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Simplified Failure-Load Envelopes for Shallow Foundation on Dense Sand

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ABSTRACT

Prediction of the ultimate load capacity of shallow, sand-supported foundations carrying vertical (*V*), horizontal (*H*) and moment (*M*) loads is a fundamental offshore engineering problem. The paper demonstrates how the complete failure-envelope of such a foundation, represented by a system of parabolas and rotated ellipses, can be transformed into either a 45° inclined *straight line* or a *unit circle* by referring the applied loads to an origin located below the foundation centreline. The conjugate transformation applied to the corresponding displacements generates a symmetry amongst them, for symmetrical load paths, not otherwise apparent. Extensive, model-scale, experimental data are presented that provide strong support for the simple, transformed failure-envelopes.

INTRODUCTION

Prediction of the load-capacity and load-displacement response of shallow, rigid footings on granular soils is perhaps the fundamental problem in foundation engineering. Even if the applied loads are essentially static, the problem in relation to offshore structures is complicated by: (i) the presence of relatively large horizontal loads applied well above seabed level, and (ii) the occurrence of complex, service-state, load-unload paths. These invariably generate substantial moment loading on the structure and therefore, almost without exception, the foundations have to resist combinations of vertical loads (V), horizontal loads (H) and moments (M). The latter can be transformed to have dimensions of force by using (M/B) in lieu of M. B is the characteristic 'breadth' of the footing. Forces and displacements are usually calculated using O (Fig. 3) as the reference point.

FAILURE ENVELOPES

Over the past few years an elegant method of presenting load-capacity data has been established for shallow, rigid foundations in the form of a 3-D failure-envelope with (*V,H,M/B*) axes (Ticof, 1977; Butterfield and Ticof, 1979; Butterfield, 1980, 1981; Georgiadis and Butterfield, 1988; Gottardi, 1992; Gottardi and Butterfield, 1993, 1995; Butterfield and Gottardi, 1994).

Fig. 1 is a stereo-pair of such a failure-envelope established by 67 sets of data points obtained from numerous plane-strain model tests on dense Adige and Leighton-Buzzard sands (at high relative densities *Dr*: $75\% \le Dr \le 85\%$) using model, rough, rigid, surface footings with breadths ranging over ($50 \le B \le 100$)mm (Ticof, 1977; Georgiadis and Butterfield, 1988; Gottardi, 1992). In this figure all planes which contain the *V* axis intersect the surface in simple, second order parabolas, whereas sections parallel to the (*M/B* – *H*) plane intersect the surface in rotated ellipses.

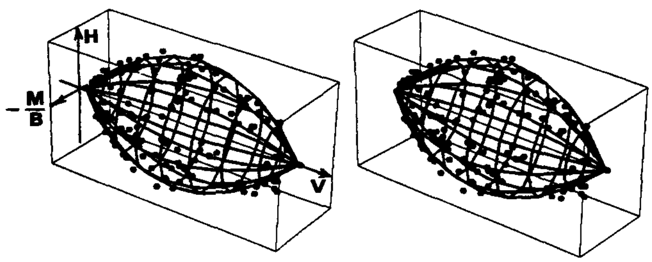

Fig. 1 Stereo-pair of complete failure-envelope for surface footing subject to vertical, horizontal and moment loading

The equations to the *V* versus *H* and *V* versus *M/B* parabolas, which involve V_{max} the fundamental (assumed known) vertical, centreline load capacity of the footing, are:

$$(H/t_h) = (V/V_{max})\cdot(V_{max}-V) \text{ and } (M/B\cdot t_m) = (V/V_{max})\cdot(V_{max}-V) \quad (1)$$

$t_h = \tan(\delta_h)$, δ_h is therefore the pad-soil friction angle (since, in the first of Eq. 1, $H \to V\cdot\tan(\delta_h)$ as V approaches 0) and $t_m = \tan(\delta_m)$ are the corresponding quantities in the second of Eq. 1. The values for these parameters, established from the above results (Butterfield and Gottardi, 1994), are $t_h = 0.52$ (i.e., $\delta_h = 27.5°$) and $t_m = 0.35$ (i.e., $\delta_m = 19.3°$).

Since the basic soil-strength properties, footing size and shape factors have all to be taken into account when deducing V_{max} it is anticipated that the form of the normalised failure-envelopes presented will be widely applicable. The equation for the complete Fig. 1 failure-envelope, on which all load combinations causing failure of such footings must lie, is (Butterfield and Gottardi, 1994):

$$(H/t_h)^2+(M/Bt_m)^2-2C(M\cdot H)/(Bt_ht_m) = \{(V/V_{max})\cdot(V_{max}-V)\}^2 \quad (2)$$

Such a surface has inclined elliptic cross-sections in all (*M/B* – *H*) planes and *C*, ρ and the axis-ratio (a/b) are interrelated by the following equations (Appendix, Section 1):

$$(a/b)^2 = \{1-(\tan\rho\cdot t_m/t_h)^2\}/\{(t_m/t_h)^2 - \tan^2\rho\} \quad (3)$$

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KEY WORDS: Bearing capacity, footing, sand, shallow, failure-envelope, displacements, interaction diagram.