Study for clarifying the failure mechanism of reclaimed land at Fukushima city by use of the estimated strong earthquake motion during the 2011 off the Pacific coast of Tohoku Earthquake

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SUMMARY: (10 pt)
The 2011 off the Pacific coast of Tohoku earthquake occurred on March 11 is the moment magnitude 9.0 and is the greatest earthquake so far since the seismic observation has started in Japan. As the damage in inland, many damages of houses were caused by the ground deformation due to the seismic action. As the large scale slope failure, a embanked ground at Asahidai housing complex in the Fukushima city was failed and National Route 4 was blocked up completely by the collapsed soil. In order to clarify the large-scale failure mechanism of the embankment, reappearance analysis was carried out using MPM which is possible to analyze seamlessly from an elastic behavior to a discontinuous collapse behavior. Although it is found that the shake around the 2nd peak around 100 seconds of the estimated waveform affected on the deformation of embankment, the behavior which results in moving sliding block up to National Route 4 is not evaluated quantitatively.

Keywords: The 2011 off Pacific coast of Tohoku earthquake, Failure of embankment, MPM, Estimate main shock waveform

1. INTRODUCTION

The 2011 off the Pacific coast of Tohoku earthquake occurred on March 11 is the moment magnitude 9.0 and is the greatest earthquake so far since the seismic observation has started in Japan. Furthermore, huge tsunami was generated and attacked the area along the shore side of the north Japan from Aomori Prefecture to the Chiba prefecture, and brought about serious damage. The people killed in the huge tsunami resulted in about 20,000 people including the missing person, and became an unprecedented great earthquake. As the damage in inland such as Sendai of Miyagi Pref. and inland area named as Nakadoori of Fukushima Pref., many damages of houses were caused by the ground deformation due to the seismic action. As the deformation, the slope failure of embanked land developed for housing lot and the settlement of support ground were generated. As a example of the large scale slope failure shown in Photograph.1, a embanked ground at Asahidai housing complex in the Fukushima city was failed and National Route 4 was blocked up completely by the collapsed soil. The damages of houses due to the Pacific coast of Tohoku Earthquake are caused by the ground deformation and the damage mechanism is different from the damages caused by collapsed house itself due to the 1995 Hyogoken Nanbu earthquake. Moreover, when the survey of theground deformation at housing lots in Iwaki, Fukushima Pref. was investigated, the talk about the behavior of the ground was able to be heard from the residents. They said that the difference of the ground was started after the shaking of main shock passed 1.5 minutes. In order to make a clear the failure mechanism of ground deformation, it is necessary to verify the effect of not only the intensity of the earthquake ground motion but also the length of duration time.

Photograph 1. The collapse situation of developed embankment at Asahidai housing complex

The objective of this paper is to make a clear the cause of ground disaster. First of all, a embanked history of failure ground, material characteristics of the soil are investigated. And aftershock observation was carried out for three months from May 11, 2011 to August 16 near the failure point to estimate the acceleration time history of main shock at the point. Next, the reappearance analysis of the failure behavior was tried based on not only the acceleration time history of the estimated main shock by using the site characteristic substitution method but also the strength property of the collapsed ground. Furthermore, the influence of the characteristics of earthquake ground motion on a collapsed behavior has been known. Material point method (so called MPM) was used for analysis. The method is possible to analyze seamlessly from an elastic behavior to a discontinuous collapse behavior.

2. THE DAMAGE OUTLINE OF ASAHISDAI HOUSING COMPLEX AT THE FUKUSHIMA CITY

Asahidai housing complex was developed since 1965 to 1975 and collapsed embankment is the west side slope which faced National Route 4 as shown in Figure.1. The comparison of the aerial photograph before the development to that after the development is shown in Figure.2. The comparison of the topographical map before the development to that after the development is shown in Figure.3. Based on these comparisons, it is found that the collapsed embankment is constructed on the valley filled embankment.

