EVALUATION OF SIMULTANEOUS FAILURE PROBABILITY FOR TWO QUAY WALLS IN DIFFERENT SITE CONSIDERING THE DISTANCE

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ABSTRACT :

A method to evaluate the failure probability of a quay wall under the condition that another quay wall was damaged by the earthquake is proposed. The shorter the distance of the two quay walls, the stronger correlation on the failure probability exists. And the simultaneous failure probability shall be increased. This is dependent not only on the locations of the two quay walls, but also on the locations of the faults. However, a simple parametric study enables to consider the correlation of failure probability at two sites. Thus the simultaneous failure probability of two quay walls can be evaluated using the proposed method. And the evaluated simultaneous failure probability can be a key index of port planning to avoid the disastrous situation such as the whole quay wall was damaged. As a conclusion, a simple procedure to evaluate the simultaneous failure of two quay walls was summarized to enable an efficient arrangement of earthquake-resistant quay walls comprehensively.

KEYWORDS: Quay wall, failure probability, port planning, conditional probability, lifeline

1. INTRODUCTION

The seismic design for quay walls is important since the functional loss of ports may cause a severe economic loss in a region. Furthermore, in the trend of 'Globalization', the possibility of port suspension due to an earthquake is a serious risk for an international industry which has a large amount of import/export cargos. In case the seismic hazard of the region is high, it is necessary to prepare some seismic resistant facilities to prevent the whole functional loss of the port.

The key point to consider the risk of port function is that not all facilities must be safe but the survival of a certain amount of facilities is enough to satisfy the requirement. This is different from other kind of lifeline facilities such as railways or expressways, since these shall be suspended even by a single but critical slope failure along the pass. In other word, the worst scenario for port is a simultaneous failure of multiple facilities, and a method to evaluate the possibility of the multiple failures is necessary. If the probability of the simultaneous failure can be evaluated, it is possible to make a reasonable port planning with the consideration of back-up facilities to avoid the worst situation.

If the failure of each quay wall is independent, the risk evaluation for such a worst situation is very simple. However, the failures are usually not independent. For example, if the two quay walls locate in neighborhood, it is easily imagined that the both quay walls damaged simultaneously in a same way.

In this research, as a first step, a simple procedure to evaluate the failure probabilities of multiple quay walls considering the correlation. A case study in Hiroshima area, Japan, is also introduced. Note, since this is only the first step, the procedure described in this paper is based on a very simple fragility curve approach (Ichii et al., 2004) and attenuation approach (Nozu et al., 1997). As a future study, some more modern style approach shall be included. In this case, the ground motions should be assessed by Green's function method considering site response characteristics and the probability of failure should be evaluated by effective stress based FEM. Detailed fault parameters such as the location of the asperities also should be considered.

2. AN EXAMPLE OF THE PROBLEM TO BE SOLVED

Hiroshima bay locate in western part of Japan, and this area is a hometown of some international industry (i.e. Mazda). Therefore, the function of quay walls in this area has an important role for the world economy.

The large-scale quay walls in this region (Length of 240 m or more and depth of 10 m or more, which corresponds to the ship size of approx. 20,000GT) locate at 4 sites, Hatsukaichi, Itsukaichi, Ujina and Kure. As same as other sites in Japan, this area is also anticipated to be attacked by some earthquakes in near future. One of the most severe earthquakes to be expected is an intra-plate type earthquake at the sea side. The probability of the occurrence of a large earthquake (M6.7~7.4) in coming 30 years is evaluated as 40% (HP1). The possible source location and the locations of 4 sites are summarized in Fig. 1. The hatched quadrangle (abcd) is the region of the possible source location.

