(Abstract)

Probability of Failure of Concrete Retaining Walls due to Earthquakes in Kanto Area

(関東地方におけるコンクリート擁壁の地震による破壊確率に関する研究)

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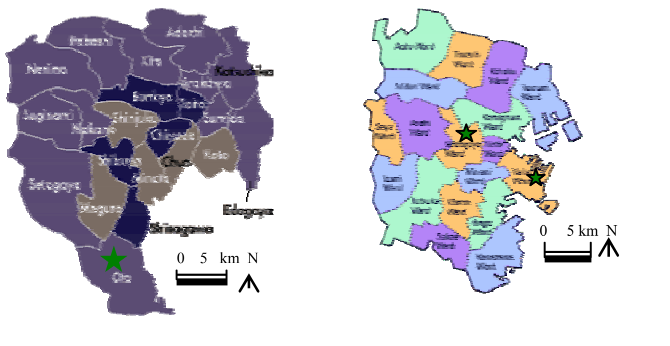
1. Introduction

Retaining structures are constructed to protect a slope surface when banking or cutting cannot be conducted in accordance with the standard cross section. They are common in highway and railway embankments, large constructions, individual houses and housing lots. Stability of any construction is dependent on various factors like topography, geology, structural arrangement of construction and work conditions. Now-a-days, additional safety of structure from rare natural disasters and human induced activities is more widely considered. Such rare disasters include earthquake, wind or typhoon, heavy precipitation, flooding and chemical or other environmental problems. Much of attention and researches have been carried out about retaining wall failure concentrated for highways and railways. But many individual houses and housing lots have retaining walls for supporting their buildings and structures which is also important part to be concerned. If the retaining wall failure of individual houses, housing lots and small scale streets occurs due to any disasters, it may cause up to large scale loss of property and life.

When safety of our society is concerned, the safety of city and then our environment should be considered. Moreover, the social safety of our life is related to the integrated safety of built environment with our social and physical environment. When we make efforts to ensure this safety, safety of slope becomes quite important which is contributing to retaining walls for their stability. Thus, retaining walls are important in supporting our social and physical environment. The building safety is widely discussed and has been well studied in many engineering fields. In contrast to this, the safety of retaining walls, which equally contribute to the safety of our physical and social environment, is not yet studied from reliability approach. On these backgrounds, my study is focused on the safety of concrete retaining walls in Kanto area from probabilistic approach. Safety evaluation of those retaining walls and method for finding the probability of failure are proposed in this study.

2. Study area and Objectives



a) Tokyo Metropolitan b) Yokohama Municipality

Figure 1: Location of study area

Parts of Yokohama Municipality and Tokyo Metropolitan are chosen for the field survey and data collection about retaining walls. It represents the southern part of Kanto area, consisting Ota ward in Tokyo Metropolitan and other two wards-Hodogaya ward and Naka ward in Yokohama Municipality (Fig 1).

These areas consist of little sloppy and fragile ground condition which may be affected by the problems of retaining wall failures. The strength, age and properties of the concrete retaining walls were assessed by the field survey and they were analyzed from probabilistic approach.

The main objectives of this study are:

- Conduct a field survey to find out the strength, age and properties of concrete retaining walls in Kanto area, and find out the relationship between strength and age of the concrete.
- Estimate the probability of failure of concrete retaining walls due to earthquakes based on the seismic hazard curve of the field sites due to occurrence of earthquakes.

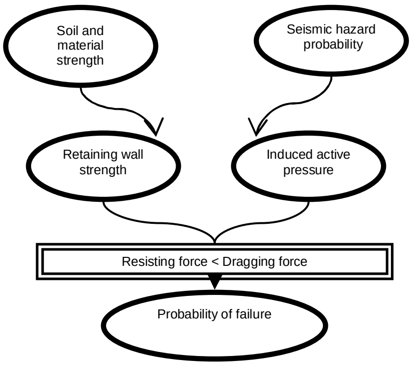


Figure 2: Conceptual flow chart

3. Procedures

3.1. Wall properties and strength assessment

A field survey was conducted to collect the information about wall properties and to measure strength using the Schmidt Rebound hammer. The PROCEQ N type hammer was used to carry out the strength measurement of the concrete wall from the field. During the strength measurement, wall surface was tentatively divided into grids of one square meter and 3-5 rebound values were measured and mean of them was obtained. Then it was converted into compressive strength value considering reduction factor. Damages due to Niigata Chuetsu earthquake were observed. Further, damages of retaining wall due to some major earthquake were analyzed.

3.2 Numerical methods

Numerous structural arrangements can be applied for the construction of retaining walls while the concerned concrete retaining walls belong to almost cantilever type retaining walls. So, the following relationship was applicable to find out the earth pressure given to the wall.