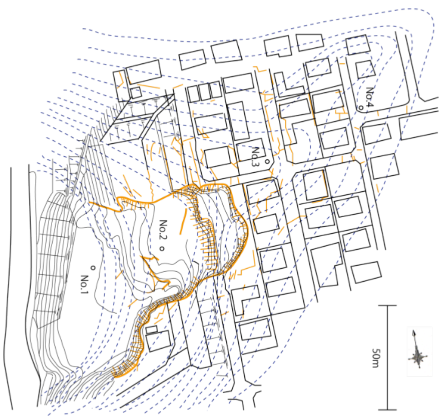


Figure 1. Plain view of the collapse of embankment

a) Photography 1947 b) Photography 2007

Figure 2. Change of geographical feature by photography

a) Survey 1952 b) Survey 2007

Figure 3. Change of geographical feature by survey

The other failure of embanked slope is generated around the south faced slope of embankment and the failure is smaller than that of the east faced slope. The embankment is also the valley filled embankment as well as the east faced slope.

As the dimension of the sliding block, the width and length are about 90 m and 110 m respectively. Banking material is the clay mixed with gravel and the color is blackish brown, the N value is as small as since 0 to 7.

3. ANALYTICAL METHOD AND MODEL

3.1 Introduction to the material point method

The general MPM developed by Sulsky et al. is an explicit time-marching calculation, and the body of the continuum analyzed is described as a cluster of particles as shown in Figure. 4. The particles, which carry all Lagrangian parameters such as stress, strain and pore water pressure, can move freely across the boundaries of a stationary Eulerian computational mesh that should cover the position of the analyzed body (see Figure. 5). The computational mesh can remain constant for the entire computation, thereby eliminating the large deformation disadvantage of the conventional finite element method (FEM) related to the problem of mesh distortion.

3.2 Modelling of Ground Structure of Collapse Slope, and Material Characteristics

The two-dimensional ground structure model for 160 m from the back place of collapse to National Route 4 is used for analysis. The ground structure is modelled as the three-layer structure including upper two layers as banking part and a base ground layer based on a surface wave investigation result and is shown in Figure.6. The output position of the analysis result is also shown in Figure .6. Here, as the shear wave velocity (Vs) of each layer, the upper layer of banking part, a lower layer of banking part, and a base layer are 0.15 km/s, 0.24 km/s, and 0.33 km/s, respectively. As the back lattice used for the analysis of MPM, horizontal lattice and vertical lattice were arranged at intervals of 1 m respectively, and every two particles are arranged into the lattice (1 m x 1 m).

