Transverse Loading on Pile

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1. INTRODUCTION

Transverse loading on a pile arises from ground movements around the pile. There had been a number of cases of unacceptable structure movements or collapse because the design did not consider this type of transverse loading. Tschebotarioff (1973) [1] reported that 'several unpublicised cases occurred in the 1950's where this kind of movement proved troublesome even on pile supported bridge abutments'. Similar cases had been reported in Malaysia and other parts of the world; examples are given in Chan (1988) and Stermac *et al.* (1968)[2,3]. The problem is not confined to bridge abutments only. There are other cases where problems were reported due to transverse loading on pile, for example Chin (1979); Tan (1988); Ting and Tan (1997)[4,5,6]. Therefore, there are various design situations in which transverse loading on pile needs to be evaluated and designed for.

Though the problem was made know since 1950s, the common design codes used in Malaysia do not address the problem specifically. However, the recently released Eurocode 7 (BS EN 1997-1:2004) [7] has now stipulated transverse loading as one of the loadings which needs to be considered in pile design. Therefore, this article is written to alert local practicing engineers on the issue. A brief description of design situations and suggested method of evaluating the loading is given in the subsequent sections.

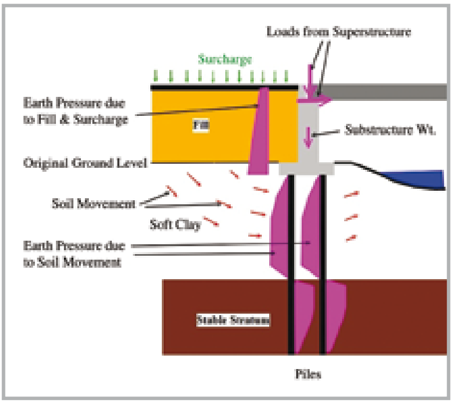

Figure 1: Piles subjected to lateral soil movement due to nearby embankment.

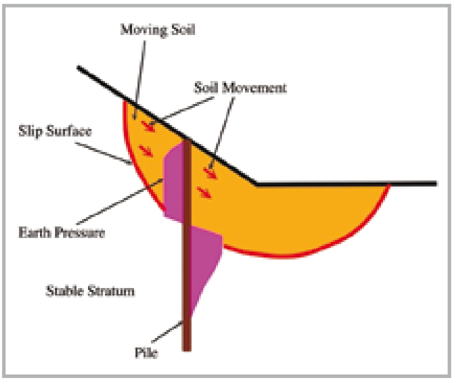

Figure 2: Pile subjected to lateral soil movement in an unstable slope.

2. DESIGN SITUATIONS

There are a number of design situations in which piles will be subjected to transverse loading. These include:

a) Piles with unsymmetrical surcharge on either side; *e.g.* in or near embankment, like bridge abutment piles
b) Piles in an unstable or creeping slope
c) Piles supporting building on or near unstable slope
d) Piles in a marginally stable riverbank with high fluctuating water level
e) Piles near an excavation
f) Inclined piles in settling ground
g) Piles in a seismic region

Figures 1 and 2 illustrate the problem involved for Cases A and B respectively. In both cases, the lateral ground movement takes place and induces transverse loading on the pile. Indeed, the mechanistic behaviour for Cases C and D is similar to one of the two cases previously described. This article shall exclude discussion and design for Cases F and G.

3. LOADING EVALUATION

A method of evaluating transverse loading on pile is proposed based on Ting and Tan (2004)[8]. The method applies to a single pile only. It consists of the following steps:

I. Slope stability analysis
II. Determination of lateral ground movement profile
III. Determination of maximum transverse loading

IV. Evaluation of probable transverse loading on the pile

Slope stability analysis is first carried out using lower bound strength conditions. The depth of lateral ground movement can be deduced from the stability analyses. The appropriate lateral ground movement profile can then be determined. The degree of stability [as Factor of Safety (FoS)] is determined for all the potential failure surfaces. FoS of stability has a role to play in the evaluation of transverse loading. This is described in a later part of this section.

The next step is to determine the maximum transverse loading that can act on the pile. As ground movement around the pile increases, transverse loading is acting on the pile by shear transfer. As soil has some definite shear strength, ultimately, the soil will flow around the pile and maximum (ultimate) loading is acting. Transverse loading is determined by considering the interaction between the pile and the moving soil mass. One way of evaluating the loading is to use ALP. It is a program that analyses a laterally loaded pile with the soil modelled as discrete non-linear springs, and the pile as elastic beam elements. ALP permits soil displacement to be an input to the program. Other programs with similar capabilities can also be used. Using the technique, ground movement is inputted using the ground movement profile and varying magnitude of ground movement. The objective is to determine the maximum forces acting on the pile. The values are used to evaluate probable transverse loading.

As mentioned earlier, FoS has a role to play in determining the extent of ground movement. This is demonstrated by Tschebotarioff (1973) and Stewart *et al.* (1994)[1,9] (see Table 1). It can be seen that there is a distinct relationship between FoS and pile head displacement; the displacement becomes smaller as FoS is increased. The stability of the soil in terms of FoS can, therefore, be applied as a starting point in deciding on the quantum of ground movement to be applied to a pile. The interpretation is indirect as the available quantity is pile head displacement that is in turn related to ground movement. As more research is carried out for different configurations of lateral pile/soil interaction, it will be possible to build a data base (of soil displacements directly). Much work remains to be done and in the interim, reliance would have to be placed on engineering judgment within the framework of existing studies.

Table 1: Factor of safety (FoS) and displacement

FoS	1.0	1.20	1.50	1.70	2.00	3.00
Pile Displ./ Ult. Pile Displ.	1.0	0.64	0.37	0.27	0.18	0.07
BM / Ult. BM	1.0	0.65	0.38	0.28	0.19	0.08

Note: Pile Displ. – Pile Head Displacement, BM – Bending Moment in the pile

4. CONCLUSION

Transverse loading on a pile arising from ground movements around the pile shall be evaluated in pile design. Slope stability analysis is first carried out to determine the extent of ground movement. Using the determined ground movement as an input, maximum transverse loading on pile is then determined using the theory of a beam on a deformable medium characterised by the modulus of subgrade reaction. The degree of stability as represented by the FoS of the slope is then used to quantify the probable transverse loading on the pile. ■

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