A methodology to select seismic coefficients based on upper bound “Newmark” displacements using earthquake records from Turkey

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A B S T R A C T

Strong motion records taken during earthquakes in Turkey are used to calculate Newmark displacements in slopes. These displacements are then utilized in developing a novel displacement-based methodology to select the seismic coefficient which is used to calculate pseudostatic safety factor. In the first step of the study, calculated Newmark displacements are evaluated in three different categories which are as follows: using all data, using data for different earthquake magnitude (M) ranges with and without distance constraint and using data for different peak acceleration (\(a_{\text{max}}\)) ranges. For all categories, different equations are obtained to assign slope displacements as a function of the ratio of yield acceleration to peak acceleration. The results show that categorization of data is an important issue, because the displacements are earthquake magnitude and peak acceleration dependent. In the second step, equations obtained for different peak acceleration ranges are used to propose charts linking upper bound slope displacements (\(D\)), seismic coefficients (\(k_h\)) and pseudostatic safety factors (PSF), which are three important parameters of a pseudostatic approach. This enables the \(k_h\) values be chosen based on the allowable displacements, instead of the current applications based on judgement and expertise. The results show that \(k_h\) values for any allowable displacement should be based on anticipated \(a_{\text{max}}\) values, while use of high PSF values results in lower displacements. Extensive comparison with solutions from the literature is also made. The methodology is best suited for earthquake triggered shallow landslides in natural slopes, consisting of materials which do not lose strength during dynamic loading.

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1. Introduction

Earthquake induced landslides have caused great damage and loss of life throughout history. Earthquake motions can generate significant horizontal and vertical dynamic stresses in natural and manmade slopes and embankments. Increases in shear stresses may result in exceedance of available shear strength on potential failure planes and slopes become unstable. Consequently, depending on the characteristics of the earthquake motion and the slopes, damage is observed [1]. Since their damage potential is well acknowledged, landslides caused by ground shaking are important for spatial earthquake damage assessment studies [2–6].

There are two different conventional methods to evaluate the performance of slopes under seismic loading: application of a seismic coefficient to calculate the pseudostatic safety factor or calculation of permanent displacements. Both of these approaches employ pseudostatic limit equilibrium analysis. Until around 1960s, engineers employed a seismic coefficient to access the safety factor of dams and embankments [7]. In the current state of the art, seismic coefficient values coupled with minimum pseudostatic safety factors are still used in pseudostatic analysis, where selected seismic coefficients rely on expertise and judgement. However, safety factor approach does not give any idea about the deformations that are expected to occur during earthquake loading. Deformation is a better indicator of slope performance and therefore seismic slope stability is evaluated more and more frequently based on the permanent deformation rather than the safety factor criterion [8]. In this context, Newmark’s [9] sliding block model is a widely used tool to calculate permanent slope displacements. The displacements are mostly calculated by equations based on yield (\(a_y\)) and maximum accelerations (\(a_{\text{max}}\)).

Based on the above arguments, there is a need to link slope displacements, seismic coefficients and pseudostatic safety factors founded on sound methodology. This will enable the designers to predict slope displacements based on selected seismic coefficients. In this paper, permanent slope displacements are calculated through the Newmark[9] method using Turkish earthquake data. Equations are sought between slope displacement (\(D\)) and acceleration ratio (\(a_y/a_{\text{max}}\)). Displacement data are investigated with and without categorization. The categorizations are made with respect to earthquake magnitude (\(M\)) ranges and peak acceleration (\(a_{\text{max}}\)) ranges. Average and upper bound displacement equations are developed.

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