Soil Dynamics and Earthquake Engineering 31 (2011) 1311–1323

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Pseudo-static limit analysis by discontinuity layout optimization: Application to seismic analysis of retaining walls

C.C. Smith [a,*], M. Cubrinovski [b]

[a] Department of Civil and Structural Engineering, University of Sheffield, Sheffield, UK
[b] Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

ARTICLE INFO

Article history:
Received 10 August 2010
Received in revised form
18 March 2011
Accepted 30 March 2011
Available online 28 May 2011

ABSTRACT

Discontinuity layout optimization (DLO) is a recent development in the field of computational limit analysis, and to date, the literature has examined the solution of static geotechnical stability problems only by this method. In this paper the DLO method is extended to the solution of seismic problems though the use of the pseudo-static approach. The method is first validated against the solutions of Mononobe–Okabe and Richards and Elms for the seismic stability of retaining walls, and then used to study the effect of a wider range of failure modes. This is shown to significantly affect the predicted stability. A framework for modelling water pressures in the analysis is then proposed. Finally an example application of the method is illustrated through the assessment of two quay walls subjected to the Kobe earthquake.

1. Introduction

Various methods have been developed for seismic analysis of retaining structures ranging from simplified pseudo-static methods to sophisticated dynamic numerical procedures in which detailed response of the soil–structure system is considered including effects of excess pore water pressures and complex stress–strain behaviour of soils [1]. Key objectives in the assessment of seismic performance of retaining walls are to estimate the threshold acceleration (earthquake load) required for triggering instability of the system and to estimate the permanent wall displacements caused by earthquakes.

In the simplified approach, these objectives are achieved in two separate calculation steps. In the first step, a pseudo-static analysis typically based on the conventional limit equilibrium approach is conducted to estimate the threshold acceleration level required for onset of permanent wall displacements. In this analysis, the seismic earth pressure from the backfill soils is commonly approximated by the Mononobe–Okabe solution [2,3]. In the second calculation step, a simplified dynamic analysis is carried out in which the displacement of the wall due to an earthquake is estimated using a rigid sliding block analogy [4,5]. Strictly speaking, the Mononobe–Okabe method is applicable only to gravity retaining walls that undergo relatively large displacements and develop the active state of earth pressures in the backfills. Even for these cases the method is seen only as a relatively crude approximation of the complex seismic interaction of the soil–wall system and ground failure in the backfills. Experimental evidence suggests however that the dynamic earth pressure estimated by the Mononobe–Okabe solution is reasonably accurate provided that the method is applied to a relevant problem [6,7] and with an appropriate value for the effective angle of shearing resistance ϕ'.

In this context, a modification of the Mononobe–Okabe method and alternative simplified pseudo-static approaches have been recently proposed allowing for a progressive failure in the backfills [8,9]. The single most significant shortcoming of the simplified pseudo-static approach arises from the assumption that dynamic loads can be idealized as static actions. In the case of gravity retaining walls, the key questions resulting from this approximation are what is the appropriate level (acceleration or seismic coefficient) for the equivalent static load and how to combine effects of seismic earth pressures and inertial loads in the equivalent static analysis. Clear rules for the definition of the equivalent static actions have not been established yet, thus highlighting the need for systematic parametric studies when using the pseudo-static approach for assessment of the seismic performance of retaining structures.

In spite of these limitations however, classical theories and simplified solutions based on these theories are likely to remain of practical value even when sophisticated deformation analyses are readily available. This is particularly true for problems involving significant uncertainties in soil parameters, field conditions, stress–strain behaviour of soils and earthquake loads (*e.g.* representative

* Corresponding author.
E-mail address: c.c.smith@sheffield.ac.uk (C.C. Smith).

0267-7261/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soildyn.2011.03.014