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Seismic uplift capacity of shallow horizontal strip anchor under oblique load using pseudo-dynamic approach

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Abstract

In this paper, an analytical method to compute the uplift capacity of an obliquely loaded horizontal strip anchor under both static and seismic conditions is described using the limit equilibrium method. The distribution of the soil reactions on a simple planar failure surface is obtained through the use of Kötter's equation, and the pseudo-dynamic approach is used to obtain the net seismic vertical uplift capacity factor for the unit weight component of the soil ($F_{\gamma d}$). The results for the static and seismic vertical uplift capacity factors are determined for various combinations of input parameters, such as the load inclination, the soil friction angle, the embedment ratio, the soil amplification and both horizontal and vertical pseudo-dynamic seismic accelerations. It is observed that the orientation of the load significantly affects the seismic uplift capacity of the horizontal strip anchor. $F_{\gamma d}$ is seen to decrease with an increase in both horizontal and vertical seismic accelerations and soil amplification, whereas it is seen to increase with an increase in the embedment ratio and the soil friction angle, as expected. The results in terms of the non-dimensional net seismic uplift capacity factor are presented in graphical and tabular forms. The present results are compared and found to be in good agreement with similar results available in literature.

Keywords: Horizontal strip anchor; Kötter's equation; Oblique load; Limit equilibrium method; Pseudo-dynamic approach; Soil amplification; Seismic uplift capacity; Closed-form analytical solution

1. Introduction

Ground anchors are commonly used as foundation systems for important structures requiring uplift resistance, such as transmission towers, pipe lines buried under water, sheet pile walls, etc. It is well known that horizontal anchors are subjected to the vertical uplift load, and that when it reaches the ultimate load condition, failure surfaces develop around the anchor plate. These failure surfaces reach the ground surface for shallow anchors. The problem becomes more complex and important under seismic conditions due to the devastating nature of earthquake forces on such ground anchors. The importance of the computation of the vertical uplift capacity of horizontal ground anchors is clear; it is an important topic for geotechnical engineers to address, under both static and seismic conditions. Hence, the effect of earthquakes on the uplift capacity of a strip anchor is studied in the present theory, as this knowledge is vital to the study of the behavior of strip anchors under seismic conditions.

For static conditions, numerical solutions for the uplift capacity of horizontal anchors were obtained using the limit equilibrium method (Vesic, 1971; Meyerhof and Adams, 1968). The finite element method was used with a limit analysis to

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compute the uplift capacity of anchors (Kumar and Kouzer, 2008; Merifield and Sloan, 2006; Tagaya et al., 1983). Experimental results and analytical solutions were obtained using the limit equilibrium method and a limit analysis (Rowe and Davis, 1982; Murray and Geddes, 1987; Tagaya et al., 1988; Dickin and Laman, 2007). Analytical models were presented by some researchers (Chattopadhayay and Pise, 1986; Deshmukh et al., 2011), whereas Kumar (1999) and Subba Rao and Kumar (1994) used an upper bound limit analysis to predict the pullout capacity of ground anchors, and Honda et al. (2011) employed a two-dimensional distinct element analysis to obtain the uplift capacity of belled and multi-belled piles in sand. Series of centrifuge tests were presented by Hugo et al. (2010) to determine the effect of gapping on the uplift capacity of a shallow skirted foundation. Miyata et al. (2011) obtained the accuracy of a single square anchor plate for obtaining the capacity in a multi-anchor wall system by applying two models.

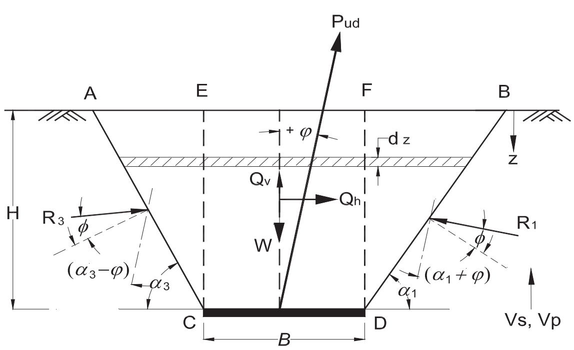

Fig. 1. The typical model considered under seismic conditions.

