FEM SEISMIC ANALYSIS ON THE EFFECT OF TOPOGRAPHY AND SLOPE STRUCTURE FOR LANDSLIDING POTENTIAL EVALUATION

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ABSTRACT

In order to make clear the effect of topography and slope structure on seismic performance of the slopes, which are similar to the slopes around Shimane nuclear power plant (Shimane NCPP), using ABAQUS FEM software, after confirmed the validity of the method used in the study by existing centrifuge test of a slope, two kinds of slope models are built based on the results of field geological investigation of the slopes around Shimane NCPP. Three homogenous slope models with a same height of 100 m and different slope angles as 20 deg., 30 deg. and 40 deg. are built to study the effect of the slope angle. Three homogenous slope models with a same slope angle of 30 deg. and different slope heights as 75 m, 100 m and 150 m are built to study the effect of the slope height. Four alternately distributing layered slope models with a same height of 100 m, a same slope angle of 30 deg. and different dip angles as 10 deg., 20 deg., 30 deg. and 40 deg. are built to study the effect of the dip angle. The 2000 Western Tottori M7.3 earthquake is taken as input seismic motion to study the amplification of seismic acceleration, and two times enlarged 1995 M7.2 Kobe earthquake is taken as input seismic motion to study the possible slope failure styles. The results indicated that, (a) the seismic acceleration amplification of the slope top increases with the slope angle decreasing and the slope height increasing, and the amplification becomes larger duo to the existing slope structure, (b) When a homogenous slope gets damaged, the slope angle controls the sliding face angle, while the slope height almost has no influence. (c) When a slope with structure gets damaged, the slope with a smaller dip angle than the slope angle slides along the softer layers, while the slope with a larger dip angle than the slope angle activates as the corresponding homogenous slope.

Keywords: Slope topography, Slope structure, Amplification of seismic acceleration, Slope failure style, ABAQUS.

1. INTRODUCTION

Many great earthquake events indicate that a landslide is huge menace to human beings and facilities in mountain terrains, especially to important engineering projects as a nuclear power plant. If a slope failure is triggered near the nuclear power plant by an earthquake, serious impacts on human beings are unimaginable. The Shimane nuclear power plant (Shimane NCPP) is just the case which is surrounded by slopes. Furthermore, the nuclear power plant is only 9 km away from Matsue city, the capital city of Shimane Prefecture, which has a population of about 2 million. As a matter of fact, the Fukushima nuclear plant got exploded because of the Tsunami caused by the 2011 Tohoku earthquake. So, the seismic safety of the Shimane NCPP has received much attention of the Japanese government.

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The Shimane NCPP is located at the Shimane peninsula which belongs to a marine environment. There are five slopes with different heights from 50m to 150m around the Shimane NCPP. And the slopes have special slope structure with alternately distributed layers in them. Because of the secrecy of the Shimane NCPP, taking photos is not allowed around there, but the similar slope in the nearby area can be seen in Figure 1. In this photo, slope structures with alternately distributed shale layers and tuff layers can be observed. And the mean thickness of the shale layers is about 15m and that of the tuff layers is 20m.

Figure 1. Slope with alternately distributed shale layers and tuff layers

Slope topography can amplify the seismic acceleration and thus landslides are trigged, moreover, the slope failure also easily occurs along soft layers in slopes. Some researchers (Gaztas G., 1987; Athanasopoulos et al., 1999; Qi et al, 2003; Cetin et al. 2004) find the amplification of topography by comparing earthquake damage between slope toe and slope crest, some researchers (Luzi and Pergalani, 2000; Sepúlveda et al., 2005) get the amplification of topography according to accelerometric records monitored at different place of a slope, some record shows the acceleration on crest is 3 times enlarged comparing that at bottom of the canyon. Some laboratory tests as centrifuge test (Brennan and Madabhushi, 2009) and shaking table tests (Wang et al.,1987; Xu et al., 2010) are also used to simulate the seismic performance of slopes. In recent years, some numerical simulation works have been done to study the effect of topography on slopes during earthquakes using FEM and DEM software (Qi et al, 2003; Xu et al., 2008).

