefore, clear that these classifications are based on damage and hazard evaluations. In this connection, the undersigned proposes following criteria for the evaluation of hazard and classifications in connection with Factor of Importance. Since, most of the hazard and damages in oil refineries and petrochemical industries are due to fire and explosion, it may be considered worth while to classify the items on the basis of (a) internal pressure and temperature for various equipment/piping/vessels, etc. and (b) explosive nature of internal fluid/gas.

In petrochemical plants, hydrocarbons at high temperature and pressure are often circulated. The leakage or rupture of these pipelines/reactors/vessels may create all the possibilities of explosion depending on the nature of the fluid/gas. In this connection, it may be worth while to note the explosion which occured on 1st June, 1974 at Flixborough Works at UK wherein the entire plant was demolished by explosion of war like dimensions. From the findings of the court of enquiry, it is concluded that cause of explosion was ignition of a massive vapour formed by the escape of cyclohexane under condition of high pressure and temperature consequent upon rupture of 20"ø dog leg pipe which was installed as a by-pass assembly. A rupture in a similar 20"ø pipeline having different temperature and pressure condition and different fluid/gas characteristics would not have cause an explosion of this magnitude even though in both cases, earthquake force to cause a rupture due to earth-movement may be the same.

Considering the above, the author may like to consider classification of various items on the basis of internal pressure and temperature and service conditions including chemical nature of the fluid/gas.

The author may also please indicate the details of classification that he has considered and the other precise technique for high class items as mentioned in the paper.

Author's Closure

The author greatly appreciates the very informable question from Mr. Gandhi. He has almost none to add to Mr. Gandhis valuable comment.

The author described approximate procedure to categolize items according to "Factor of Importance" in his paper appeared in the document (1). Briefly describing it in the followings:

1) Assuming the potential leaking condition under a destructive earthquake condition without anti-earthquake design of related equipment.

2) Estimating the worst distribution of gas according to the gas concentration from equipment.

3) According to the nature of gas, evaluating the potential hazard caused by the diffused gas.

For example, in a case of chlorine gas estimating the areas of exceeding 3.5ppm and 35ppm, and multiplying by population density of those area. The result of the former area shows the potential number of people who should evacuate from the gas, if such potential accident will occur. The latter figure shows the number of potential death caused by gas addition to the direct disaster of the earthquake. We should decide the permissible number of potential death according to the social condition of the area where the plant will be situated.

For other types of materials. We evaluate the area of detonation, the pressure of blasting wind or the radiation from flame and fire balls in a same way.

However, these procedure may be rather complicated job for daily design business. Therefore, we can set up the table of the classification according to materials, the maximum amount of potential leakage under an earthquake condition and environmental condition of the site. We have been using this method in a certain area of Japan (2).

Such analysis is only for leaked and diffused gas. As the discussor mentioned, the effect of blasting of a vessel, column or other enclosures may be evaluated. However, according to the knowledge of the author, such type of disaster was rather seldom. Only the cases are the blasting of furnaces, except explosive material such as some nitrates. In a case of fire of the over-all plant, some storages may explode by the heat from outside. Although in Japan, we donot consider this effect, we can say that this effect may have some relation to the amount of potential leakage above-mentioned.

Reference

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