STUDY ON SEISMIC PERFORMANCE AND STRUCTURAL INSPECTION OF RETAINING WALL

Kosh Nath Adhikari* **Supervisor: Dr. Masahito TAMURA****
MEE06001

ABSTRACT

Seismic performance of concrete block retaining wall with concrete backing was evaluated by the shaking table test and compared for acceleration and displacement at various nodes with the theoretical calculation by finite element method. Two dimensional elasto-plastic dynamic analyses were performed by using recorded Kobe NS component acceleration as input motion for both cases. Structural inspection helps to alleviate secondary disaster after an earthquake. A regular inspection of retaining walls in the vicinity of inhabitants is necessary not to allow the situation of retaining walls to worsen by the natural agencies. Proposed manual for inspection will be helpful for the inspection and rating the level of risk which will inspire residents for regular upkeep of retaining walls. Finally, a newly developed non-destructive Surface Wave Method (SWM) for the evaluation of stiffness of retaining wall is introduced.

Keywords: Seismic performance, elasto-plastic, structural inspection, surface wave method.

INTRODUCTION

Nepal is located at the boundary of Indian and Tibetan tectonic plates which are colliding with each other. Because of its location, Nepal is prone to large magnitude earthquakes and earthquakes in the past have claimed thousands of lives and properties. Retaining wall is an indispensable structure whether it is for the construction of building and other physical infrastructures or for the slope stabilization measures in Nepal owing to its fragile and difficult nature of topography. A retaining wall is a structure whose primary purpose is to provide lateral support for soils at slopes steeper than their angle of repose.

Shaking table tests for both concrete block retaining walls without concrete backing and with concrete backing were observed during the study and the obtained results were compared with Finite Element Analysis for the case of retaining wall with concrete backing. FEM is the only reliable method to observe behaviors of such structures and it has importance for our country where there is no lab for conducting the shaking table test. Generating awareness about the surrounding environmental condition of retaining wall plays a vital role among the parties concerned for the regular inspection of retaining walls not to allow the situation to worsen. A inspection guideline is utmost important and the practice has been started in this paper with the help of already prepared manuals of Japan and field visit right after occurrence of earthquakes at Noto and Niigata in 2007.

Survey data analyzing part is an important work which I have performed here about structural inspection of retaining walls for Ueno and Akabane areas of Japan. This survey was conducted by Building Research Institute (BRI) with cooperation of housing companies and universities of Japan. Newly developed non-destructive test for structural evaluation of retaining wall by Surface Wave Method (SWM) was studied as an introductory part to continue it further in my future study.

---

* Engineer, Dept. of Urban Development and Building construction, Nepal, ** Chief Research Engineer, International Institute for Seismology and Earthquake Engineering

SHAKING TABLE TEST AND FINITE ELEMENT METHOD

Shaking table test

Preview

Concrete block retaining wall without concrete backing and with concrete backing were two types of specimens for one dimensional full scale shaking test. The inclinations of walls were nearly 78^0 to resemble the field practices in Japan though the prevailing code has restricted the construction of former type retaining wall. Overall dimensions of specimen are illustrated in figure 1.

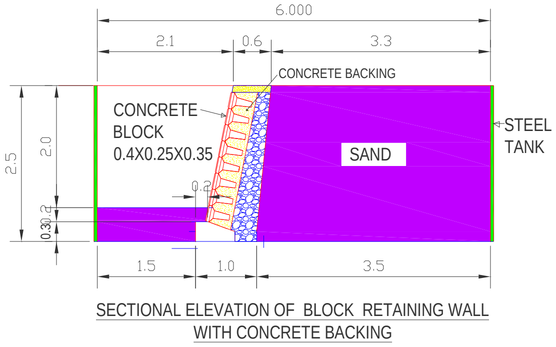

Figure 1 Cross section of specimen
(All the dimensions are in meter)

Photo 1 specimen after application of 818 gal

Photo 2 Specimen after application of 1000gal

The design compressive strength of concrete block was $18N/mm^2$. Edosaki sand having physical properties as wet density of $16.3KN/m^3$, dry density 14.29 KN/m^3 and the natural water content 14.1% was used as backfill material.

Test procedure

Shaking was performed by applying Kobe earthquake NS component recorded by the Japan Metrological Agency (JMA). Input level of acceleration was 100gal, 200gal, 400gal and 818 gal. After the application of acceleration of 400 gal, some displacement on the top of the soil and the retaining wall was noticed. After the application of 818 gal acceleration, settlement in soil and gap between the wall and soil were widened though the specimen still survived as shown in photo 1.