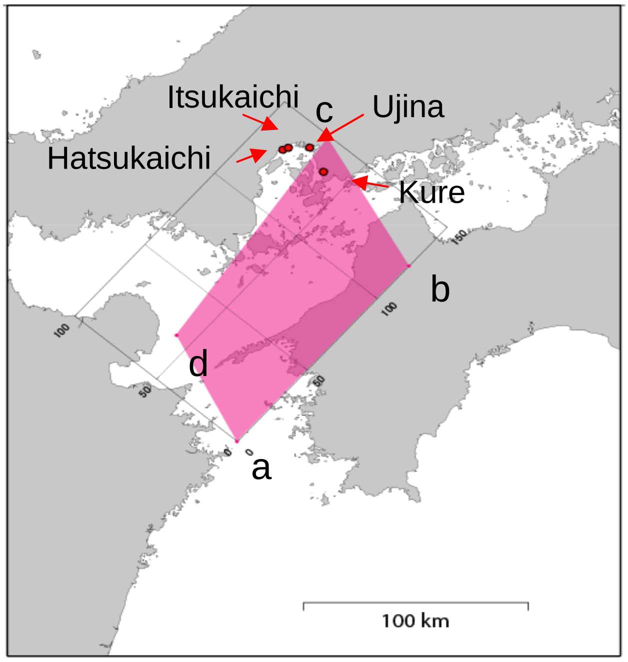

Fig.1 The location of possible earthquake source (abcd) and targeted quay walls

For the regional economy, it is very important to maintain the import/export function of port. Therefore, at least one of these 4 quay walls should be survived after the earthquake. In other word, the worst scenario is that those 4 quay walls simultaneously damaged in the earthquake. And the target of the study is to assess the probability of the worst scenario in a reasonable way.

3. A SIMPLE MODEL AND TEST RESULTS

3.1 A simple procedure to evaluate the probability of failure

As a simple example model, let us assume that the source of the earthquake will be in the region of large L by L square shown in Fig.2. The magnitude is fixed as M6.5, and the probability of source location uniformly distributed in the square. The earthquake must occur once, but only once, in the expected time range. There are two facilities to be considered. Facility A locate at the center of the region, and the location of facility B varies.

As the first step, the possible region divided into small meshes (N by N) as shown in Fig.2. In this case, the region is divided into total 16 small meshes (4 by 4). As a simplification, the possible source can only locate at the center of the mesh, C_i.

The probability of the earthquake occurred at i-th mesh, G_i, is proportional to the area of the i-th mesh. Thus, following equation can be given.

$$G_i = \frac{1}{N^2} \tag{3.1}$$

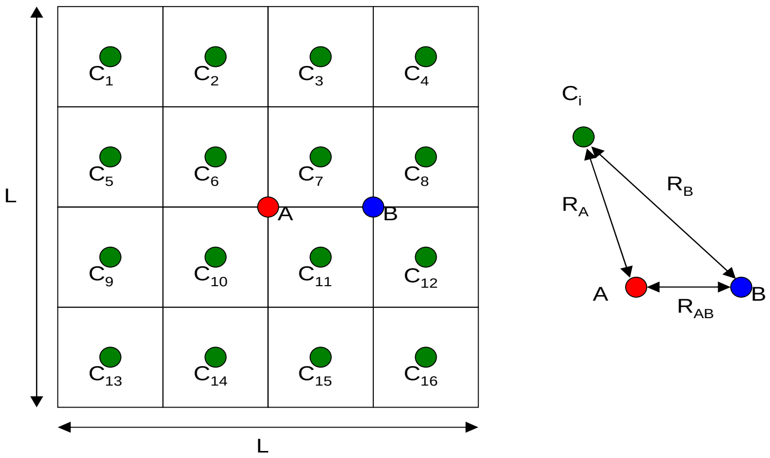

Fig.2 The simple model for the failure probability evaluation for A and B

When the earthquake occurred at i-th mesh, the distance between the source C_i and A is R_A, the distance between the source C_i and B is R_B, and the distance between A and B is R_{AB}. The peak acceleration at A can be given by an attenuation relationship (Nozu et al., 1997).

$$\log_{10} A_{COR} = 0.55M - \log_{10}\left(R_A + 0.005 \cdot 10^{0.55M}\right) - 0.00122 R_A + 0.502 \tag{3.2}$$

Note, A_{COR} is the estimated peak acceleration, R_A is the distance from the fault, M is the JMA magnitude.