From the past research works above, the studies on the effect of slope topography on the behavior during earthquake are based on limit slopes which are investigated after an earthquake disaster or tested in the lab. In numerical works, almost all slope models are built as step-like homogenous slope models with single face, which can't consider the real slopes with double faces and slope structure. The slopes are numerically analyzed based on FLAC software by which it is difficult for model building.

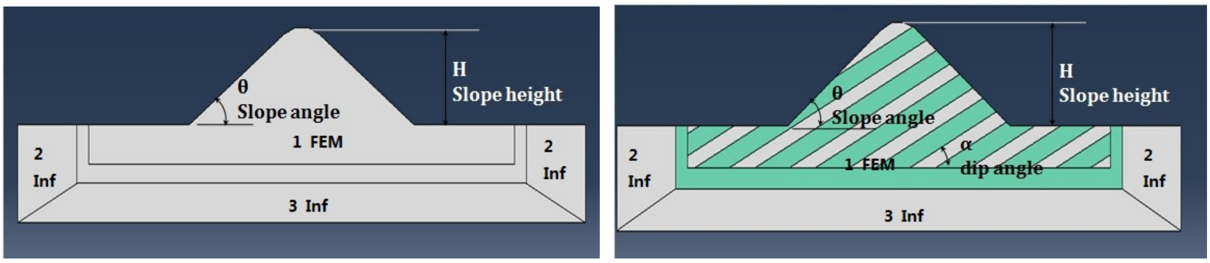
In practical cases, some nuclear plants were constructed in the sites surrounded by mountain slopes similar as Shimane NCPP. It is meaningful to study the effect of topography and slope structure on seismic acceleration response and the possible slope failure styles based on the special double-face slope models extracted from the real slopes around Shimane NCPP using ABAQUS software, which is user-friendly software and ease for model building

2. RESEARCH METHOD AND ITS VERIFICATION

2.1. Model building

Based on the real slopes investigated in field works and their geological materials, two types of analysis models are extracted using ABAQUS software (Figure 2). One is a homogenous slope model made up of tuff and the other is an alternately distributed layers slope in which the thickness of the tuff layers is 20 m and shale layers is 15 m.

For the two kinds of slope models, the height from slop toe and bottom is 100 m, and the 40 m area above bottom is bottom boundary area (3 Inf). The distance from slope toe to lateral boundary area on each side is half of the distance between the two slope toes. Two kinds of materials, tuff and shale, are for finite elements and belong to Mohr-Coulomb material, the other two kinds of materials are only for infinite elements (used for boundary condition) and belong to elastic material (Table 1).



(a)Homogenous slope (b) Slope with alternately distributed layers

Figure 2. Homogenous slope model and slope model with alternately distributed layers (1, analysis area; 2, lateral boundary area; 3, bottom boundary area)

Table 1. Mechanics parameters of the four materials used in the modeling (by **Rock Engineering**: Course notes by Evert Hoek, 2000)

Material	Density (kg/m^3)	Elastic modulus (Pa)	Poisson ratio	Cohesive strength (Pa)	Friction angle (deg.)	dilate angle (deg.)	Thickness (m)	Damping ratio
Shale	2100	2.0E+09	0.28	1.0E+06	27	2	15	3%
tuff	2200	4.0E+09	0.27	1.5E+06	30	4	20	3%
Lateral boundary	2200	4.0E+09	0.27					
Bottom boundary	2500	9.0E+09	0.25					

To simulate such semi-infinite bodys as slopes (Figure 2), all the boundary areas (2 Inf & 3 Inf) are set as infinite elements, Mohr-Coulomb models are set to the analysis region (tuff and shale), and elastic model as set to boundary infinite elements. The input of the earthquake motion using a seismic wave of acceleration is set between the top of the bottom boundary and the bottom of the slope model. The underground record at Hakuta station (8 km away from the epicenter) during the 2000 Western Tottori M7.3 earthquake is chosen as input earthquake acceleration, whose peak value is 2.54 m/s^2 (Figure 9).

