Soil Dynamics and Earthquake Engineering 30 (2010) 875–878

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Technical Note

Seismic stability analysis of gravity retaining walls

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ARTICLE INFO

Article history:
Received 22 September 2009
Received in revised form
1 February 2010
Accepted 3 April 2010

Keywords:
Seismic stability
Limit analysis
Gravity retaining walls
Yield acceleration

ABSTRACT

A new approach based on the category of upper bound theorem of limit analysis is presented in this study to consider the seismic stability of gravity retaining walls. The retaining wall and the backfill soil were taken as a whole system. For a translational failure mechanism assumed, formulas are provided to calculate directly the yield acceleration and the inclination of the failure surface. An example is shown to illustrate the method. Comparisons are made with limit equilibrium method, and the results are found consistent. Based on a limited parametric study, it is shown that the wall roughness has remarkable influence on the yield acceleration.

1. Introduction

Gravity walls are widely used as earth retaining systems supporting fill slopes adjacent to roads and residential areas, also in regions prone to earthquake. Many researchers have developed design methods for retaining walls during earthquakes by using different approaches. Though the quest for rational design methods of retaining structures has been pursued for several decades, deformations ranging from slight displacement to catastrophic failure have been observed in many earth retaining structures during the recent major earthquakes, including the 1999 Ji-Ji earthquake [1], the 2004 Chuetsu earthquake [2], and the 2008 Wenchuan earthquake [3].

To date, the theoretical approach is the most widely used method to analyze seismic stability of earth retaining structures. The majority of the methods used by practitioners usually require estimating the earth pressure behind the wall and expressing the stability of soil structure by a factor of safety. The effect of earthquake is represented pseudo-statically by an approximate static force acting in the horizontal direction. To compute the active earth thrust acting against retaining walls in seismic conditions, the Mononobe–Okabe method or its extensions are most widely used [4–6]. The Mononobe–Okabe solution treats earthquake loads as pseudo-dynamic, generated by uniform acceleration in the backfill. The retained soil is considered as perfect plastic material, which fails along a planar surface, thereby exerting a limit thrust on the wall. The method has prevailed mainly due to its simplicity and the familiarity of engineers with the Coulomb method. However, the Mononobe–Okabe method presents a basic shortcoming: the solution is based on the limit equilibrium of the soil wedge without taking into account the presence of the wall. Caltabiano et al. [7] suggested a new solution based on the pseudo-static equilibrium of the soil–wall system and applied it to soil–wall systems with surcharged backfills. More recently, Mylonakis et al. [8] presented a stress plasticity solution for determining gravitational and earthquake-induced earth pressures on gravity walls retaining cohesionless soil. The solution is essentially an approximate slip line approach, based on the theory of discontinuous stress fields, and takes into account the following parameters: (1) weight and friction angle of the soil material, (2) wall inclination, (3) backfill inclination, (4) wall roughness, (5) surcharge at soil surface, and (6) horizontal and vertical seismic acceleration.

The finite element method is certainly the most comprehensive approach to analyze the performance of soil structures subjected to seismic loading. Psarropoulos et al. [9] utilized the finite-element method to study the dynamic earth pressures developed on rigid or flexible non-sliding retaining walls. And more recently, a two-dimensional, effective-stress finite element procedure in conjunction with a generalized elasto-plastic constitutive model, with slight modifications, was conducted by Alyami et al. [10]. Certainly, the finite element method has some advantages in considering the natural failure mechanisms and the interaction of structure–soil system, however, its use usually requires high numerical costs and accurate measurements of the properties of the component materials, which are often difficult to achieve. This makes the use of finite element method not very attractive for current applications.

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doi:10.1016/j.soildyn.2010.04.005