The probability of failure for A, $f_i(A)$, can be evaluated by the fragility curve approach.

$$f_i(A) = \Phi[Z] = \int_{-\infty}^{Z} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz \tag{3.3}$$

Note, Z is the parameter given by the following equation, and parameter c = 414.8, ζ = 0.45 were used in this paper. This is corresponding to the situation of gravity-type wall with caisson's aspect ratio of 0.9, equivalent SPT-N values of 10, thickness of the sand deposit below the caisson is a half of the caisson height, and expected damage is degree III (Ichii, 2004).

$$Z = \ln\left(A_{\max}/c\right)/\varsigma \tag{3.4}$$

Thus, the probability for the situation that the source locate in i-th mesh and facility A is failed, $P_i(A)$, can be given by the multiplication of G_i and fi(A).

$$P_i(A) = f_i(A) \times G_i \tag{3.5}$$

$$P_i(B) = f_i(B) \times G_i \tag{3.6}$$

Since the proposed fragility curve can consider the difference of the geotechnical site condition and the difference of structure shape, it can be regarded that the estimated failure probability is almost independent. Therefore, the simultaneous failure probability for A and B can be given by a simple multiplication.

$$P_i(A\cap B) = f_i(A)\times f_i(B)\times G_i \tag{3.7}$$

The next step is the case when the location of the source is unknown. In this case, the probability of failure for A can be given as the summation of the $P_i(A)$. This is based on the total probability theorem.

$$P(A) = \sum\{f_i(A)\times G_i\} \tag{3.8}$$

$$P(B) = \sum\{f_i(B)\times G_i\} \tag{3.9}$$

This is same for the simultaneous failure probability.

$$P(A\cap B) = \sum\{f_i(A)\times f_i(B)\times G_i\} \tag{3.10}$$

Therefore, the conditional probabilities are also can be estimated as follows.

$$P(A|B) = \frac{P(A\cap B)}{P(B)} \tag{3.11}$$

$$P(B|A) = \frac{P(A\cap B)}{P(A)} \tag{3.12}$$

3.2 Example of evaluated probability: the distance of the two sites

The effect of the distance between two sites on the evaluated probability is examined for 3 simple cases shown in Fig.3. The fault (possible source location) is assumed to be square with L = 100, 200, 400 km. The site A locate at the center of the fault, and the site B move toward the right side of the fault.

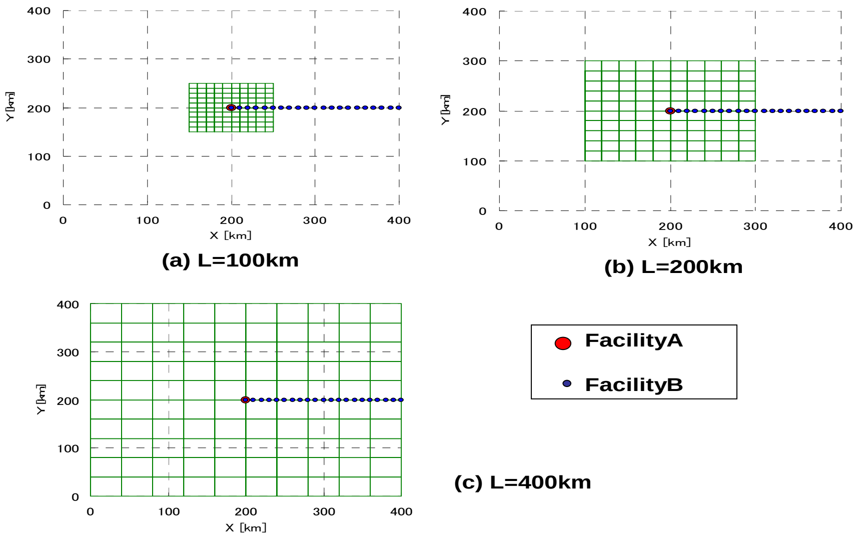

Fig.3 Models for simplified cases with different distance between A and B

The evaluated failure probability for A and B, the conditional probability of failure A when B failed, and the conditional probability of failure B when A failed were summarized in Fig.4. These probabilities are corresponds to P(A), P(B), P(A|B) and P(B|A) in the figure, respectively. P(A) is always constant. However, P(B) decrease when R_{AB} increase. The conditional probability is also not constant. It indicates the failure probability of A and B is not independent. And the correlation of failure A and failure B is strongly dependent on the distance of A and B.