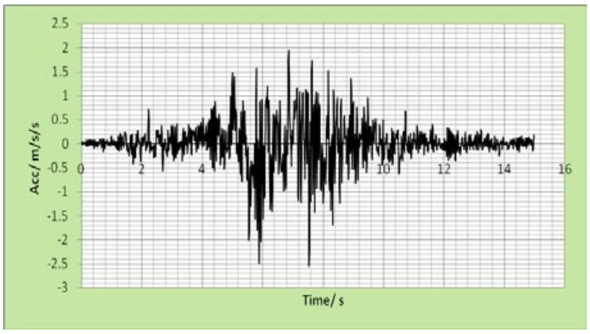


Figure 3. Input acceleration time history (http://www.kik.bosai.go.jp/kik/)

2.2. Verification of the model building way by centrifuge test result

To validate the reliability of the model-building which will be used in this study, the centrifuge test results, which were obtained by the University of Cambridge (Brennan and Madabhushi, 2009) about amplification of seismic acceleration at slope crests, are used as a reference criterion. A corresponding ABAQUS slope model is built, which is taken the same mechanics parameters and infinite element boundary condition. Under the same amplitude level earthquake input motion, at same monitored points, the ABAQUS model shows the same seismic response regularity with the centrifuge model as (1) at the bottom of the slope, the peak values and the waveform are almost the same as the input wave, (2) at the top of the slope which is far from the crest, the peak value is slightly larger than the input wave, but the waveform is almost the same as the input wave, (3) at the crest of the slope, the peak value is about 1.5 times of the input wave, and the waveform is almost the same with the input wave. The result means that the seismic wave was amplified at the crest. All the results mean the method is practically acceptable.

3. THE EFFECT OF TOPOGRAPHY AND SLOPE STRUCTURE ON SEISMIC ACCELERATION REPOSNE OF SLOPES AND SLOPE FAILURE STYLE

3.1. Studied slope models

In order to study the effect of the slope topography (slope angle and slope height) and slope angle (dip angle on seismic performance of slopes, three kinds of slopes models are built as (1) to study the effect of slope angle, three homogenous slope models with height of 100 m and different slope angles as 20 deg., 30 deg., and 40 deg., (2) to study the effect of slope height, three homogenous slope models with angle of 30 deg. and different slope heights as 75 m, 100 m, and 150 m, (3) to study the effect of dip angle, 4 alternately distributing layered slope models with slope angle 30 deg., slope height of 100 m, and different dip angles as 10 deg., 20 deg., 30 deg. and 40 deg. which present different relationship with the slop angle.

3.2. Slope topography and structure effect on seismic acceleration response

Under seismic input motion of the 2000 west Tottori earthquake shown as Figure 3, the horizontal peak values of seismic response on bottom surfaces of each slope can be gotten. The amplification factors equal to these peak values divide by the peak value of input motion, Figure 4 shows the amplification factors distribution along the slope height for each kind of slope models.

