

Comparison of Russian, Chinese and European seismic design on pseudo-static seismic coefficient in slope analysis

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Abstract: Most design codes and specifications recommend a simple pseudo-static approach for the analysis of slope stability under seismic conditions. The codes in different countries appoint different pseudo-static seismic coefficient. The present work list different seismic coefficients in Russian, Chinese and European codes. A sensitivity analysis of a case slope was carried out using GeoStudio, then determined that the stability of the slope is more sensitive to material cohesion and seismic coefficient than material density and friction angle. It's shown that the chosen of the seismic coefficient has a big effect on slope stability.

Keywords: codes; seismic coefficient; pseudo-static method; sensitivity analysis; slope stability.

1. Introduction

In Russia, China and Europe there are a few territories suffering from earthquakes, such as Greater Sochi, Province Sichuan, and Italy. These regions are susceptible to seismic landslides or slope failure [1-3]. Although dynamic analysis with considering ground-motion is more advanced than the simplified pseudo-static analysis, most design codes and specifications still recommend the pseudo-static method for conventional projects. In Russia, there are some codes relating to the pseudo-static method for slope analysis, like ODM 218.2.006-2010 [4]. In China different industries specifies different codes on seismic design of slope, like DZ/T0219-2006, DL5073-2000, GB50330-2013, JTJ044-89 and GB50111-2006 [5-9]. In Europe Eurocode 8 is widely used for slope analysis under seismic condition [10]. In pseudo-static method seismic coefficient appears to be the most important parameter for slope stability analysis. It should be mentioned that the seismic coefficient specified in many codes in China came from the previous codes in USSR [11]. Therefore those values in Chinese codes are same as Russian codes. However, a specification released by China Geological Survey gives a different value from others [5]. In present work, Russian code "ODM 218.2.006-2010" [4], Chinese code "DZ/T0219-2006" [5] and European code "Eurocode 8" [10] are compared on pseudo-static seismic coefficient.

2. Simplified pseudo-static analysis

A pseudo-static analysis represents the effects of earthquake shaking by accelerations that create inertial forces. These forces act in the horizontal and vertical directions at the centroid of each slice. In present work, only the horizontal force is considered, as shown in Figure 1. The seismic force is defined as:

$$F_h = k_h W \quad (1)$$

where: k_h – horizontal seismic coefficient; W – the material weight.

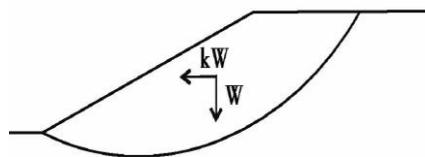


Figure 1. Schematic map of slope analysis with seismic force

3. Pseudo-static seismic coefficients in Russian, Chinese and European codes

Russian code “ODM 218.2.006-2010” specifies seismic coefficients referring to different earthquake intensity as table 1 shows. While, Chinese code “DZ/T0219-2006” and European code “Eurocode 8” indicates values of seismic coefficient which are more than counter-value of Russian code (see table 2-3). It's shown that seismic coefficient in Chinese code can be twice than Russian code; seismic coefficient in European code – 4 times than Russian code.

Table 1. Seismic coefficient in Russian code “ODM 218.2.006-2010”

Earthquake intensity	7	8	9
Design ground acceleration	0.1g	0.2g	0.4g
Seismic coefficient	0.025	0.05	0.1

Table 2. Seismic coefficient in Chinese code “DZ/T0219-2006”

Earthquake intensity	7	8	9
Design ground acceleration	0.1g	0.2g	0.4g
Seismic coefficient	0.1	0.2	0.4

Table 3. Seismic coefficient in European code “Eurocode 8” on type A ground

Earthquake intensity	7	8	9
Design ground acceleration (when according to MSK-64)	0.1g	0.2g	0.4g
Seismic coefficient	0.05	0.1	0.2

