Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SH-4

A SEISMIC RISK ASSESSMENT OF INDUSTRIAL FACILITIES

Kohei SUZUKI[1] and Fumio HARA[2]

[1]Department of Mechanical Engineering, Tokyo Metropolitan University, Setagaya-ku, Tokyo, Japan

[2]Department of Mechanical Engineering, Science University of Tokyo, Shinjuku-ku, Tokyo, Japan

SUMMARY

This paper proposes a seismic risk assessment methodology which can be applied to estimate seismic hazard preventability of huge industrial zones,particularly, those having petrochemical and oil refinery facilities. The risk assessment program was investigated and developed by the Sub-Committee of Seismic-Fire Disaster Prevention under the sponsorship of Kanagawa Prefectural Government (Ref.1). Detailed works were carried out by the Keihin Area Disaster Preparedness Association.

According to the method,assessment is realized by a simplified procedure in which the total seismic risk for the industrial zone can be evaluated by synthesizing following three principal risk elements;
(1) potential risk of liquid outflow from storage tanks,
(2) capacity of disaster preventability closely related to earthquake hazard preparedness in industries and
(3) environmental risk by which possibility of hazard spreadness to surrounding region can be assessed.

Risk evaluation is performed with respect to every seismic mesh zone [$500^m \times 500^m$] determined in advance and totally represented by three-axes diagram. Six categories are presented in order to classify the assessment results and shown in a map for representative three major industrial zones designated in Kanagawa Prefecture .

INTRODUCTION

Japan keeps high level of industrial development exposed to high seismicity (Ref.2). From this viewpoint, the Keihin industrial complexes area should be regarded as a remarkable area, which means bay area across Tokyo, Kawasaki and Yokohama along Tokyo Bay.Many huge industries such as heavy industrial companies and petro-chemical facilities are concentrated along the Keihin Bay area. Therefore, Tokyo Metropolitan- and Kanagawa Prefectural Governments have perserved so far their efforts to improve earthquake hazard reduction counterplanning for this zone. Several Hazard reduction works have been made considering past severe damages experienced in petroleum industries caused by Niigata(1964), Miyagi-ken-oki(1978) and Nihonkai-chubu(i983) earthquakes. Among the works,seismic risk evaluation for the zone keeps especially important position. However, risk evaluation programs so far established have not taken a serious view of following factors which have to be significant to assess earthquake hazard risk fot the industrial zone;
(1) structural strength inspection of the facilities to withstand earthquake,
(2) organizational preparedness and preventability in individual facilities and
(3) environmental potential risk to spread hazard to surrounding regions.

This paper presents a new methodology of seismic risk assessment applicable to estimate hazard preventability for petroleum and oil refinery industries paying particular attention to the above mentioned factors.

OUTLINE OF RISK ASSESSMENT PROGRAM

Proposed seismic risk assessment is basically carried out by evaluation of fundamental 3 risk components E_1, E_2 and E_3. Here, E_1 means a potential risk of liquid outflow from the storage tank located in a designated industrial zone. In order to evaluate E_1 , following 6 factors have to be calculated corresponding to an individual storage tank under inspection;
(1) anti-seismic structural strength of the tank which can be diagnosed based upon the updated inspection criterion established by regulatory agencies,
(2) liquid characteristics —— degree of poisonous, flammability and classification of liquid content,
(3) liquid amount requested to be stored within a tank,
(4) environmental hazard preparedness around facilities against disaster spreadness,
(5) choice of tank materials and structural type (cylindrical, spherical or horizontal)and (6) aging effect.

E_2 means disaster preventability of individual industries under assessment. It has been recognized that such a factor cannot be numerically evaluated.In this program, particular effort was devoted to the evaluation of the factor. Here E_2 can be evaluated by summarizing two sub-elements E_A and E_B. E_A evaluates preventability based on facilities, in other words, "hard ware counterplan" by use of fire protection facilities and oil spill recovery equipments. On the other hand, E_B provides a capacity of "software counterplan" in which disaster prevention organization such as manpower for protection and emergency command and notification system are investigated.

