

## **ANALYTICAL STUDY ON GEOTEXTILE-REINFORCED SOIL RETAINING WALLS DAMAGED DURING THE 2004 MID NIIGATA PREFECTURE JAPAN EARTHQUAKE**

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**ABSTRACT:** This paper reviews in brief case histories on the seismic performance of geotextile-reinforced soil retaining walls during the 2004 Mid Niigata Prefecture Earthquake. In addition, by comparing the results of calculations of suitability of these walls based on current design methods with seismic performance of each of structures during the 2004 Mid Niigata Prefecture Earthquake, the applicability of current seismic design to performance-based design is also shown.

**Keywords:** Reinforced Soil Retaining Wall, 2004 Mid Niigata Prefecture Earthquake, Performance-based Design

### **INTRODUCTION**

It is presumed that geotextile-reinforced soil retaining walls that have had their seismic stability assessed by means of safety factors contained in current seismic design methods<sup>1)</sup> have a high seismic performance. However, it would be more rational and economical if their seismic stability was assessed based on the seismic performance required to withstand a strong earthquake. In order to enable the rational design of these walls, it is first necessary to thoroughly understand the problems in the current seismic design methods.

In this paper, case histories on the seismic performance of geotextile-reinforced soil retaining walls during the 2004 Mid Niigata Prefecture Earthquake are reviewed in brief. In addition, by comparing the safety factor of geotextile-reinforced soil retaining walls damaged by the 2004 Mid Niigata Prefecture Earthquake, calculated based on current seismic design methods, with seismic performance of each of the structures studied in this paper, the applicability of current seismic design to performance-based design is investigated.

### **REVIEW OF CASE HISTORIES**

Geotextile-reinforced soil retaining walls, which are the objects of this study, are located in 25 locations within 30 kilometer of the epicenter of the 2004 Mid Niigata Prefecture Earthquake, as shown in Fig. 1. Although five of the reinforced soil retaining walls (plotted in black in Fig. 1) at these 25 locations suffered damage severe enough to influence the road traffic function, serious damage—such as a reinforced soil

retaining wall losing its integrity and collapsing—did not occur. Simplified plans of three reinforced soil retaining walls labeled (a), (b) and (c) in Fig. 1, which suffered damage that influenced road traffic functions, are shown in Fig. 2 as (a), (b) and (c), respectively.

Reinforced soil retaining wall (a) suffered the most damage of any of the walls in this study. Its crest settled along the boundary between the original slope and the embankment. Although reinforced soil retaining wall (b) itself was not seriously deformed, its raising embankment deformed, crack could be seen at its crest, and liquefaction occurred in its foundation ground. Damage to reinforced soil retaining wall (c) was very slight—a crack occurred between the original slope and the embankment—and no deformation could be seen in the wall itself. Damage to the fourth and fifth reinforced soil retaining walls was also very slight, limited to small cracks or settlement occurring at their crests, and no large-scale deformation of the walls themselves could be seen.

### **METHODOLOGY OF CASE ANALYSIS**

In this study, the estimated maximum acceleration that affected each reinforced soil retaining wall during an earthquake, the critical design seismic coefficient, and the design safety factor were all compared with the level of earthquake-induced damage in each structure.

The estimated maximum acceleration and the level of earthquake-induced damage for each structure are also shown in Fig. 1. Estimated maximum acceleration was determined based on results of Suetomi et al. (2002)<sup>2)</sup>. Earthquake-induced damage level was classified into six

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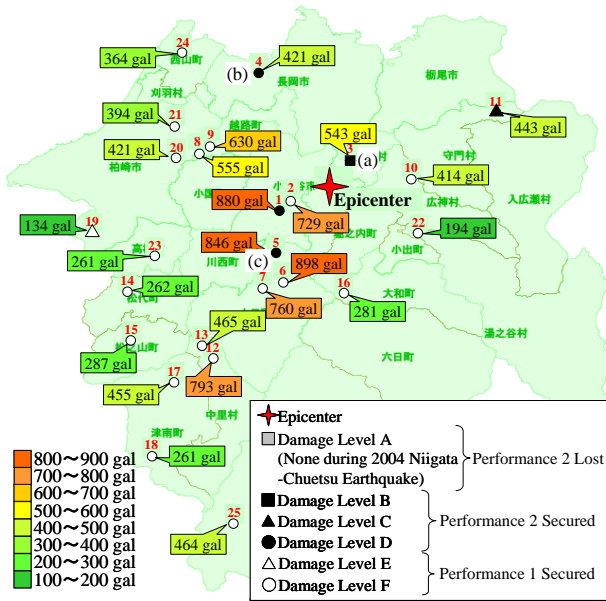