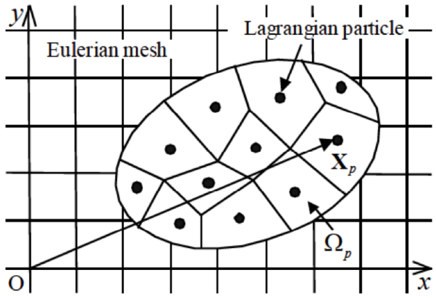


Figure 4. Continuum body in the MPM approach

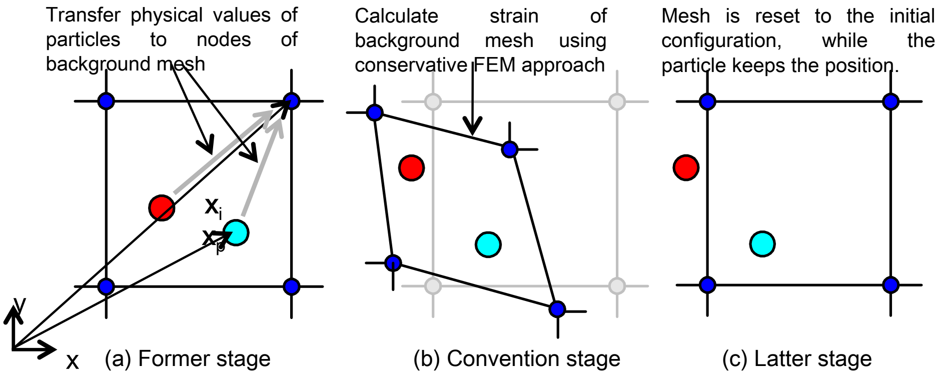


Figure.5 Outline of flow in the material point method

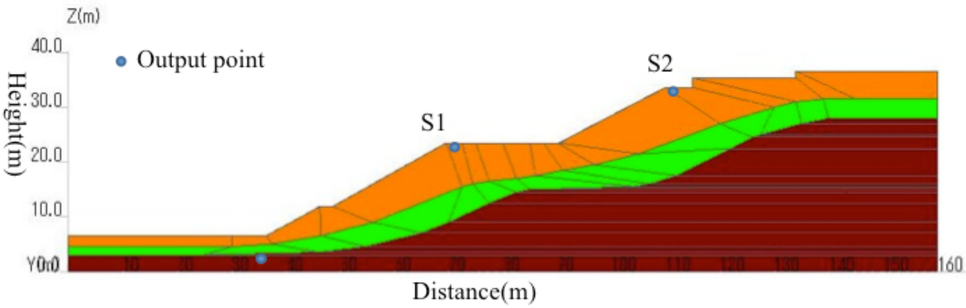
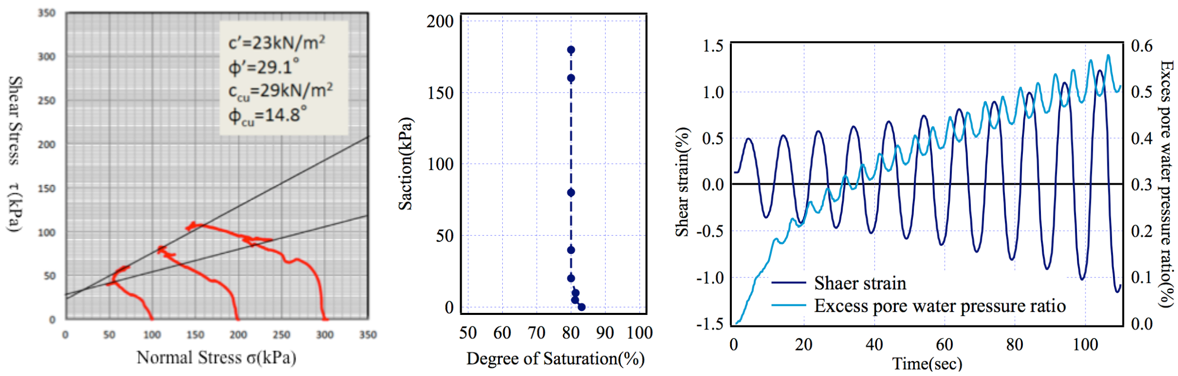


Figure 6. Analytical model as cross section of the collapsed embankment



a) Strength Characteristics(simple shear test) b) Water retention curve C)Cyclic shear

Figure 7. The strength characteristics obtained by

Drucker-Prager model is used for the stress-strain relation of banking material. As for modelling tensile strength, not only the considering case but also not considering case are used as the model. The strength characteristics of banking material are obtained by simple shear test by using the soil sampling in site and are shown in Figure.7 a). In order to carry out total stress analysis in this report, the internal friction angle (Φcu) and cohesion (Ccu) are used as the strength characteristics to be 14.8 degrees, 29 kN/m2 respectively. Moreover, the water retention curve of the banking material is shown in Figure.7 b). Even when suctions are 180kPa, a degree of saturation is as high as 80%. This is the reason why natural water content was about 50% without rain. Furthermore, as the example of results obtained by hollow cylinder torsional shear test using the undisturbed sample of banking material, the time histories of shear strain and excess pore water pressure ratio under the cyclic shear stress of 30kPa is shown in Figure.7 c). It is found that shear strain is increasing from about 0.5% to the value exceeding 1% by the rise of the pore water pressure. Although the effect long duration which exceeds 3 minutes had to consider to determine the strength characteristics of the banking material, the strength properties mentioned above is used here.

3.3 Input motion using for analysis

3.3.1 Site effect substitution method

The method proposed by Hata et al. is simply composed of three steps. First, the Fourier amplitude of strong motion at a target site (Site A) for a large earthquake is evaluated by correcting the Fourier amplitude at a nearby permanent strong-motion station (Site B) for the same event based on the difference of the site amplification factors at the two sites (Site A and Site B). Then, the Fourier phase of strong motion at the target site (Site A) for the large earthquake is approximated by the Fourier phase at the same site (Site A) for a small earthquake that occurred close to the main rupture area of the large earthquake. Finally, an inverse Fourier transform is conducted to obtain the time histories of strong ground motions at the target site (Site A) for the large earthquake. One of the key assumptions of the method is that the Fourier phase for the large event can be approximated by the Fourier phase for a small event, and, in fact, it has been shown that the assumption is appropriate for many of recent damaging earthquakes in Japan (**e.g.**, Nozu and Irikura 2008).