By element E_3 , we can evaluate environmental risk around a specific tank under assessment. This value provides a potential risk of giving rise to major disaster in the periphery such as gas flammability, location and crowdness of tanks.

After evaluation of three elements E_1,E_2 and E_3 , total risk assessment is realized by making three axes presentation as shown in Fig.1. Evaluated results with respect to elements E_1,E_2 and E_3 have never to be algebraically summed up or combined since each value gives somehow "subjective" assessment and do not make any physical sense. However, through representation in a three axes fashion, balancing among hazardous risk and preventatbility associated with a specific zone can be estimated. In this program, total six types of balancing are categorized by applying the procedure to actual facilities located in the designated industrial zones in Kanagawa Prefecture. Those are summarized as below;
[a] E_2 - uniaxial type; This category corresponds to a zone in which no tank to be assessed is located. Therefore, seismic risk is extremely low.
[b] E_2 - prominent type; Risk potential of liquid outflow is low and facility environmental risk is also low compared with a capacity of disaster preventability. Total risk seems to be very low.
[c] E_1,E_2 - prominent type; Although risk potential of oil outflow seems to be significantly high,capacity of preventability associated with the risk is considered to be sufficient. In addition, environmental risk is low.
[d] E_2,E_3 - prominent type; This category associates with a zone which has a low risk potential of liquid outflow. Environmental condition to prevent disaster spreadness is not so good. However, prevention facilities and systems are expected to be enough.
[e] Balance type(A); Evaluation of all three elements leads to be low. Although risk potential keeps to be low at the present, it is preferable to improve preventability and environmental condition against destructive earthquake disaster.
[f] Balance type(B); A zone categorized into this type corresponds to the industrial area where high risk huge facilities are located. Correspondingly, hardware and software prevention programs have to be carefully established in order to reduce hazard spreadness to surrounding area. Continual efforts for preparedness are also requested.