Fig. 1 Outline of cases that are objects in this study categories, as shown in Table 1, based on the influence

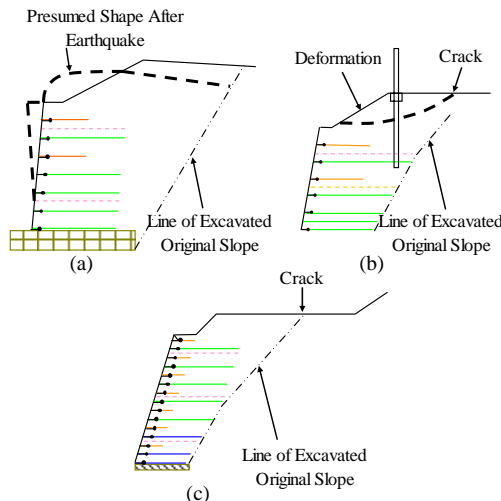


Fig. 2 Simplified plans of geotextile reinforced soil retaining walls

the structure had on the road traffic function following damage sustained during an earthquake, as shown by Onodera et al. (2005, 2006)<sup>3)</sup> and <sup>4)</sup>. For example, the damage level of reinforced soil retaining wall (a) shown in Fig. 1 and Fig. 2 was determined as Damage Level B, because although earthquake-induced damage to the wall impeded the road traffic function, it was possible to restore it in a short period of time. As for defining the seismic performance of reinforced soil walls as shown in Table 2, this means that Damage Levels B, C and D secure the Seismic Performance Level 2, and Damage Levels E and F secure the Seismic Performance Level 1.

The critical design seismic coefficient and the design safety factor were calculated based on the circular arc method in the investigation of general stability shown in the current manual of design<sup>1)</sup>—although the mode of deformation in actual phenomena does not always coincide with that supposed in the circular arc method.

Critical design seismic coefficient calculated is a design seismic coefficient that makes a minimum safety factor of 1.0. The design safety factor was calculated using design seismic coefficient  $k_h=0.13$  (Zone B, Ground Type I, Large Earthquake Ground Motion) as a safety factor during earthquakes. The soil and ground parameters used were, in principle, those that had been used in design or determined by considering the property of the soil and ground based on the current manual of design<sup>1)</sup>. However, there are several reinforced soil retaining walls that have, as a result of calculation, a safety factor, even in ordinary conditions, of less than 1.0. In making calculations for these walls, cohesion was considered as making the safety factor 1.2 under ordinary conditions.

Table 1 Definition of Damage Level (Onodera et al.<sup>3), 4)</sup>

A: Road traffic function is lost, and a long time is required to restore it.
B: Road traffic function is lost, but it can be restored in a short time.
C: Emergency vehicles can use road, and it can be restored in a short time.
D: General vehicles can use road, and it can be restored in a short time.
E: Usual traffic function can be secured, and road can be restored by ordinary maintenance and repair.
F: No influence.

Table 2 Definition of Seismic Performance

Seismic Performance	Seismic Serviceability Design	Seismic Emergency Repairability Design
Seismic Performance Level 1: Keeping the sound functions	To ensure the normal functions	No repair work is needed to recover the functions
Seismic Performance Level 2: Limited damages and recovery	Capable of functions within a short period after the event	Capable of recovering functions by emergency repair works
Seismic Performance Level 3: No critical damages	-	-

## RESULTS OF CASE ANALYSIS

Fig. 3 shows the relationship between damage level and design safety factor against an earthquake ground motion ( $k_h=0.13$ ). There are several reinforced retaining walls that have a design safety factor against earthquake ground motion of less than 1.0. However, all the reinforced soil retaining walls that are the objects of this study could secure a seismic performance of 2, although some of them could not secure the Seismic Performance Level 1. In addition, the correlation between damage level and safety factor cannot be seen clearly in the causes of the differences in seismic ground motion having affected said structures and other objects. Therefore, below looking into the relationship among estimated maximum acceleration affecting reinforced soil walls, critical design seismic coefficient and seismic performance level, seismic coefficients that should be considered in performance-based design is investigated.