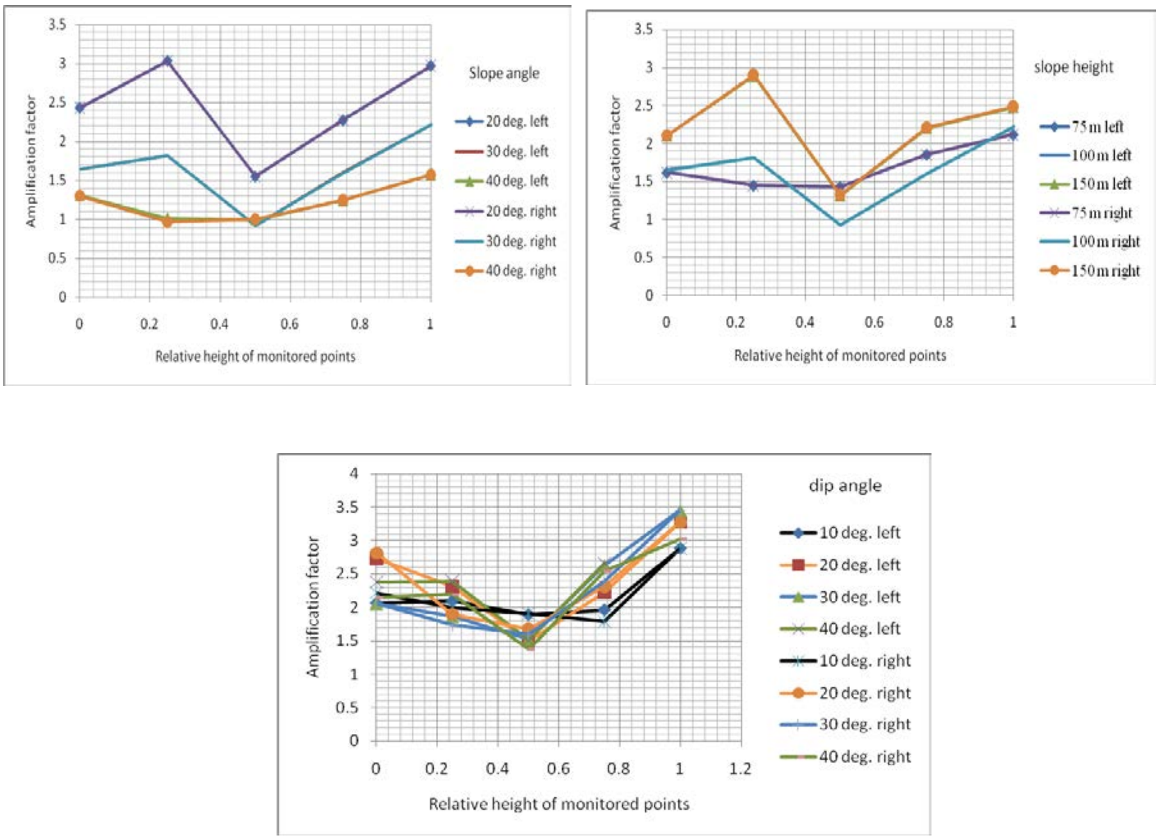
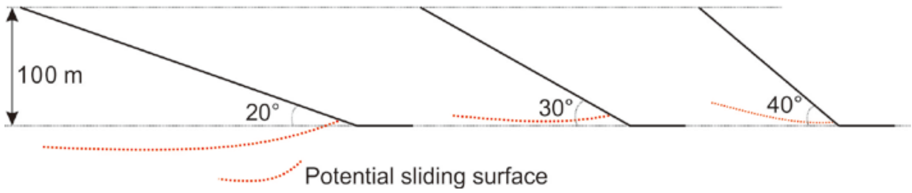


Figure 4. Seismic acceleration amplification of each monitored point along relative slope height

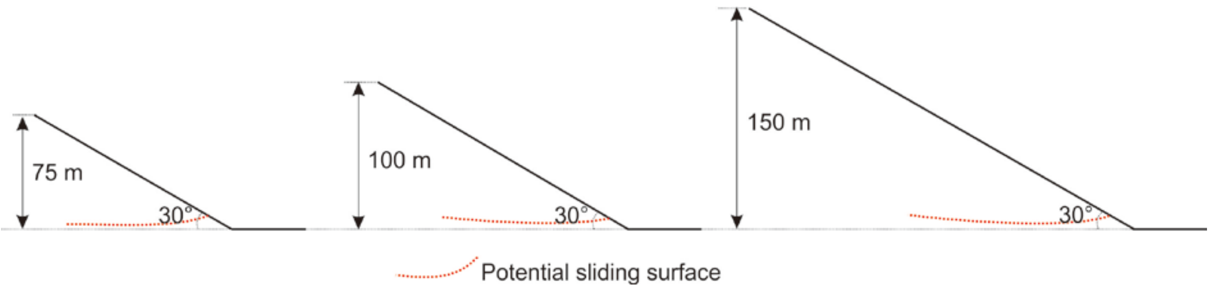
From the figure 4, the trend of the perk acceleration value is as follows: (1) The slope top has clear amplifying effect. (2) The amplification of seismic acceleration is not always becoming larger along the slope from its toe to the top. The minimum amplification always occurs at the middle slope. (3) For some slopes smaller slope angle (e.g. 20 deg.) and larger slope height (150 m), larger amplification occurs at ¼ relative slope height. (4) There is symmetry of the amplification of the both surfaces for each slope. (5) The amplification of the slopes with a smaller slope angle appears larger. (6) The amplification of the slopes with slope structure is larger than that of homogenous one.