Under the static condition, minimum active thrust on a wall can be obtained from equation 1, as given by Coulomb's theory.

$$P_A = \frac{1}{2} K_A \gamma H^2 \qquad (1)$$

where,

$$K_A = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \cos(\delta + \theta)\left[1 + \sqrt{\dfrac{\sin(\delta + \phi)\sin(\phi - \beta)}{\cos(\delta + \theta)\cos(\beta - \theta)}}\right]^2}$$

δ is the angle of interface friction between the wall and the soil.

This P_A is assumed to act at a point located H/3 above the height of a wall of height H.

The pseudo static thrust could precisely be obtained from Mononobe-Okabe method (1929) which is based on Coulomb's static earth pressure theory. Thrust for the active case condition will be

$$P_{AE} = \frac{1}{2} K_{AE} \gamma H^2 (1 - k_v) \qquad (2)$$

where, the dynamic active earth pressure coefficient, K_{AE}, is given by

$$K_{AE} = \frac{\cos^2(\phi - \theta - \psi)}{\cos\psi \cos^2\theta \cos(\delta + \theta + \psi)\left[1 + \sqrt{\dfrac{\sin(\delta + \phi)\sin(\phi - \beta - \psi)}{\cos(\delta + \theta + \psi)\cos(\beta - \theta)}}\right]^2}$$

where, $\phi - \beta \geq \psi$, $\gamma = \gamma_d$, and $\psi = \tan^{-1}[k_h/(1 - k_v)]$.

In this calculation, the vertical component was neglected as suggested by Seedman and Whitman (1970). Then it becomes,

$$P_{AE} = \frac{1}{2} K_{AE} \gamma H^2 \qquad (3)$$

The total active thrust, P_{AE}, can be divided into a static component, P_A and a dynamic component, ΔP_{AE}

$$P_{AE} = P_A + \Delta P_{AE} \qquad (4)$$

As given by Kramer (1996), earthquake loading is represented pseudostatically by the dynamic thrust, Δ_{PAE}. It can be found as

$$a_c = \left(1.45 - \frac{a_{max}}{g}\right)a_{max} \quad (5)$$

Here, ac is peak acceleration at centroid of wall, amax is maximum ground acceleration. Further, dynamic thrust from

$$\Delta P_{AE} = 0.375\frac{a_c \gamma^{(b)} H^2}{g} \quad (6)$$

where, $\gamma^{(b)}$ is the unit weight of the backfill soil

The results obtained from Mononobe-Okabe method and the separate calculation of dynamic component and static component were checked to verify the total thrust given to the wall.

The point of act of earth pressure may differ as given for static component. Seedman and Whitman (1970), has recommended to use as,

$$h = \frac{P_A \frac{H}{3} + \Delta P_{AE}(0.6H)}{P_{AE}} \quad (7)$$

Using this height, the overturning moment can be calculated by,

$$M_o = (P_{AE})_h h \quad (8)$$

The resisting moment can be calculated using the wall configuration with reference to its toe. In this case, backfill unit weight, base width and height of the wall, and other soil properties may be influencing parameters. The cohesionless sandy soils are assumed to have been widely used for retaining wall constructions. The sliding force developed at the base of the retaining walls was calculated. The shear force was calculated by bending moments.

Resistance of retaining walls against different modes of failure was analyzed. The main failure modes were -failure by overturning, sliding, shearing, and tensile force. The failure probability of each mode can be found by,

$$P_f = P[Q_D > Q_R] \quad (9)$$

where, Q_D is driving force and Q_R resisting force

Probability of Q_D to be greater than Q_R is found as probability of failure. In this way, the probability of failure is

$$P_f = 1 - \Phi(\beta), \quad (10)$$

where, β is the reliability index and can be given as,

$$\beta = \frac{\lambda_R - \lambda_D}{\sqrt{\zeta_R{}^2 + \zeta_D{}^2}}$$

4. Results and Discussions

4.1. Strength of wall and damages

The present strength value and the age of the retaining wall show the strength decreasing pattern (Fig. 2). The design strength as defined by the regulation of Building Standard Law at the time of construction is assumed to be the minimum value of the retaining walls during construction. The change in the minimum strength value defined by Building Standard Law can also be noticed from figure 2a. For the mean value of strength for 5 year range, strength decreasing pattern can be noticed significantly (Fig. 2b) however we can expect some limitations.

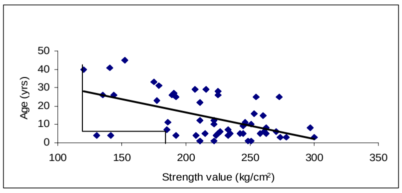


Figure 2a: Strength and Age relation

Figure 2b: Strength and age relation in 5 year range

From case studies of major earthquake damages, large scale damages of retaining wall are associated with ground condition and slope failures. The relation between deformation on ground soil and retaining wall damages is well established for the walls constructed in housing lots or individual houses rather than those of highway or railway embankments. Preparation of contour map for the intensity of earthquake will be an appropriate method to predict damages and it is also useful to estimate the hazard.