Few researchers have obtained the vertical uplift capacity of horizontal plate anchors under seismic conditions (Kumar, 2001; Choudhury and Subba Rao, 2004; Rangari et al., 2011a).

Based on field and laboratory tests, a semi-empirical relation was developed for the breakout resistance of a horizontal strip anchor under an oblique load by Meyerhof (1973). Das and Seeley (1975), on the other hand, obtained model test results for a square anchor in dry sand subjected to inclined loads and presented in graphical form.

A pseudo-dynamic approach, developed by Steedman and Zeng (1990) and upgraded by Choudhury and Nimbalkar (2005), was used by Ghosh (2009) to obtain the seismic uplift capacity of a horizontal plate anchor by considering the effect of seismic amplification using an upper bound limit analysis and assuming a simple planar failure surface.

In a pseudo-static analysis, the dynamic loading induced by an earthquake is considered as time-independent, which ultimately assumes that the magnitude and the phase of the acceleration are uniform throughout the depth of the soil layer. Also, in a pseudo-static analysis, the effect of the amplification of vibrations cannot be considered; this effect generally occurs towards the ground surface and depends on various soil parameters, such as damping and the shear modulus of the soil (Steedman and Zeng, 1990). Rectifying these shortcomings of the pseudo-static approach, Steedman and Zeng (1990) proposed a pseudo-dynamic approach, which considers the effect of the finite shear wave velocity, horizontal seismic acceleration and the amplification of vibrations, to obtain the active earth pressure on retaining walls for a particular value of soil friction angle. Later, Choudhury and Nimbalkar (2005) modified the approach further to consider the effect of vertical acceleration also due to vertically propagating primary waves along with horizontal seismic acceleration; they

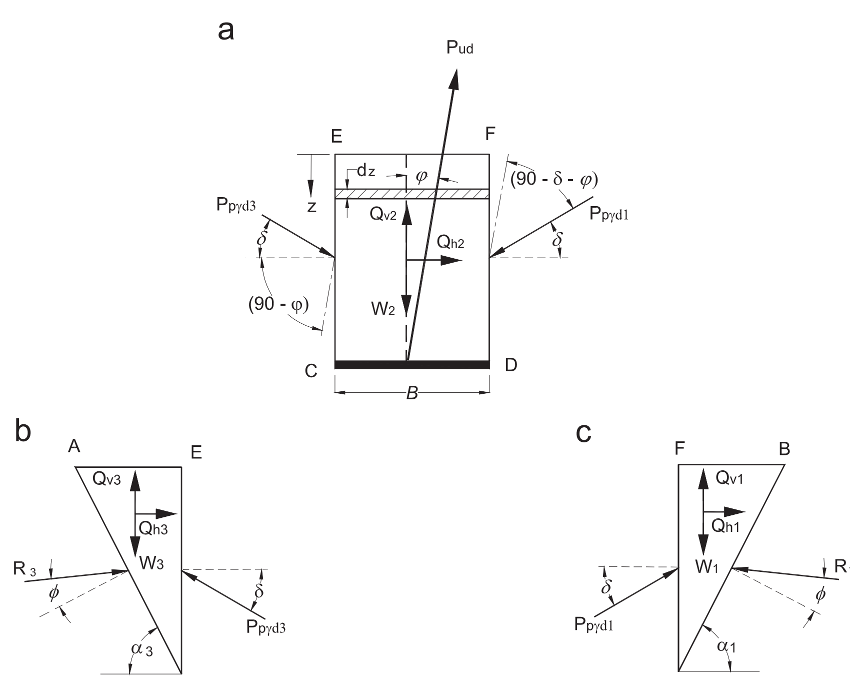

Fig. 2. Free body diagram with various forces on failure wedges.