4. Sensitivity analysis of physical-mechanical and seismic parameters

The simple landslide models with 8 different slope angles of 10, 20, 30, 40, 50, 60, 70 and 80 are considered in the GeoStudio software with limit equilibrium method (Fig.2). A sensitivity analysis can help analyze which parameter the stability of the slope is more sensitive to [12]. SLOPE/W of GeoStudio allows to specify a value range of the material parameters and seismic effect, and will compute the safety factor automatically when each value of the parameters is used [13]. Based on the experimental result of a mudstone slope case in Sochi (see table 4), the variability of the material properties is known: the unit weight is 18-20 kN/m³, cohesion is 10-25 kPa and friction angle is 25-30°. Regarding seismic coefficient, earthquake intensity is set to be 8, and the range of values is based on the boundary of different codes. As for Russia, seismic coefficient equals 0.05 according to Russian code “ODM 218.2.006-2010” (see table 1). In Chinese code “DZ/T0219-2006 Specification of design and construction for landslide stabilization”, seismic coefficient equals 0.2 corresponding to intensity 8 (see table 2). While, Eurocode 8 applied in many European countries indicates that seismic coefficient equals 0.1 in the condition of the design ground acceleration 200 cm/s² on type A ground (see table 3). Based on those codes the variation of seismic coefficient is considered from 0.05 to 0.2 during the sensitivity analysis, as shown in table 4.

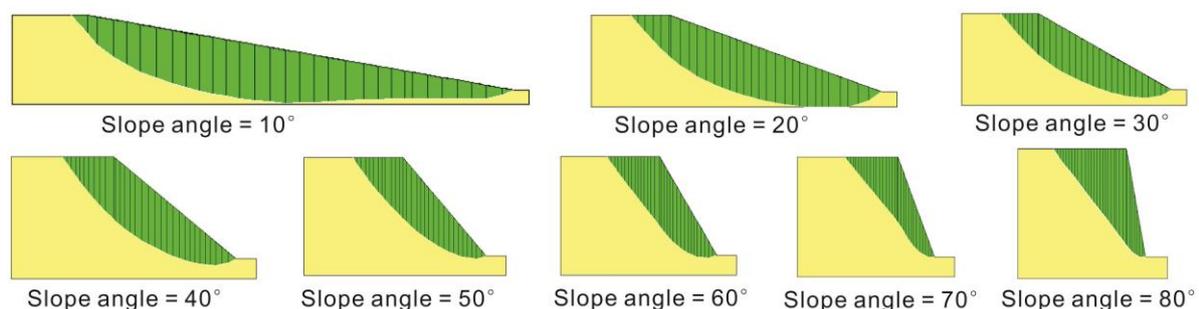


Fig. 2. Analysis models for slope stability from eight different slope angles (10°, 20°, 30°, 40°, 50°, 60°, 70° and 80°)

Table 4. The basic mudstone physical and mechanical parameters of studied slopes and seismic coefficients

	Unit weight (kN/m ³)	Cohesion (kPa)	Friction angle (°)	Horizontal seismic coefficient according to different codes
Range of values	18-20	10-25	25-30	0.05-0.2
Average value	19	17.5	27.5	0.125

The sensitivity analysis was then conducted in slope models with various slope angles. For presentation purposes, all the strengths are normalized to a value ranging between 0.0 and 1.0. Zero means the lowest value and 1.0 means the highest value. For the example here, zero means a cohesion of 10 kPa and a seismic coefficient of 0.05. A value of 1.0 means a cohesion of 25 kPa and a seismic coefficient of 0.2.

Sensitivity graphs (Fig. 3-10) show the computed factor of safety (FOS) at different values of the parameters. The crossing point represents the safety factor when the average value of all the parameters is used (see table 1). The results of 8 sensitivity graphs indicate that the safety factor is most sensitive to the cohesion and seismic coefficient, and is least sensitive to the material unit weight and friction angle.

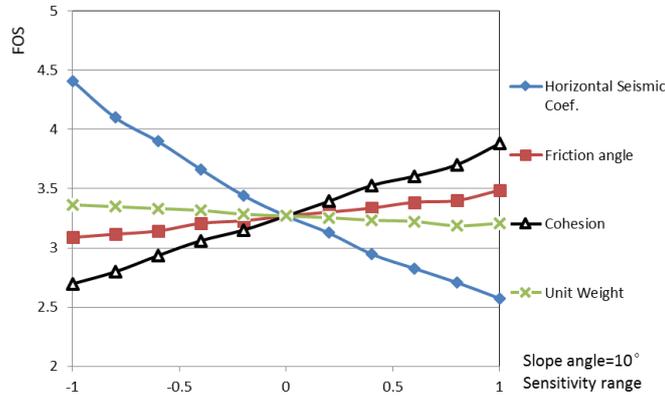


Fig. 3. Sensitivity graph for slope stability with slope angle = 10° : the safety factor of the slope is most sensitive to the seismic coefficient.