3.3. Slope topography and structure effect on slope failure style

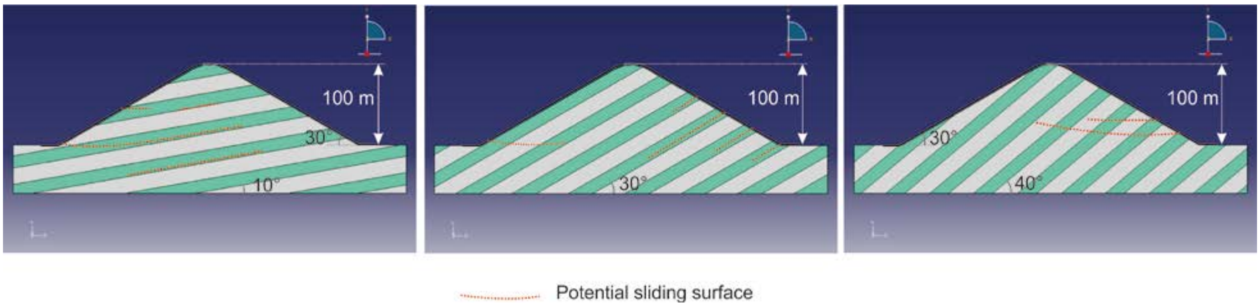
In order to get the slope failed, two times enlarged Kobe earthquake is used as input seismic input motion. Based on the results of the slope failure duo to the slope angle, the slope height and the dip angle, the corresponding slope failure schematic figure can be gotten (Figure 5).



(a) The effect of the slope angle on the slope failure style



(b) The effect of the slope height on the slope failure style



(c) The effect of the dip angle on the slope failure style

Figure 5. Schematic figure of the slope failures duo to topography and slope structure

From the Figure 5, the regularity of slope failure styles duo to the slope angle, the slope height and the dip angle are easy to find as (1) the potential sliding surface becomes higher with the slope angle increasing according to Figure 5(a), the slope angle controls the slope failure styles; (2) the potential sliding surface almost the same in Figure 5(b), the slope height has no obvious effect on the slope failure style; (3) the slope failure style is more complicated for slopes with slope structure, for slopes with smaller a dip angle than the slope angle, the potential sliding surface will be along the soft layer (shale layer), for slopes with a similar dip angle as the slope angle, the potential sliding surface will be along the soft layer (shale layer) behind and cut the alternately layers in front, for slopes with a larger dip angle than the slope angle, the potential sliding surface will cut the alternately layers and its behavior is similar as that of the corresponding homogenous slope.

6. CONCLUSIONS

Using FEM program ABAQUS, the effect of topography and dip angle on slope seismic acceleration and slope failure styles is studied. Some remarkable conclusions are summarized as follows :

(1) The slope angle and the slope height have influence on seismic acceleration response. The amplification of seismic acceleration response on the slope top is decreased with the slope angle increasing, and increased with the slope height increasing. For smaller slope angle and higher slopes, it is prone to be amplified near the slope bottom. Generally, the amplification is smaller at the middle of the slope and larger at the slope top.

(2) The slope angle affects the slope failure style very much, while the slope height has almost no effect on the slope failure style. The slope toe is prone to get damage first. The potential slope failure sliding face becomes higher with the slope angle increasing.

(3) The slope structure has clear effect on the amplification of seismic acceleration response. Compared with homogenous slope, the acceleration response is amplified obviously, especially on the slope top.

(4) The slope structure also influences slope failure style very much. If the dip angle is less than the slope angle, the slope will slide along the interface of soft layers and hard layers. If the dip angle equals to the slope angle, the slope will slide along the interface of rock layers at the back slope, while the sliding surface will occur in front of the slope with cutting the rock layers. If the dip angle is larger than the slope angle, the slope structure has less effect on the slope failure style. The slope failure style is similar as that of a homogenous slope.

(5) FEM ABAQUS is a useful tool for dynamic analysis of slope response under seismic loading.

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