# A SIMPLE EVALUATION METHOD FOR EARTHQUAKE DAMAGE TO THE QUAY WALLS

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**ABSTRACT :**

In Japan, a lot of reclaimed lands had been constructed for port and industry facilities since the head of the 20th century. A reclaimed land is generally composed of both the quay walls and the backyard ground. A key of the seismic safety of reclaimed lands is sustainability of the quay walls. A simple evaluation method for earthquake damage to the quay walls has been constructed empirically based on actual earthquake damage by such the past earthquakes as 1995 Hyogo-ken Nanbu and other moderate magnitude earthquakes. This method is limited to be applied in order to pick up the weak quay walls with less seismic performance.

**KEYWORDS:** quay wall, earthquake damage, sand liquefaction, evaluation method, PGV

## 1. INTRODUCTION

A lot of the quay walls which locate alongshore on reclaimed land having the important port and industry facilities have not sufficient seismic performance, because they were constructed in the old age.
During 1995 Hyogo-ken Nanbu earthquake, many gravity quay walls suffered heavy damage as shown in Figure 1 and Figure 2.

Figure 1 Large seaward displacement of quay

Figure 2 Large settlement of backyard ground

Representative damage to gravity quay walls involves large seaward displacement and settlement with the value of several meters accompanying large settlement of backyard grounds caused by liquefaction of backfill sand.
It is known that the shaking even with the JMA seismic intensity scale V did damage to the quay walls in the past earthquake.
When the port facilities like the quay walls suffer heavy damage and the access route to damaged area from the sea is cut off, such restoration resources as water, food, medical materials and equipments can not be conveyed smoothly just after earthquake attack. So, it is quite important thing that sufficient seismic performance is guaranteed to the quay walls. In addition, it is pointed out that a simple evaluation method of earthquake damage to the quay walls is necessary in order to pick up efficiently the weak quay walls with less seismic performance, because several types of the quay walls spread alongshore with long distance and cross the various ground conditions.

In this paper, a simple evaluation method of earthquake damage to the quay walls has been proposed based on actual earthquake damage by such the past earthquakes as 1995 Hyogo-ken Nanbu earthquake and other recent moderate magnitude earthquakes.

## 2. A SIMPLE EVALUATION METHOD

Figure 3 shows the flow of evaluation of earthquake damage to the quay walls by this method considering the damage level as horizontal seaward displacement D at the top of the quay walls as shown in Figure 4. Major parameters used for evaluation are quay walls structural types, peak horizontal ground velocity PGVs on backyard ground surface, thickness of liquefied backfill sand in backyard ground, liquefaction potentiality of the substitution sand mat beneath the quay walls. Two structural types are considered, one is gravity type and another is steel sheet pile type.