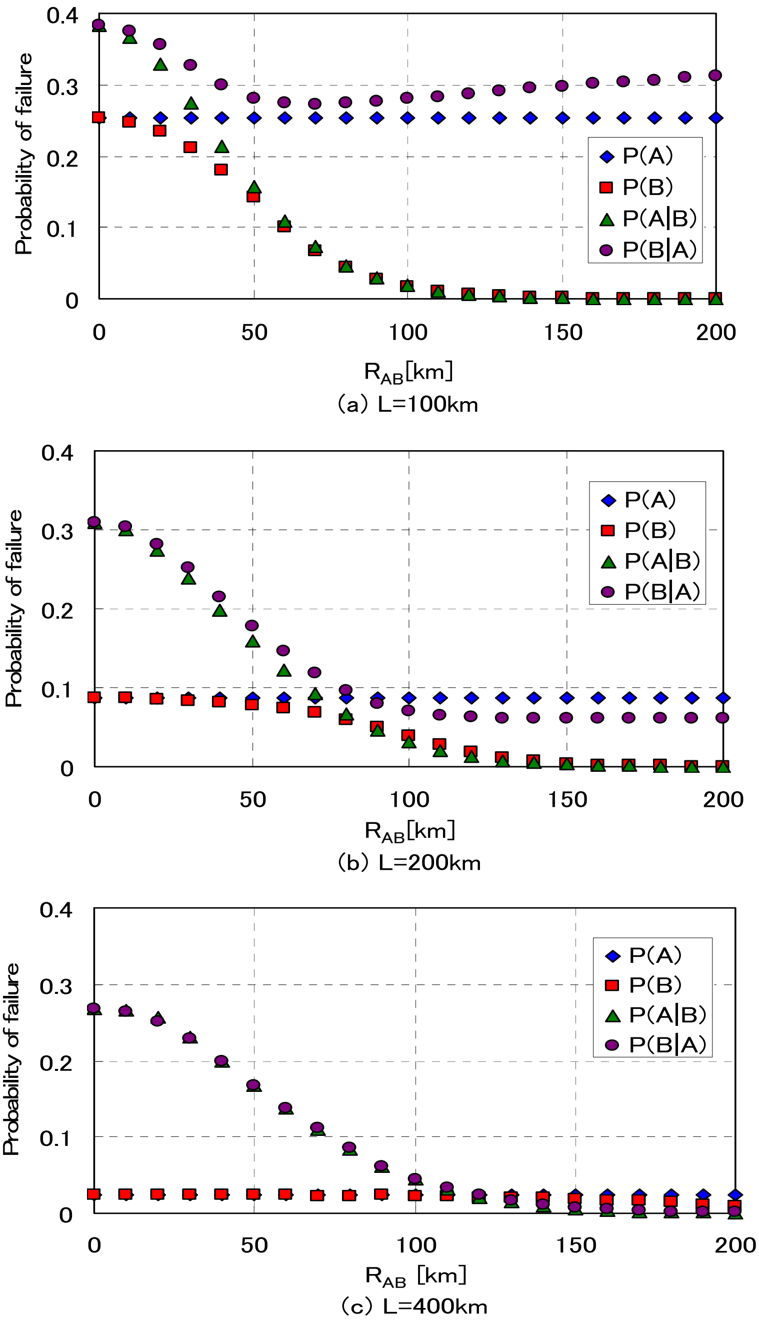

Fig.4 Evaluated probability of failure dependent of the distance between A and B

As a simple conclusion, the simultaneous failure probability can be given as shown in Fig.5. This is for the case of L = 400 km. If the R_{AB} is small, P(A)P(B|A) is larger than P(A)P(B). This means that the failure of A and B is strongly correlated. However, for the large R_{AB}, P(A)P(B|A) is smaller than P(A)P(B). This means that the failure of A and B is negatively correlated, and the facility B can be work as a back up of facility A.

