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DISCUSSION

On the behaviour of quay walls in earthquakes

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The Authors assume that the distribution of lateral earth pressures acting on an anchored sheet pile quay wall (Fig. 2) corresponds to the classical fixed earth hypothesis. This is the traditional way of explaining the wall fixity and moment reversal observed in actual walls as shown, for example, in Figs 7 and 14. I disagree with this assumption because anchored sheet pile quay walls tend to displace outwards from their initial position along their entire height. Therefore, it is fundamentally impossible for the passive earth pressure state to develop anywhere along the inboard face of the wall as shown in Fig. 2. Consequently, the active earth pressure state must exist along the entire inboard face and the passive state only along the outboard face as assumed in the classical free earth hypothesis. However, this still leaves unanswered how the observed fixity can develop. I would offer a hypothesis for this.

I have previously proposed an alternative hypothesis for anchored sheet pile quay wall fixity (Horvath, 1990). The explanation involves two phenomena. First, and more important, the vertical forces on the wall must be considered. Such forces exist and must be in equilibrium even though they are neglected in the traditional free-earth and fixed-earth hypotheses. The vertical forces come primarily from soil–wall friction. There may also be vertical forces from anchor sag and external loads. To be in static equilibrium under the vertical forces, the wall behaves as a deep foundation element under axial load. In fact the downward vertical forces tend to exceed the upward (assuming no vertical movement of the wall) and so the wall tends to move downwards until it develops sufficient additional upward frictional resistance near its bottom to balance the downward forces exactly. This is a classical negative skin friction or downdrag situation on a pile and is shown in Fig. 22. The depth on the inboard side at which the shear stresses reverse direction will vary with each problem. Thus, although the lateral earth pressures acting on the wall near the bottom of its inboard face are active, not passive, they will increase in magnitude (above the normal value) because of the sign reversal of the soil–wall friction angle from that which normally develops under active conditions. The relative increase is approximately double the normal active earth pressure magnitude. The significance of the sign of the soil–wall friction angle on the relative magnitude of lateral earth pressures (both active and passive) has been recognized (Tschebotarioff, 1973, p. 373 et seq.) but is generally overlooked in both textbooks and practice. As noted in the case history described on p. 389 et seq. of Tschebotarioff (1973), the failure of a gravity-type retaining wall was directly linked to the reversal (from the usual conditions) of the soil–wall friction angle under active conditions.

A secondary aspect of my hypothesis is the recognition that passive resistance along the outboard face of the wall is not mobilized to the same degree with depth because the lateral deformation of the wall into the outboard soil is not uniform. Essentially a greater percentage of the passive resistance is mobilized near the soil surface as opposed to the bottom of the wall. Thus the distribution of passive earth pressure along the outboard face of the wall is not triangular as is normally assumed but roughly parabolic in shape as shown on p. 523 of Tschebotarioff (1973).

In summary, I would suggest that the fixity of anchored sheet pile quay walls develops as a result of the simultaneous increase in active earth pressure on the inboard side and decrease in passive earth pressure on the outboard side near the bottom of the wall. The active pressure increases because of a reversal in direction of soil–wall friction, and the passive pressure decreases because of decreasing lateral deformations with depth. The key elements of this hypothesis (downward movement of the wall reversal of shear stress sign along the inboard face of the wall, and lateral earth pressure distributions) have all been found in analyses I performed of a typical anchored sheet pile quay wall using the finite element method (Horvath, 1990). The behaviour is consistent with the extensive observations on this type of wall by Tschebotarioff. Future research needs to be directed at developing a simple yet reasonably accurate (for

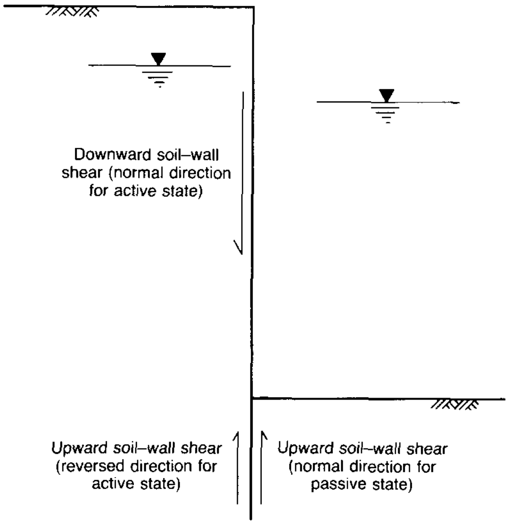

Fig. 22. Soil–wall shear stresses acting on an anchored sheet pile quay wall

routine analysis and design purposes) method for developing diagrams of lateral earth pressure that reflect these phenomena.

Authors' reply

Although the point by Dr Horvath regarding earth pressure distribution is not technically the theme of our Paper, it is an important issue in the design of anchored sheet pile walls.

It has been widely accepted that the determination of precise distribution of earth pressures on a retaining wall (even in the most simple case, a gravity retaining wall) is a complicated problem. The exact solution of such a problem depends on a number of factors. Among the most important factors are the mechanical properties of the backfill soil, the stiffness of the retaining wall and the anchor system, the construction procedures of the retaining wall and the safety factor used for design. Therefore, we strongly believe that although some generalized methods such as the Rankine and Coulomb theories may be used in many cases (as has been done widely by engineers), it is necessary to treat each case individually in order to derive the most appropriate solution. It is most likely that the resulting earth pressure distribution will be non-linear. The negative skin friction suggested by Horvath could be one of the factors affecting earth pressure distribution, but in our opinion not an exclusive one.

Both fixed earth and free earth methods have been used widely in engineering practice. Each method has its advantages and disadvantages and it is important to understand their applicability. It is generally accepted that in the case of dense cohesionless soils (which is the case for our model tests), the fixed earth method is most appropriate. We disagree with the argument that 'because anchored sheet pile quay walls tend to displace outwards from their initial position along their entire height . . . it is fundamentally impossible for the passive earth pressure state to develop anywhere along the inboard face of the wall'. The extent of wall rotation and the location of the pivot point will depend on many factors, including the geometry of the problem, soil characteristics and structural stiffness. If the anchor system is not rigid, as in our model tests, rotation of the wall is quite possible and hence high earth pressure (if not full passive pressure) at the toe on the backfill side can be developed. In our case also, the backfill was dense sand and the safety factor for design under static loading was marginal (so that the failure mechanism under earthquake loading could be studied). Because of these factors we assumed an earth pressure distribution on the wall similar to that used in the fixed earth method. We believe that it simplified the complex field situation but that it is a reasonable simplification.

We agree that further research effort is necessary to develop reasonably accurate procedures for estimating earth pressure on an anchored sheet pile wall. However, as the problem is complicated and needs to be treated case by case, we doubt that a comprehensive method will be simple and applicable for all field problems. In the meantime, the conventional methods used by engineers for decades appear to work reasonably well in most cases even though one may argue that they are conservative and inaccurate in some aspects. For the problem described in the Paper, we maintain that the conventional approach is technically sound and provides a satisfactory interpretation of the observed data.

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