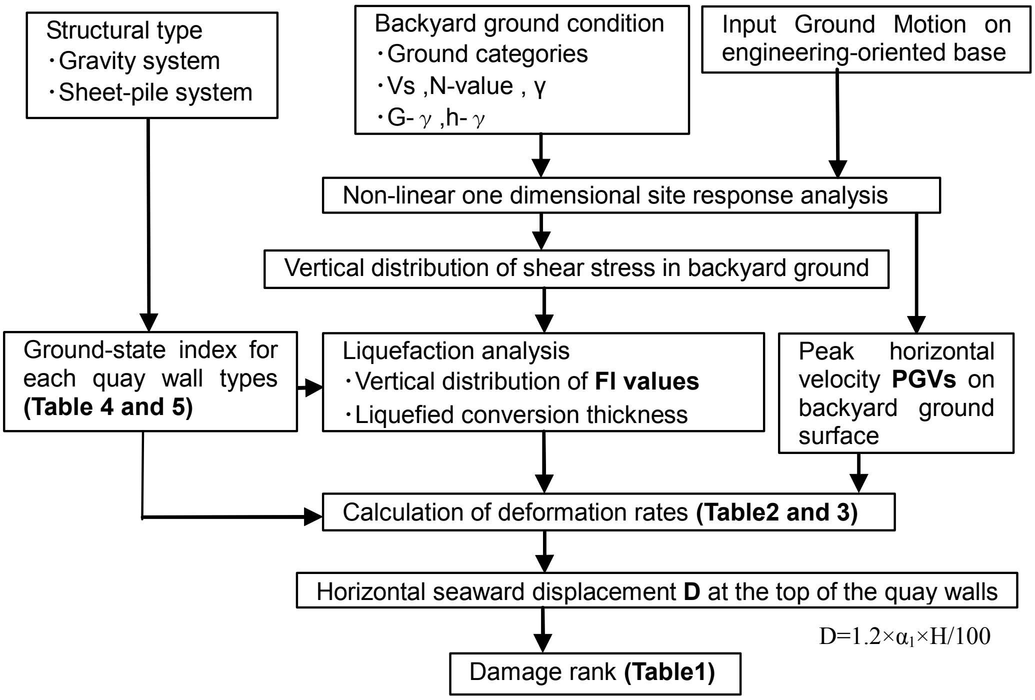


Figure 3 Flow of evaluation for earthquake damage to the quay walls

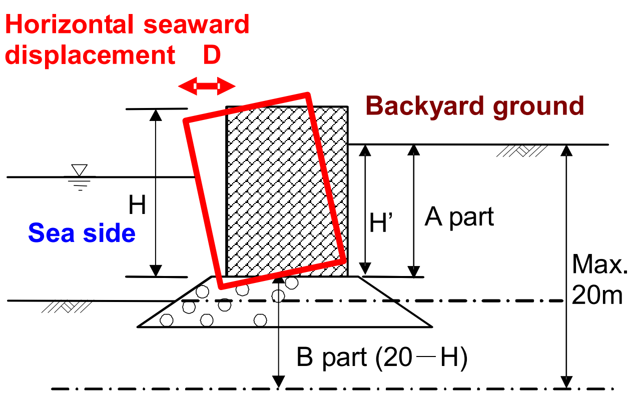


Figure 4 Definition of horizontal seaward displacement D

If all parameters are same condition except structure types, evaluated damage of sheet pile type is slightly heavier than gravity type.
For determination of PGVs, non-linear one dimensional site response analysis is used to be conducted referring the boring log data of backyard ground.
Liquefaction analysis of Specification for Highway Bridge (2002) is adopted to estimate the thickness of liquefied backfill sand using vertical distribution of shear stress by above-mentioned non-linear one dimensional site response analysis. The thickness of liquefied backfill sand is defined as total thickness of sub layers with FL value of less than 1.0.
If we can not get the physical properties of the substitution sand on site, those of the Port island and the Rokko island are used where the substitution sand was experienced liquefaction during 1995 Hyogo-ken Nanbu Earthquake, with N value from 5 up to 15.

Table 1 shows the damage rank by D on the point of restoration.

Table 1 Damage rank of the quay walls

| D(cm) | Damage rank | Damage state |
|---|---|---|
| 0 | 0 | No damage |
| 0 - 25 | Ⅰ | A little repair |
| 25-70 | Ⅱ | Considerably damaged |
| 70-200 | Ⅲ | Heavily damaged |
| more than 200 | Ⅳ | Collapse |

Eqn. 1 is used to calculate horizontal seaward displacement D (cm) and deformation rate (%).

$$D=1.2\times\alpha_1\times H/100 \qquad (1)$$

Here, $\alpha_1$: Final deformation rate (%),
H : Quay wall height (cm),
$\alpha_0$: Initial deformation rate (%).
The factor of 1.2 expresses the safety factor covering uncertainty of ground information.
Observed deformation rate $\alpha$ from actual damage is defined as $D/H\times100$ (%).

Table 2 represents the relationship between deformation rate $\alpha_1$ and $\alpha_0$ for each ground-state index.

Table 2 Final deformation rate $\alpha_1$

| Ground-state index | Final deformation rate $\alpha_1$ (%) |
|---|---|
| Ⅱ G−1, Ⅲ G, Ⅱ S−1<br>Ⅱ S−4, Ⅲ S | B: Thickness of liquefied total soil layer<br>B＜2m : $\alpha_1=0.5\times\alpha_0$<br>2m≦B＜5m : $\alpha_1=0.8\times\alpha_0$<br>5m≦B : $\alpha_1=1.5\times\alpha_0$ |
| Ⅰ G, Ⅱ G−2, Ⅰ S−1<br>Ⅰ S−2, Ⅱ S−2, Ⅱ S−3 | $\alpha_1=\alpha_0$ |

$\alpha_0$ is determined from the relationship between ground-state index and peak horizontal ground velocity PGVs (cm/s) on backyard ground surface shown in Table 3.
Table 4 and 5 show the ground-state index for gravity type and sheet pile type respectively which represent the relationship between liquefaction potentiality and its areas of backyard ground. C Part in Table 5 shows anchor of tie rod of sheet pile type. Ground condition of C part is considered, too.

Above all parameters are calibrated and constrained to actual earthquake damage data from such the past earthquakes in Japan as 1968 Tokachi-oki, 1973 Nemuro-hanto-oki, 1983 Nihonkai-chubu, 1993 Kushiro-oki, 1993 Hokkaido-Nansei-oki, 1995 Hyogo-ken Nanbu.

Table 3 Initial deformation rate $\alpha_0$

| Ground-state index | PGVs＜10 | 10≦PGVs＜25 | 25≦PGVs＜50 | 50≦PGVs＜100 | 100≦PGVs |
|---|---|---|---|---|---|
| Ⅰ G | 0 | 0.1×PGVs | | | 10 |
| ⅡG−1･ⅡG−2 | 0.2×PGVs | | | | 20 |
| ⅢG | 0.4×PGVs | | | | 40 |
| ⅠS−1･ⅠS−2 | 0 | 0 | 0.2×PGVs -5 | | 15 |
| ⅡS−1･ⅡS−2 | 0 | 0.2×PGVs -2 | 0.48×PGVs -9 | 0.1×PGVs +10 | 20 |
| ⅡS−3･ⅡS−4 | 0 | 0.4×PGVs -4 | 0.96×PGVs -18 | 0.2×PGVs +20 | 40 |
| ⅢS | 0 | PGVs -10 | 1.4×PGVs -20 | 0.5×PGVs +25 | 75 |