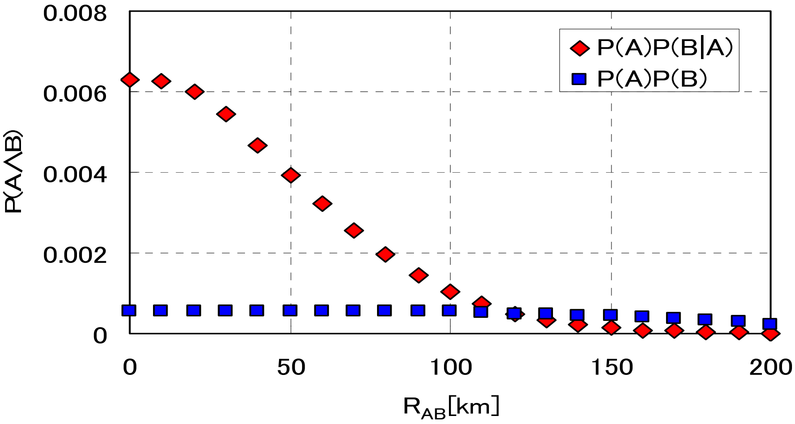

Fig.5 Probability of simultaneous failure for A and B

4 A CASE STUDY FOR HIROSHIMA BAY

The failure probabilities of 4 quay walls in Hiroshima bay, which are already introduced in Fig.1, are examined as a case study. The possible source region is divided into 100 small triangular meshes as shown in Fig.6. Although square meshes were assumed in the procedure above, similar calculations can be applied with the triangular meshes.

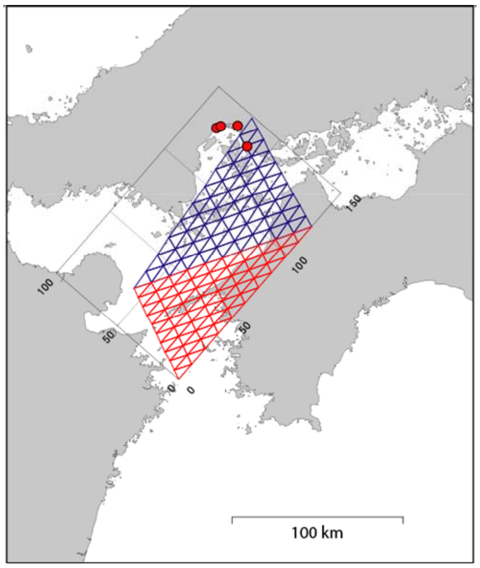

Fig.6 Meshes of possible earthquake source location on the fault

The detailed location of 4 quay walls is summarized in Fig.7. Since all quay walls locate in a small region around the north corner of fault, it is easily understood that the failures of these quay walls are strongly correlated. The problem is how quantify estimate the strong correlation of failures. The targeted time range is assumed as 30 years, and the possibility of earthquake occurrence is 40 % based on the historical data. Magnitude is assumed to be between 6.7 and 7.4, and its probability is uniformly distributed in this range.

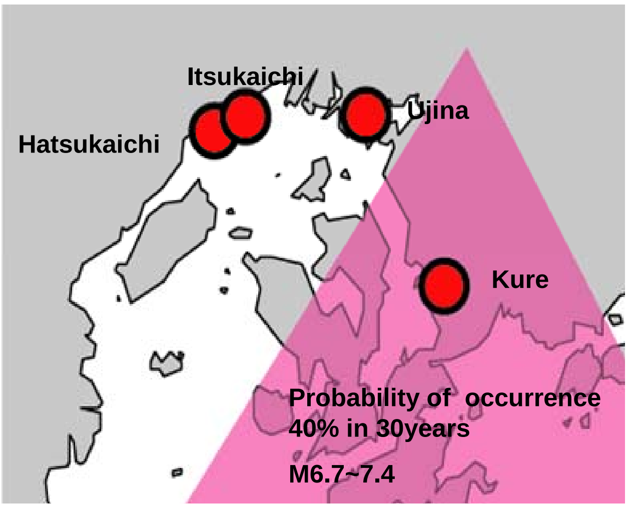

Fig.7 The detailed location of targeted quay walls and the fault

The calculated failure probability for each facility is summarized in Fig.8. Since the Kure site locates inside the fault, the failure probability is most significant. The simultaneous failure probabilities of Hatsukaichi site and other site are summarized in Fig.9. The results obtained by the proposed method and the results of the case where the correlation is neglected are compared. It proved the instinct feeling that the failures of these quay walls are strongly correlated.