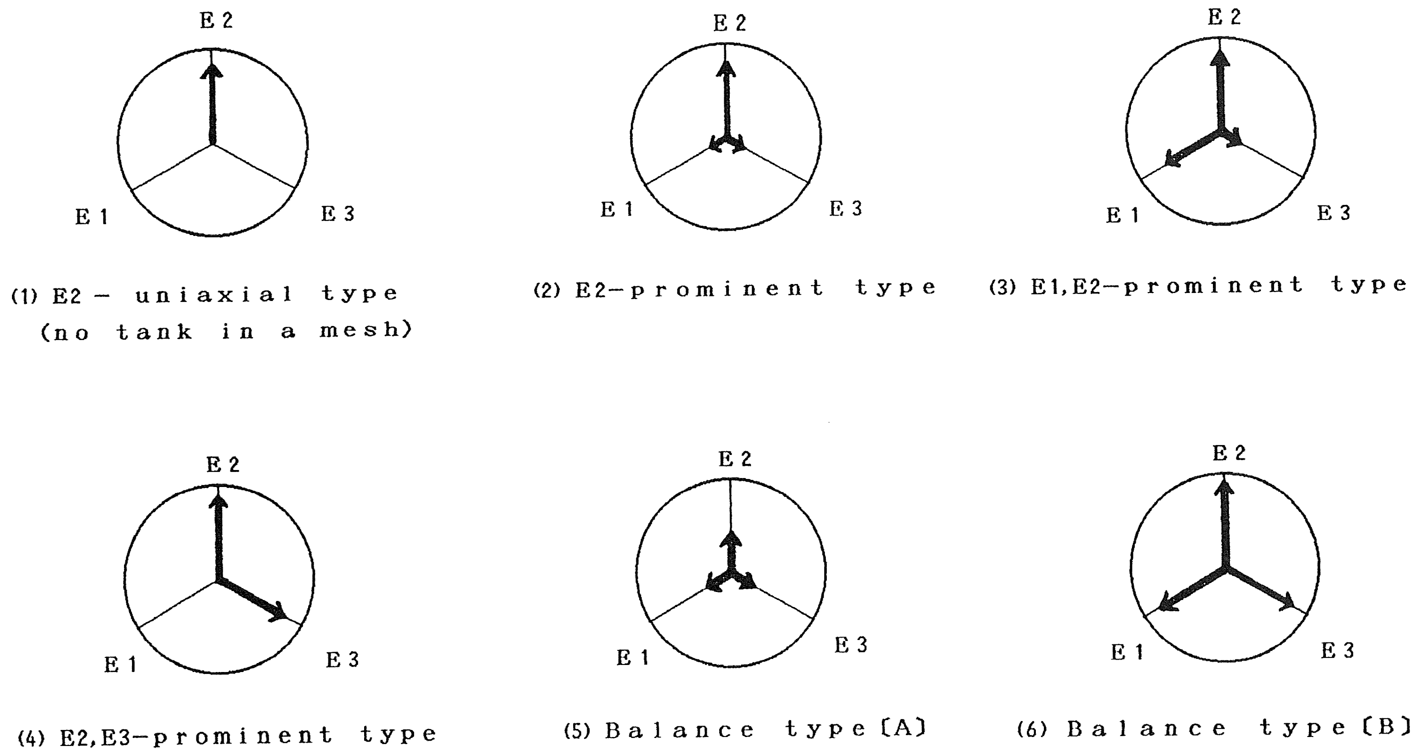

Fig. 1 THREE AXES REPRESENTATION OF SEISMIC RISK ASSESSMENT FOR INDUSTRIAL FACILITIES

EVALUATION OF THREE RISK ELEMENTS

In this section, conventional formulas which provide three components of seismic risk for the industrial facilities are given. And several factors forming these formulas are explained.

Potential Risk of Liquid Outflow

In order to evaluate E_1 , outflow factor α with respect to an individual tank should be calculated in advance by

$$\alpha = F \cdot Q \cdot (R + Y_1 + Y_2 + M + S + C) \quad (1)$$

In this equation, meaning and evaluation of every factor are explained as below;

[A] Material factor F is determined to present relative dangerousness for liquid content caused by spreadness. The determination of this factor is made by the criteria in the code and standard established so far by regulatory agencies.Actually, F is evaluated 1×10^{-5} through 0.05 in accordance with the designated classification based on degree of dangerousness and spreadness.
[B] Quantity factor Q means upper limit of fluid quantity capacity controled by the code. This value is determined taking into consideration the damage experienced in Nihon-kai-chubu earthquake 1983.
[C] Structural anti-seismic resistant factor R is evaluated by the inspection code for the existing storage tanks which was established by the regulatory agencies. This code requires several strength re-evaluation paying particular attention to checking points such as thickness of annular plate, anchor bolt strength, toughness of braces and columns and so on. This value is given alternatively 0 or 1 by judging results of inspection.
[D] Age factor Y_1 represents aging effect of the storage tank facility under inspection. Values can be given 0 through 0.2 according to the progress since foundation of the tank.
[E] By factor Y_2 , structural redundancy effect is taken into account. Facilities constructed based upon the improved design code or standard have been seemed to have redundant seismic strength compared with those constructed based upon earier code. This value provides the influence on seismic risk of facility.
[F] Environmental factor M assesses surrounding seismic countermeasure whereby attached piping, anchor bolt of base mat, bracing and liquefaction of foundation are inspected. The judgement is carried out according to the inspection code established by the prefectural government.
[G] Sloshing factor S provides relative evaluation of oil spill due to sloshing. By refering the damage experience at the 1983 earthquake of the floating roof type storage tank, upper limit of the value is determined to be 0.5 % of total amount of stored oil.
[H] Conventional formula (1) also includes uncertainty factor C giving some unexpected effect including fluctuation of seismic input level introduced to assessment.