Table 4 Ground-state index for gravity type

| | Total thickness of FL≦1.0 sublayers | |
|---|---|---|
| | Less than1/2×H' | More equal to 1/2 ×H' |
| FL＞1.0 (Non liquefaction) | Ⅰ G | ⅡG−2 |
| FL≦1.0 (Liquefaction) | ⅡG−1 | ⅢG |

Table 5 Ground-state index for sheet pile type

| | | Total thickness of FL≦1.0 sublayers | |
|---|---|---|---|
| | | Less than 1/2 ×H' | More equal to 1/2 ×H' |
| FL＞1.0 | Rigid anchor structure and Non liquefaction in C part | Ⅰ s−1 | Ⅱs−2 |
| | Weak anchor structure and Liquefaction in C part | Ⅰ s−1 | Ⅱs−3 |
| There is the part of FL≦1.0 | Rigid anc hor structure and Non liquefaction in C part | Ⅰ s−2 | Ⅱs−4 |
| FL≦1.0 (Thickness less than 2m) | Weak anchor structure and Liquefaction in C part | Ⅰ s−1 | Ⅱs−3 |
| FL≦1.0 (Thickness more equal to 2m) | | Ⅱs−1 | Ⅲs |

## 3. VERIFICATIONS

Figure 4 shows comparison of D values between Observed values of previous 5 earthquakes except 1995 Hyogo-ken Nanbu earthquake and Evaluated values by proposed evaluation method. D values were caused by the maximum excitation of the JMA seismic intensity scale V. D scatters with small values, however Evaluated D values are proportional to Observed D values.

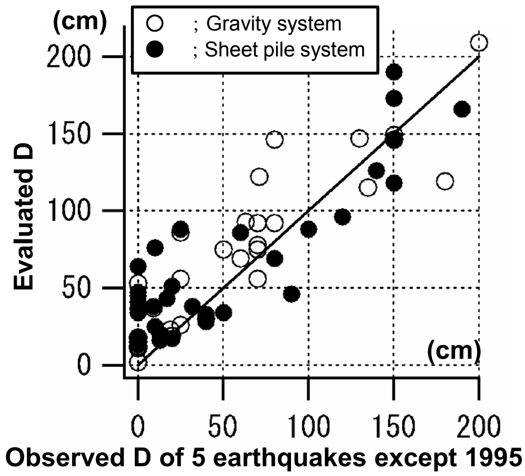


Figure 4 Comparison between Observed and Evaluated D

Figure 5 presents comparison of α value between Observed one of 1995 Hyogo-ken Nanbu earthquake and Evaluated one.

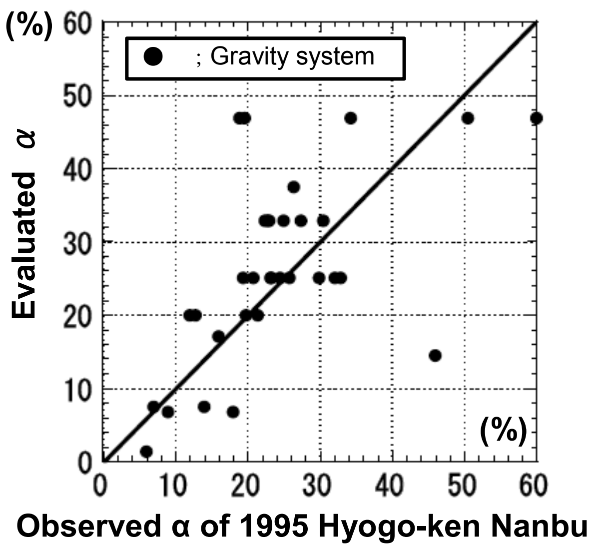


Figure 5 Comparison between Observed and Evaluated α

α values were caused by the maximum excitation of the JMA seismic intensity scale VI, where Observed D values ranged from 1.5 to 6.0 meters. Evaluated α values have good agreement with Observed D values.
It has been assured that proposed a simple evaluation method in this study has appropriate accuracy for picking up the weak quay walls with less seismic performance.

## 4. CONCLUSION

A simple evaluation method for earthquake damage to the quay walls has been proposed here based on actual damage data from 1968 Tokachi-oki, 1973 Nemuro-hanto-oki, 1983 Nihonkai-chubu, 1993 Kushiro-oki, 1993 Hokkaido-Nansei-oki, 1995 Hyogo-ken Nanbu earthquakes in Japan.

Evaluated D or α value by this proposed simple evaluation method show good accordance with Observed D or α value.
This proposed simple evaluation method is very useful for picking up the weak quay walls with less seismic performance effectively.
After screening the weak quay walls with less seismic performance, immediately, we can discuss the efficient counter measures through the earthquake response analysis and the large-scale shaking table tests and the centrifuge test, based on structural types of the quay walls and precise ground conditions and seismic intensity on specific site.
Most important things are to accumulate the actual reliable damage data in the future earthquakes, to keep doing the verification and improving an evaluation method by them.

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