Surface Wave Velocity method for the evaluation of stiffness of the retaining wall and impulse hammer test to evaluate the response of the retaining wall was performed as non destructive tests before commencement of shaking table test. A Swedish Weight Sounding test was performed for the backfill material to know the soil stratification, N values and unconfined compressive strength of soil. The same procedures were followed for both specimens. Wall without concrete backing completely collapsed after the application of 1000gal acceleration but wall with concrete backing was tilted away from the backfill as shown in photo 2.

Finite Element Method

Preview

Elasto-plastic two dimensional dynamic analyses were performed for the concrete block retaining wall with concrete backing by the use of Amiko software.

Procedure

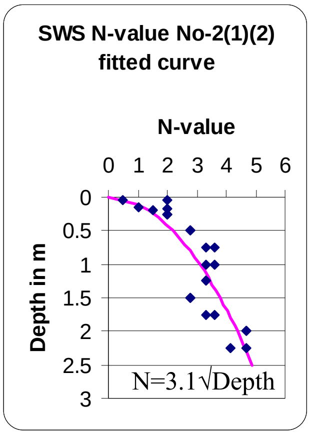

Figure 2 Best fit SWS profile

There were two sets of test data from Swedish Weight Sounding test which are plotted as scattered plot. Finally a best fit curve as shown in figure 2. N-value is assumed to be constant for the depth of each 0.5m. Young's Modulus of Elasticity, Eo,in MN/m2 of soil is determined by the equation (1) for each 0.5 meter depth. Cohesion for soil and concrete were assumed as 1Kpa and 1.0E+20 Kpa for blocks and concrete respectively.
Internal frictional angle, Ø, of soil was assumed as 35° for the calculation. Dilatancy angle, ψ was calculated by the equation 2 which was taken from the Introduction to soil strength and ground failure published by Japan Geotechnical Society (JGS) in 1995, unit weight of soil and concrete block, γ, is assumed as 16 KN/m³ and 20 KN/m^3. Poisson's ratio n, was 0.35 for soil and for concrete 0.15.

$$E_o = 1.4N \qquad \text{Eq.(1)}$$

(Relation is taken from Recommendation for the design of Building Foundations in 2001 published by AIJ.)

$$\psi = \phi - 30^0 \qquad \text{Eq.(2)}$$

Assigned different material properties are illustrated in figure 3. Legends 1 and 4 to 8 denote soil 2 represents the concrete block wall 3 represents the filter medium gravel and 9 indicate concrete backing.