Equation (1) is just provided for storage tank facility which is installed on the ground surface. In Japan, we have several tanks , in particular, will have in future, which are buried in the ground or frequently partially buried. For the evaluation for these cases, potential risk of liquid outflow into the periphery must be considerably reduced. Therefore, we have given the formula for these cases as below;

$$\alpha' = 0.5\alpha \quad ; \text{ for partially buried tank} \quad (2)$$

$$\alpha'' = F \cdot Q \cdot (Y_1 + Y_2 + C) \quad ; \text{ for competely buried tank} \quad (3)$$

After the evaluation of α, $\alpha'$and α'',potential risk E_1 due to storage tanks within the whole designated industrial area under assessment can be evaluated by

$$E_1 = \Sigma(\alpha + \alpha' + \alpha'') \quad ; \text{ for all facilities} \quad (4)$$

Seismic Disaster Preventability

As described previously, disaster preventability E_1 can be obtained by estimating E_A and E_B which associate with "hardware" preparedness and "software" preparedness respectively, and E_2 is given by equally evaluating both factors;

$$E_2 = 0.5E_A + 0.5E_B \quad (5)$$

In this program, E_A is estimated by averaging E_{Ai} which gives preventability for a particular i-th facility over total number of facilities located in the zone mesh under assessment. This E_{Ai} value can be given by

$$E_{Ai} = 0.7E_t + 0.3E_f \quad (6)$$

where E_t is the result through inspection for a particular facility and E_f is that for common facilities. Precise framework of the assessment procedure is shown in Fig. 2. Actually, assessment is carried out by using adequate inspection program provided by the regulatory agency.

On the other hand,"software" preparedness factor E_B is given by

$$E_B = E\,[0.8E_m + 0.2E_c] \quad (7)$$

in which E_m corresponds to preventability based on manpower and E_c does emergency command and communication systems.At the calculation of E_m , disaster prevention training and education are more seriously taken into account than the number of personnels for disaster prevention. However, at the evaluation of E_C ,contribution from command and communication facility and that from disaster preventive organization are equally evaluated.Detailed framework of this assessment is described as Fig. 3. Concrete assessment program for this step is provided as the form of checking list established by expert members in the Disaster Prevention Committee under the Kanagawa Prefectural Government.

Environmental Risk

Environmental risk E_3 is evaluated by

$$E_3 = \Sigma\,\{L \cdot N \cdot F \cdot Q \cdot \exp(\kappa P)\} \quad (8)$$

summarization is done for all facilities located within a designated zone under assessment. Parameters required for calculation of equation (8) are briefly explained as below;

- L ; factor of tank establishment mode whose value is given in accordance with a type of tank foundation i.e. on the surface, fully buried or partially buried
- N ; tank layout factor by which crowdness and occupation of storage tanks within a particular industrial zone under assessment are estimated
- F and Q ; material factor and quantity factor which have been proposed for the evaluation of E_1
- κ ; flammability factor whereby $\kappa = 1$ if content is flammable, and $\kappa = 0$ if it is inflammable
- P ; ignition factor by which effect of number and size of sparking tools such as electrical equipments is evaluated. This factor takes into consideration energy and spreadness of fire.

CONCLUSION FROM SYNTHETIC ASSESSMENT

By applying the methodology here proposed, synthetic assessment was carried out for representative three industrial complexes area existing in the Kanagawa Prefecture. After evaluating results through about 250 designated 500 m × 500 m mesh zones, 3 - axes representation was provided for all zones. From this particular investigation, about 90 % among all zones can be assessed to have sufficient preparedness and toughness against future destructive earthquake such as Kanto- and Tokai- expected earthquakes. Also, remaining zones are assessed not to be so risky, however, continuous disaster prevention planning has to be requested especially for these zones.

