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Prediction of Anchor Trajectory During Drag Embedment in Soft Clay

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This paper presents a method of trajectory prediction based on an upper bound collapse load analysis of the anchor together with published solutions for anchor line response. Inputs for the model include a dimensionless collapse load parameter and a critical inclination angle at which the collapse mechanism transitions from a translational to a rotational failure mode. The model also requires a user-specified initial entry angle of the fluke and the inclination of the anchor line at the seabed. Evaluation of the model from 2 case studies shows good agreement between computed and measured trajectories. Anchor characteristics, initial anchor orientation, and anchor line angle at the seabed significantly affect trajectory predictions.

INTRODUCTION

Drag anchors are an attractive option for moorings in deep water, particularly for mobile offshore drilling units (MODU), due to their relatively low installation cost, the extensive experience base with temporary moorings, and their relatively high holding capacities even in soft clays. Further, they can be easily removed and re-used on other projects. Prediction of the load capacity of a drag embedment anchor involves 2 tasks: Determining the anchor trajectory (depth versus drag distance) during installation, and determining the pullout capacity corresponding to that trajectory. As most offshore soil strength profiles increase with depth, pullout capacity correspondingly increases and realistic prediction of embedment is critical to achieving reliable estimates of load capacity. Due to the complexity of the penetration process, achieving reliable predictions of trajectory often proves to be the more challenging of the 2 tasks. Accordingly, the offshore industry has largely relied on empirical methods to predict anchor penetration depth and load capacity (e.g., Naval Civil Engineering Laboratory, 1987). To develop solutions that may be used with greater confidence than purely empirical models, more recent contributions have introduced rational approaches such as limit equilibrium analyses (Stewart, 1992; Neubecker and Randolph, 1996; and Dahlberg, 1998), plasticity theory supported by finite element studies of soil-anchor interactions (O'Neill et al., 2003), and analytical formulations for anchor line response (Vivatrat et al., 1982; Neubecker and Randolph, 1995). Aubeny et al. (2005) present an alternative upper bound collapse load analysis of a drag anchor that forms the basis of the trajectory prediction model presented here. This predictive model applies to drag embedment in soft clays with a linearly varying soil strength profile. The model involves a recursive algorithm that can be executed with modest computational effort, such as a spreadsheet or personal computer environment. It will be seen that anchor load capacity and trajectory are actually interrelated; however, this paper focuses on trajectory, with load capacity introduced primarily as it relates to trajectory.

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BACKGROUND

The problem under consideration involves a drag embedment anchor comprising the shank, planar fluke and anchor line shown in Fig. 1. The force at the shackle point T_a is oriented at an angle θ_a from horizontal. The angle between the fluke and shank is designated as θ_{fs}, and the fluke and shank are oriented θ_f and θ_s from horizontal, respectively.

Aubeny et al. (2005) compute a unique combination of T_a and θ_a at a given point in the anchor trajectory based on the intersection of 2 curves in T_a-θ_a space (Fig. 2). The first curve is the anchor line equation relating tension at the shackle point to inclination angle (Neubecker and Randolph, 1995):

$$T_a(\theta_a^2 - \theta_0^2)/2 = zE_nN_cb(S_{u0} + kz/2) \tag{1}$$

where T_a = anchor line tension at shackle point; θ_a = anchor line angle from horizontal at shackle point; θ_0 = angle of anchor line from horizontal at mudline; E_n = multiplier to be applied to chain bar diameter; N_c = bearing factor for wire anchor line; b = chain bar or wire diameter; S_{u0} = soil undrained shear strength at mudline; k = soil strength gradient with respect to depth; and z = depth below mudline.

As anchor embedment increases, the anchor line T_a-θ_a locus shifts rightward, as shown in Fig. 2. Estimates of the bearing factor N_c for the anchor line vary from 7.6 to 12. Analyses reported here use N_c = 12, from the solution of Randolph and Houlsby (1984) for translation of a rough cylinder.

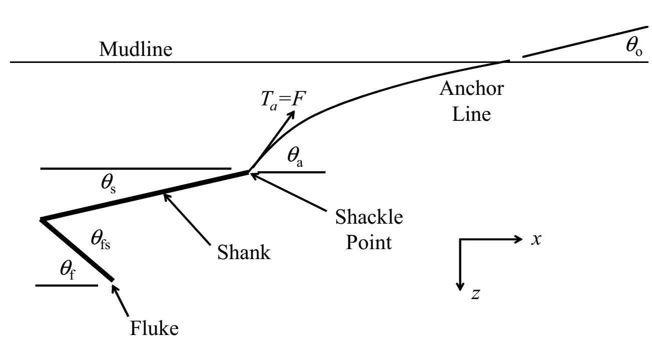

Fig. 1 Definition sketch for anchor