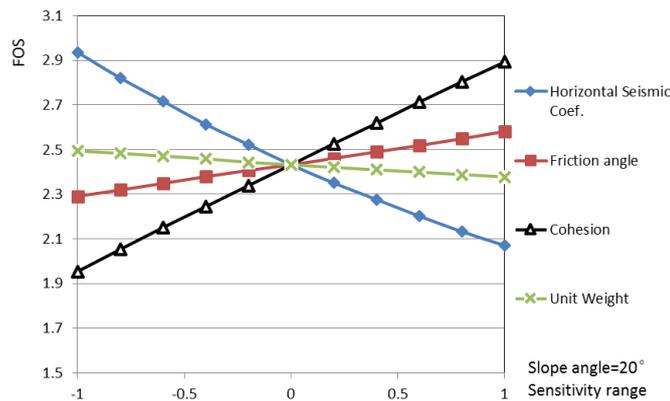


Fig. 4. Sensitivity graph for slope stability with slope angle = 20° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

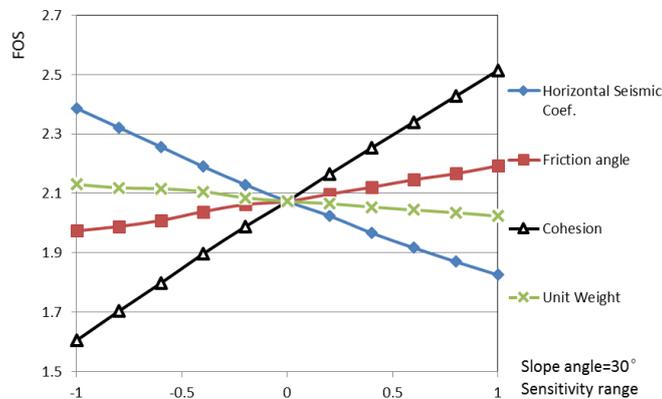


Fig. 5. Sensitivity graph for slope stability with slope angle = 30° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

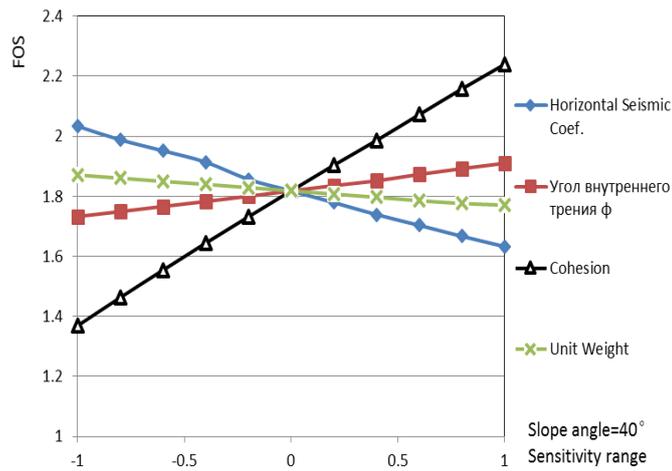


Fig. 6. Sensitivity graph for slope stability with slope angle = 40° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

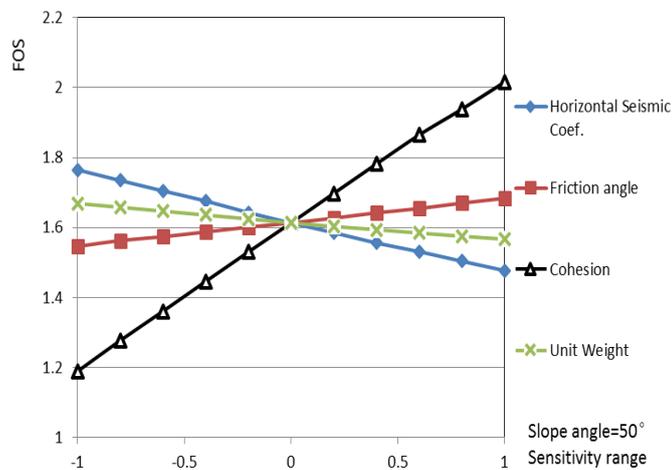


Fig. 7. Sensitivity graph for slope stability with slope angle = 50° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