REFERENCES

1. Kanagawa Prefectural Government, Report on Earthquake Disaster Assessment in Kanagawa-ken, Special Report on Disaster Assessment to Oil Refinery Complex Area, (1986)
2. Salvaduray,G.,Earthquake Hazard Reduction Techniques at Petroleum Facilities in Japan, Proceed. 3rd U.S.National Conf. of Earthq. Eng'ng, vol.3,2119-2126,(1986)

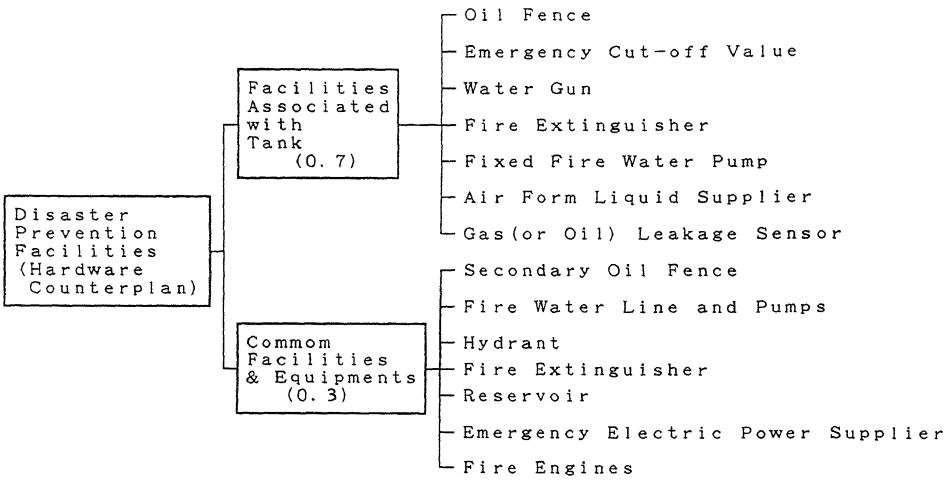

Fig. 2 FRAMEWORK OF ASSESSMENT OF "HARDWARE" DISASTER PREPAREDNESS

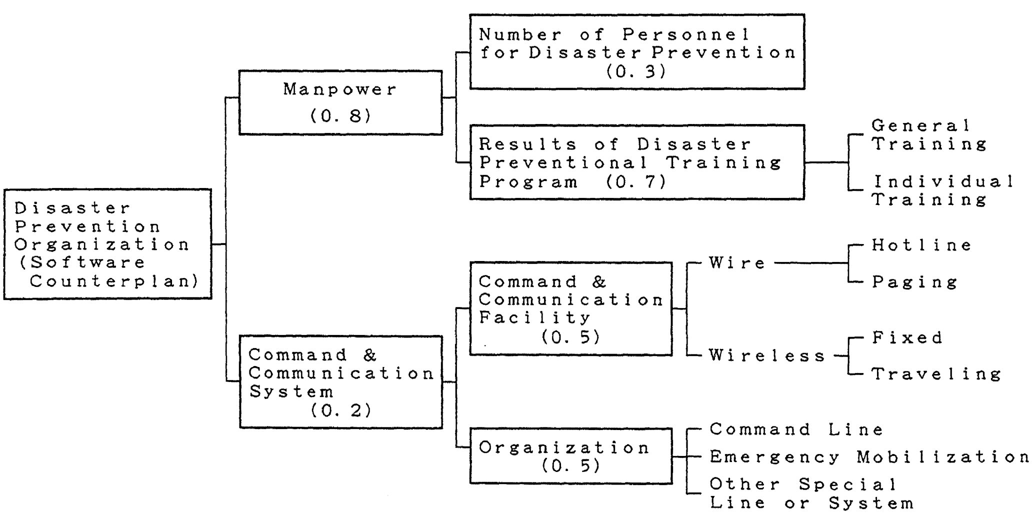

Fig. 3 FRAMEWORK OF ASSESSMENT OF "SOFTWARE" DISASTER PREPAREDNESS