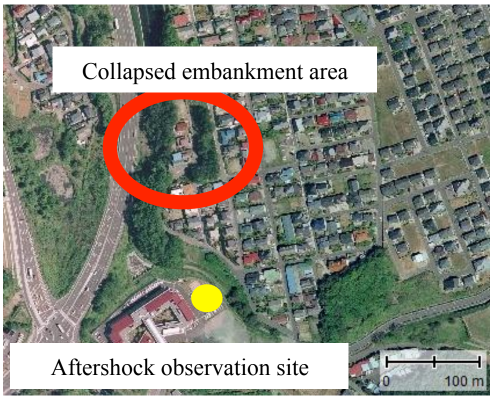
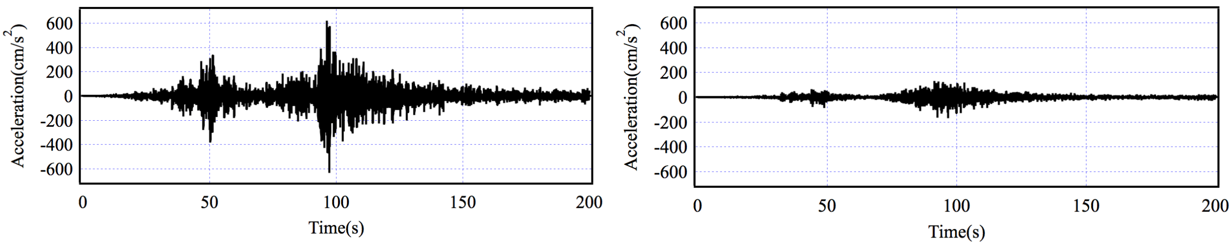


Figure 7. Aftershock observation site

It is obvious, however, that the assumption cannot be directly applied to a multiple-shock event such as the 2011 off the Pacific coast of Tohoku Earthquake, especially when contributions from two or more subevents are comparable for the target site as shown Figure.7. In fact, contributions from at least two subevents are quite evident in the waveforms observed in Iwate, Miyagi and Fukushima Prefecture, Japan, during the 2011 main shock. Even in such cases, one could still expect that the Fourier phase corresponding to each subevent is approximated by the Fourier phase for a small event. Thus, some of the authors extend the method and propose a new method that can be applied to records for a multiple-shock event. First, the waveform at kiknet site whose name is kawamata is divided into parts corresponding to each subevent (the first and the second sections) with a taper. Then, the original method is applied to each section (the first and the second sections), and the waveform at target site corresponding to each subevent is obtained. Finally, the waveforms are superposed to obtain the total waveform at target site.

3.3.2 Input motion

The main shock waveform calculated based on the site effect substitution method using the observed aftershock record is shown in Figure.8. In analysis, the obtained waveform was used as the input motion with the complex wave at the undersurface of the analysis model shown in Figure.6. As for a waveform, it is found out that the form has two peaks around 50 seconds and 100 seconds, and that the latter peak value is larger than the former peak value. In order to understand the effect of the vertical motion on the failure process, not only the case that the horizontal motion is used as the input motion but also the case that horizontal motion and vertical motion is used simultaneously as the input motion were analyzed.

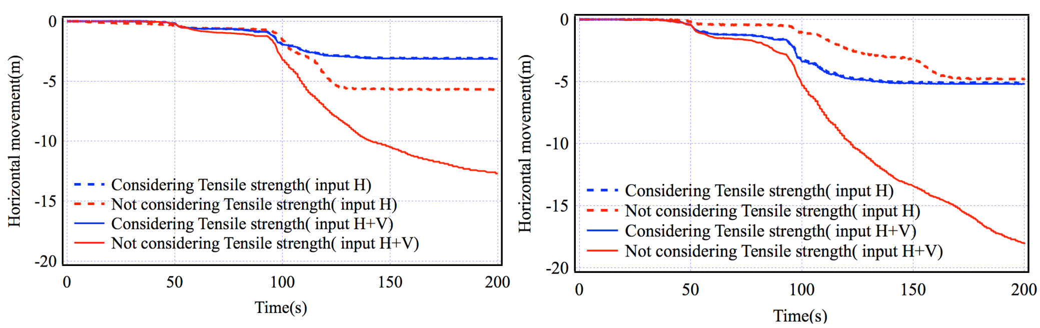


a) horizontal Component b) Vertical Component

Figure 8. Estimated main shock waveform

4. COLLAPSE BEHAVIOR OBTAINED BY ANALYSIS

Analysis carried out a total of four cases according to not only either considering tensile strength as the stress-strain relationship or not but also either considering the vertical motion with horizontal motion as input earthquake motion or not. Comparison of the time histories of the horizontal displacement at two points shown in Figure.5 is shown in Figure.9. For all cases, larger displacement has been caused after the 2nd peak of input earthquake motion. Moreover, although the horizontal displacement taking into account of the vertical motion with the horizontal motion as input motion is almost the same with that taking into account of the horizontal motion as input motion for the cases considering the tensile strength, the former displacement is lager than the later displacement for the cases not considering the tensile strength