4.2. Resistance against different modes of failure

The resistance of retaining walls in different modes of failure was computed using the above equations. The resisting force was compared with total earth pressure given to the wall during the earthquakes. The obtained results suggest that the failure by overturning is dominant mode of failure among all others. The overturning and sliding failure cause the structural failure. Compressive or shearing forces cause material failure of the concrete wall itself, however damage mostly becomes complex. The overall distribution of the failure by overturning and sliding can be seen in figure 3. The compressive strength of concrete is much higher than that of compressive stress. The shearing stress obtained from bending moment and compressive stress suggests that the walls will not fail even in large intensity earthquake such as 500 cm/s^2.

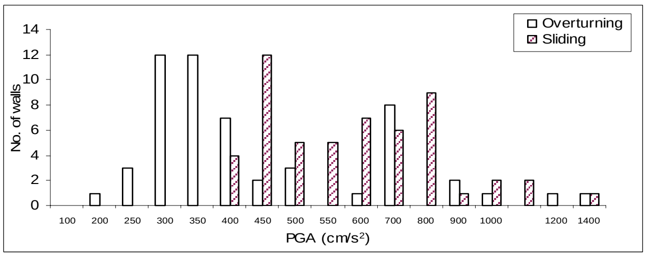


Figure 3: Distribution of overturning and sliding cases in the study area

4.3 Failure probability

The dominant failure mode was found to be the overturning mode among all others. Overturning and sliding mode are further analyzed for failure probability with view point of occurrence of earthquake for each site. This will give us the overall probability of failure for specific concrete retaining walls due to the effect of dynamic load during earthquakes. The probability of failure is obtained using the seismic hazard of respective sites.

The loads and resistance phenomena are inherently random in nature (Aoki et. al. 2000); therefore the probability assessment has become significant to measure the safety of retaining walls in terms of probability of failure.

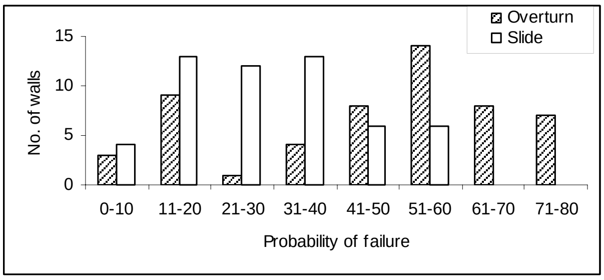


Figure 4: Distribution of probability of failure in the study area

The seismic hazard curve in terms of peak ground acceleration was used to find out for the failure probability. According to the results obtained from the analysis (Fig. 4), retaining walls can be grouped categorically into three groups: having high probability of failure (more than 60%), medium with range of 30-60% and lower probability of failure having less than 30%. The distribution for probability of failure is shown in figure 4. Overturning case has high mode in 50-60% and sliding case has a range of 10-40% for most of the walls. It can be assumed that Mononobe Okabe Method may give conservative results.

Aleatory behavior of seismic hazard, some assumption on wall and soil properties, and model may have uncertainties. So, the probabilistic method for reliability assessment of retaining walls is important in this case. Using this procedure, the failure probability can be obtained for concrete retaining walls in other areas and further, uncertainty level can be reduced in having more detailed information.

5. Conclusions

The safety of retaining walls should be considered in terms of probability because there is uncertainty in seismic behavior, ground response, wall design model or any assumed parameters etc. In this study, those uncertainties are considered in a probabilistic way and proposed the procedure to find out the failure probability of retaining walls. This procedure will be very useful in safety or reliability measurement of those structures. The variability of the load parameters, used models uncertainty and seismic hazard uncertainty makes the system complex which can be reduced by applying more detailed information about properties of retaining walls or model and seismic hazards.

References:

Aoki, Y., Ohashi, Y., Fujitani, H., Saito, T., Kanda, J., Emoto T., Kohno, M.; 2000. *Target seismic performance levels in structural design for buildings*. 12 WCEE. No. 0652.

Kramer, S.L.; 1996. *Geotechnical Earthquake Engineering*, Prentice Hall, Inc., Upper Saddle River, New Jersey, pp 653.

Mononobe, N. and Matsuo, H.; 1929. *On the determination of earth pressure during earthquakes.* Proceedings of the World Engineering Congress. Vol. 9.

Seed, H. B. and Whitman, R. V.; 1970. *Design of earth retaining structures for dynamic load*s, ASCE Speciality Conference-Lateral stresses in the ground and design of earth retaining structures at Cornell University, Ithaca, New York.