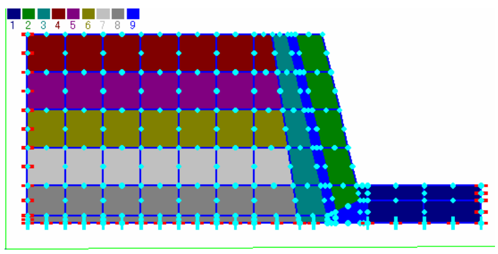

Figure 3 material properties

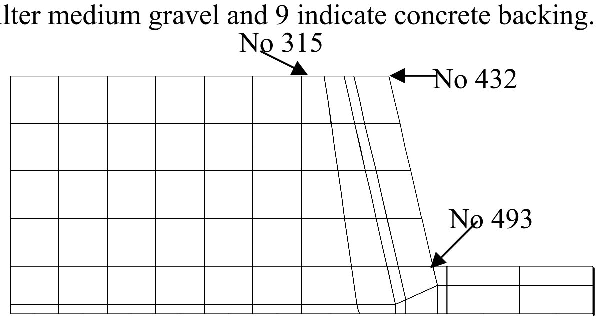

Figure 4 Mesh and node numbers

Comparison of test and calculated results

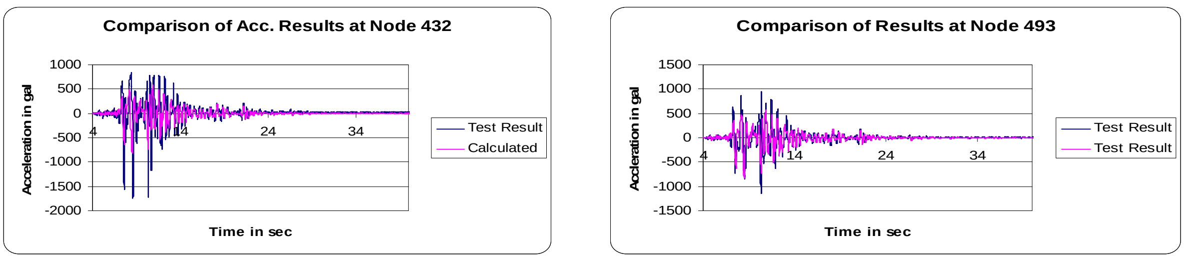

Figure 5 Comparison of acceleration with the input acceleration of 818 gal

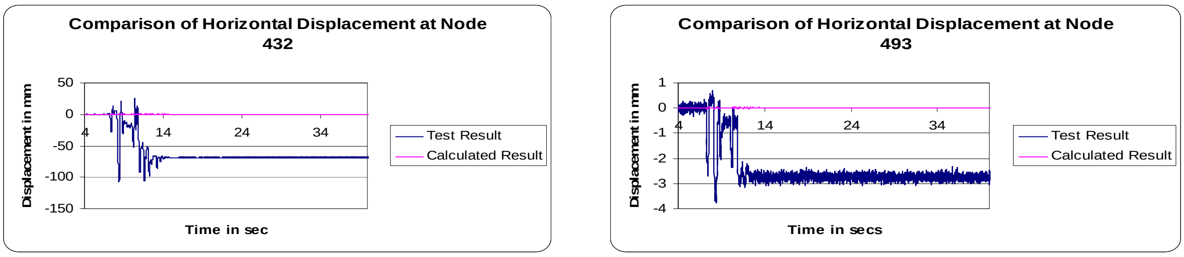

Figure 6 Comparison of displacements with the input acceleration of 400 gal

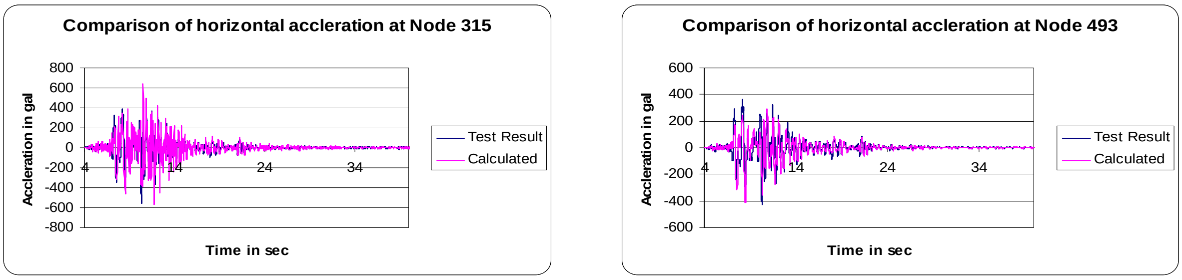

Figure 7 Comparison of accelerations with the input acceleration of 400 gal

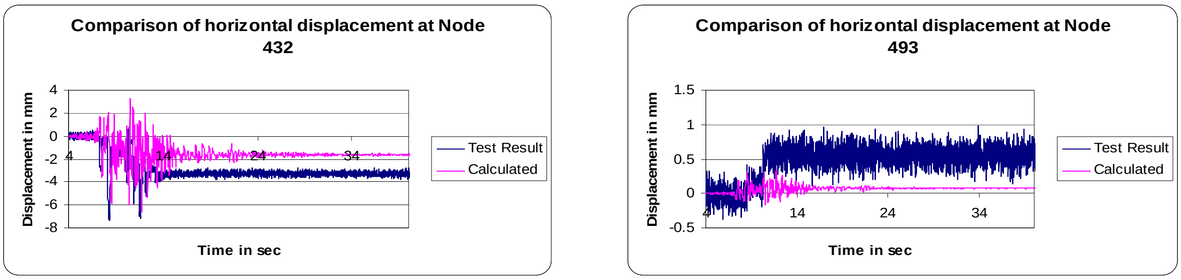

Figure 8 Comparison of displacements with the input acceleration of 400 gal

The wave forms of both the figures 5 and 7 are consistent for acceleration but the displacement in figure 6 were not consistent. FEA was again run with changing angle of internal friction from 35^0 to 30^0 by using the same 818 gal acceleration, noticeable difference was not obtained. Finally, Acceleration of 400 gal was used for analysis and the obtained displacements at various points were nearly consistent as shown in figure 8. It is found that when the attached surfaces within the body of retaining wall are separated then it does not show displacements in big quake.

STRUCTURAL INSPECTION

Structural inspection helps to alleviate or avoid secondary disasters right after an earthquake. A standard inspection and evaluation procedure is necessary to conduct a survey on the damaged area of earth retaining structures to determine the degree of hazards. The life of structure decreases with increase in time. Environmental factors such as rain, sun and vegetation will deteriorate the structures and cracks will appear. Building Research Institute had conducted survey of Akabane and Ueno area in Tokyo metropolitan area with the cooperation of housing companies and Universities of Japan. Nearly 230 retaining walls were surveyed and analysis was performed and the findings about weep holes, drainage condition and all types of cracks based on Yokohama City's criteria were presented.