Fig. 4 shows the relationship between estimated maximum acceleration  $a_{max}[\text{gal}]$  and the critical design

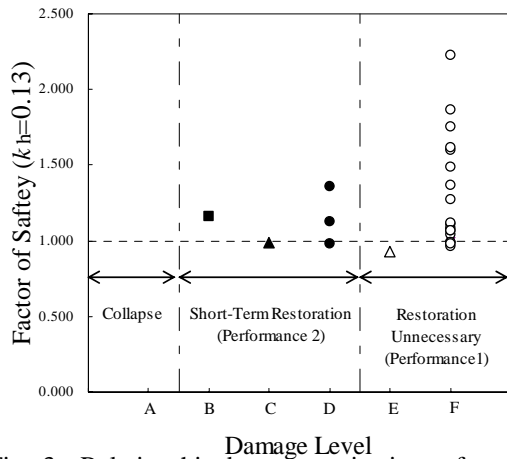


Fig. 3 Relationship between seismic performance level and safety factor

seismic coefficient calculated based on the current design method. This means that plots under the broken line in Fig. 4 were affected by stronger seismic ground acceleration than that converted from the critical design seismic coefficient. The minimum critical design seismic coefficient of reinforced soil retaining walls affected by seismic ground motion with a maximum acceleration of approximately 200 gal is approximately 0.095, and the minimum critical design seismic coefficient of reinforced soil retaining walls affected by seismic ground motion with a maximum acceleration of approximately 800 gal is approximately 0.109. Because all the walls in this study secured the Seismic Performance Level 1 or 2, it can be said that the design seismic coefficient of 0.12 to 0.16 considered in the current design method for reinforced soil retaining walls (and which is the same value as that for concrete retaining walls) is a safer value for a seismic coefficient used for the assessment of the Seismic Performance Level 2 for reinforced soil retaining walls, with regard to the cases in this study. Next, the seismic coefficient used for the assessment of the Seismic Performance Level 1 was investigated. Reinforced soil retaining walls that lost the Seismic Performance Level 1 are distributed approximately under the line of  $k_h=0.5a_{max}/g$  (black plots in Fig. 4, g stands for gravitational acceleration). Therefore, it can be said that an acceleration that is approximately 0.5 times supposed maximum acceleration should be considered as the design seismic coefficient used for the assessment of the Seismic Performance Level 1, with regard to the cases in this study. In short, a design seismic coefficient of approximate 0.1 should be considered for use for the assessment of the Seismic Performance Level 1 against medium-strength earthquake ground motion having a maximum acceleration of approximately 200 gal, and a design seismic coefficient approximate 0.4 should be considered for use for the assessment of the Seismic

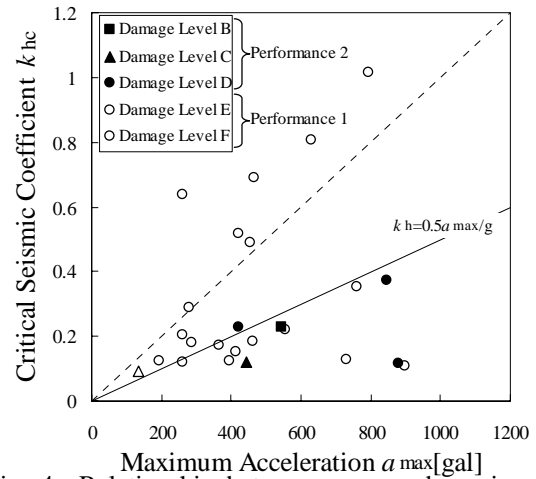


Fig. 4 Relationship between presumed maximum acceleration and critical design seismic coefficient

Performance Level 1 against large earthquake ground motion having a maximum acceleration of approximately 800 gal. However, as previously mentioned, the mode of deformation in actual phenomena does not always coincide with that in a design calculation, and it will be necessary to investigate this point in the future.

#### SUMMARY AND ACKNOWLEDGMENT

Comparing the results of calculations of suitability based on current design methods for reinforced soil retaining walls with the seismic performance level they sustained during the 2004 Mid Niigata Prefecture Earthquake, it is shown that there is a possibility of applying the current design method to performance-based design. Cases in this study were offered by the Reinforced Soil Diffusion Committee, for which we are most grateful.

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