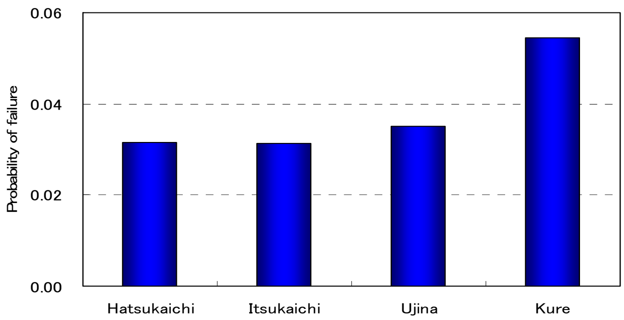

Fig.8 Probably of failure for each qua wall

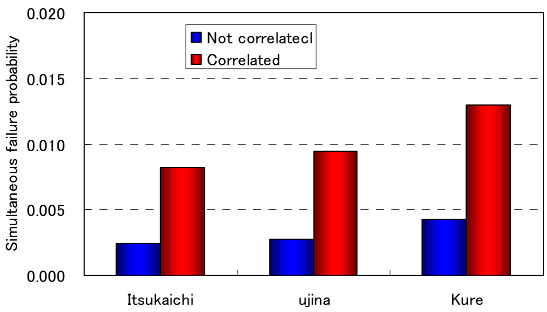

Fig.9 Probability of simultaneous failure for Hatsukaichi and other quay walls

The final results can be given as shown in Fig.10. This is the simultaneous failure probability of these quay walls. The worst disastrous scenario where all quay walls lost its function is about 5%. And what is most important is that the real probability for the worst case is almost 10 times more than the estimated probability of the worst case without considering the correlation. Therefore, the consideration of the correlation is very important for the realistic risk evaluation.

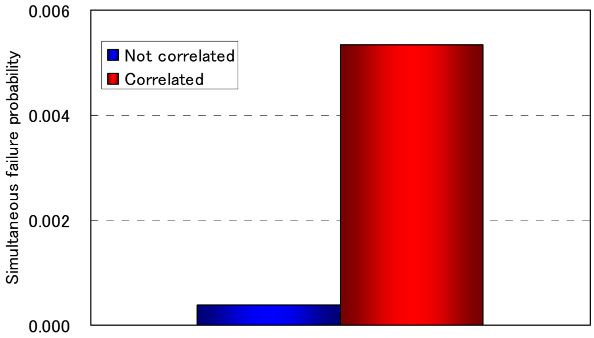

Fig.10 Simultaneous failure probability of whole quay walls with and without considering the correlation

5 CONCLUSIONS

A simple procedure to evaluate the failure probabilities of multiple quay walls considering the correlation is proposed. And the proposed method is applied to an example case study of Hiroshima bay. The major conclusions are as follows.

(1) A simple model clarifies that the correlation of failure A and failure B is strongly dependent on the distance of A and B. If the distance is small, the failure of A and B is strongly correlated. However, if the distance is large compared to the fault size, the failure of A and B is negatively correlated, and the facility B can be work as a back up of the facility A.
(2) Even a quite simple model with an attenuation relationship and the fragility curves can quantify the correlation of multiple failures.
(3) A case study in Hiroshima bay reveals that the simultaneous failure probability can be highly underestimated if the correlation is not considered.

For the future study, some more modern style approach shall be included. In this case, the ground motions should be assessed by Green's function method considering site response characteristics and the probability of failure should be evaluated by effective stress based FEM. Detailed fault parameters such as the location of the asperities also should be considered.

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