Checking algorithm for proposed manual of Nepal

Checking for the surrounding environmental conditions and other
a) Weep hole b) Exuded water c) Drainage facility
A (Reference points of retaining wall) = (The largest one is used out of scores in a) to c)

2. Checking based on the retaining wall for any:
a) Cracks b) Horizontal displacement c) Differential settlement
d) Clearance at the external corner e) Bulge f) Inclination/ Breakage
B (Changed points of retaining wall) = (the largest one is used out of scores in 1) to 6)

3. Finally, evaluating the retaining wall comprehensively
According to the obtained total score mentioned {(reference points of retaining wall A + (Changed points of retaining wall B)}, the safety of the retaining wall is ranked into any of three levels:
I Almost safe, score<=5 II Relatively unsafe, Score >5 to<=9 III High risk, Score >9
Namely, the retaining wall of house lot with higher total score is at higher risk

FIELD INVESTIGATION OF RETAINING WALL DAMAGED BY EARTHQUAKES

Noto and Niigata

A magnitude of 6.9 earthquakes hit the Hokurika region of Japan near the Peninsula by 2007, Noto Hanto Earthquake on 25 March, 2007. One person was killed in Wajima city and 170 people were injured. Toge area has a steep slope more than 20^0 and retaining walls are found to be constructed to support the approach roads embankment and houses. Failures of retaining walls are found due to increased earth pressure during earthquake as shown in photo 3

Photo 3 Failure of wall

A couple of powerful earthquakes of 6^+ in Shindo scale jolted in northwestern coast at Niigata prefecture about 14 hours interval, death toll of 11 and injured more than 1890 in Japan by Niigata Chuetsu-Oki Earthquake 2007 on 16 July, 2007.

Elderly people who were living alone in the old wooden houses were badly suffered in the earthquake. The soil of the affected area consists of fine sand. The outward thrust from the back fill soil was found to be the main cause of failure of retaining walls with slip of the soil being low shearing resistance. Most of the walls which were erected vertically without provision of front slope were severely affected. So, failure of retaining structures was the slip of the earth surface followed by the inadequate capability of retaining walls to sustain the earth pressure during earthquake as shown in photo 4.

Photo 4 Overturned wall

CONCLUSIONS

Seismic performances of retaining walls prepared by dry concrete blocks without concrete backing and with backing were viewed for shaking table tests by applying recorded Kobe NS component.

1) The wave form of acceleration obtained from the both shaking table test and finite element method is consistent at different measured nodes.

2) The displacements obtained at different locations in two cases are different for 818 gal input level of acceleration and found nearly same for 400 gal acceleration.

Structural inspection helps to alleviate loss of lives and properties caused by secondary disaster after an earthquake and this manual will be a means to judge the level of risk.

3) To generate and disseminate awareness for earthquake disaster mitigation about the existing retaining wall to residents to encourage for regular environmental inspection.

Field investigation right after earthquakes in 2007, Noto Hanto Earthquake and 2007, Niigata Chuetsu-Oki Earthquake has found similar types of impacts on retaining walls and the major causes of failure were failure of substructures, front slope more than 60^0, insufficient thickness of wall, out-of-plane and in-plane failures and slip of ground surfaces.

ACKNOWLEDGEMENT

I would like to express my thanks to Associate Professor Dr Akihiko WAKAI of Gunma University, Dr. Tsutomu HIRADE, Senior Research Engineer of Building Research Institute, Japan, Dr. Akio ABE of Tokyo Soil Research Company Limited for their guidance.

REFERENCES

AIJ, (2001) Recommendation for Design of Building Foundation, 2nd edition Tokyo: Architectural Institute of Japan.

Bajra M. Das., (2007) Principal of Foundation Engineering, 6th edition A division of Thomson Canada Limited.

Coduto D.P., (2001) Foundation Design/ Principal and Practices, 2nd edition Prentice-Hall,Inc.,New Jersey.

JGS, (1995) Introduction to Soil Strength and Ground Failure: Japan Geotechnical Society.

Joseph E. Bowels, (1996) Foundation Analysis and Design, 5th edition McGraw-Hill Companies,Inc.

MLIT, Retaining wall-Quick Inspection Guide, Japan. Evaluation of degree of hazard for the residential site by the council on network of evaluation of degree of hazard for the residential site.

National Building Code of Nepal (2004).