a) S1 b) S2

Figure 9. Comparison of response horizontal displacement time history

As for the whole deformation of the banking part, the distribution of shear strain for the case considering the tensile strength as well as the vertical input motion with the horizontal input motion at the last time of the input motion is shown in Figure.10. Furthermore, for the cases considering the vertical input motion with horizontal input motion, comparison of the final deformation shape for the case considering the tensile strength with that for the case not considering the tensile strength is shown in Figure 11. The major deformation is generated around the upper slope of embankment. Therefore, the collapsed soil block does not move up to National Route 4. As the deformation, large shear strain is generated in the embankment just around the boundary between the embankment and base layer. However, the deformation around the lower slope of embankment is small. Therefore, the deformation of whole embankment is restrained by the lower part of embankment.

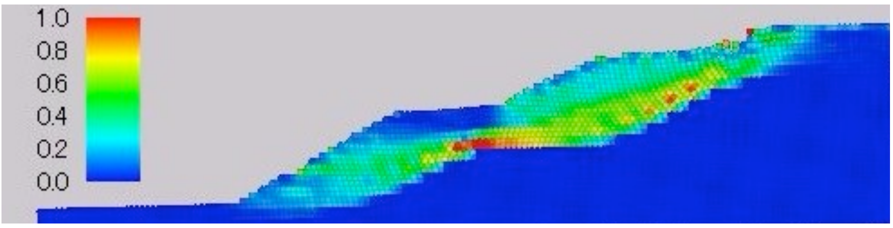
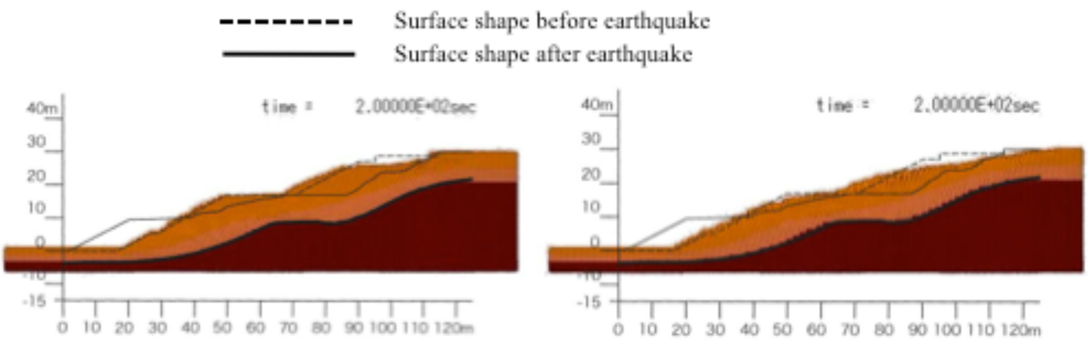


Figure 10. Distribution of shear strain for the case considering the tensile strength and the vertical input motion with horizontal input motion



a) Consideration of the tensile strength b) No consideration of the tensile strength

Figure 11. Comparison of final deformation shape for the case considering the vertical input motion with horizontal input motion

The effect of water content in the ground is not considered as the strength property in embankment. Therefore the strength property set to be constant during analysis. The reappearance analysis seems to be required to try considering the effect of strength reduction based on the rise of pore water pressure.

5. CONCLUDING REMARKS

In order to clarify the large-scale failure mechanism of the embankment developed as Asahidai housing complex in the Fukushima city damaged by the 2011 off the Pacific coast of Tohoku earthquake, reappearance analysis was carried out using MPM which is possible to analyze seamlessly from an elastic behavior to a discontinuous collapse behavior. Although it is found that the shake around the 2nd peak around 100 seconds of the estimated waveform affected on the deformation of embankment, the behavior which results in the moving sliding block up to National Route 4 is not evaluated quantitatively. The quantitative evaluation is due to be tried by reevaluating the soil characteristic including a strength property.

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