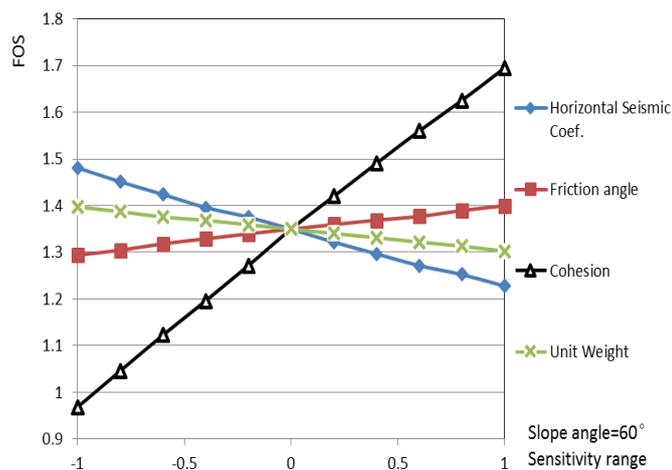


Fig. 8. Sensitivity graph for slope stability with slope angle = 60° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

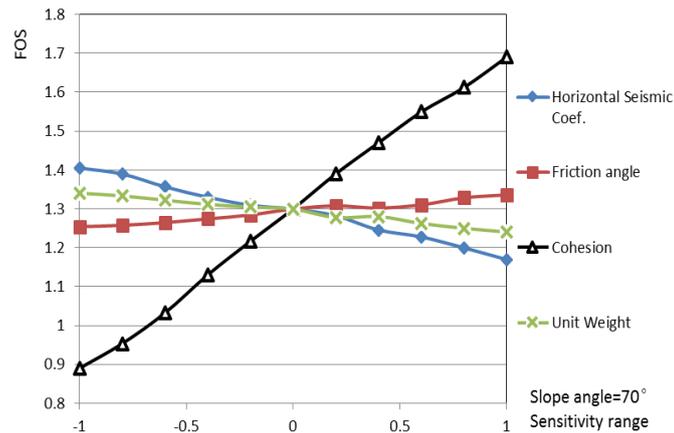


Fig. 9. Sensitivity graph for slope stability with slope angle = 70° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

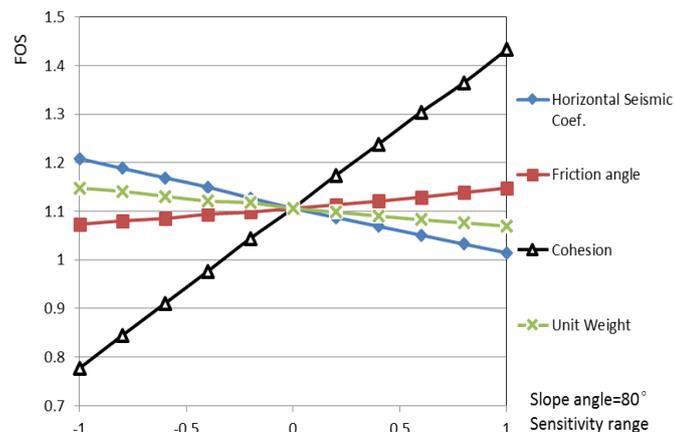


Fig. 10. Sensitivity graph for slope stability with slope angle = 80° : the safety factor of the slope is most sensitive to the cohesion, while is more sensitive to the seismic coefficient than unit weight and friction angle.

5. Conclusions

The different seismic coefficients in Russian, Chinese and European codes are presented. The seismic coefficient turned to be a crucial influence factor on slope stability. A sensitivity analysis shows that the stability of the slope is more sensitive to seismic coefficient and cohesion than material unit weight and friction angle. The chosen of the seismic coefficient has a big effect on slope stability. How to choose a rational seismic coefficient is future work.

6. References

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