Slurry trench stability—
theoretical and practical aspects

by MALCOLM J. PULLER*, DIC, MICE, MIstructE

SEVERAL FACTORS have been discussed previously as contributing towards the stability of diaphragm wall panel excavation; at the last European Soils Conference, in Madrid 1972, Fernandez Renau summarised these as follows:

(i) The specific weight of the mud suspension and the increase in this weight by non-colloidal particles in suspension, these particles being introduced deliberately or by contamination of the mud from the excavated subsoil.

(ii) The formation by the slurry of a membrane or cake on the trench sides allowing the slurry to exert pressure acting as a reaction or partial reaction to the forces tending to collapse the trench sides.

(iii) The decrease of this earth pressure by soil arching both vertically between the soil below the trench bottom and the guide walls at the top of the trench and horizontally between sub-soil adjacent to the panel excavated.

(iv) The penetration of the ground at the sides of the panel by the stabilising mud.

(v) The internal strength of the stabilising mud itself.

(vi) Osmotic effects due to the mud.

The relative practical importance of each of these factors varies according to the stability problems met in any particular job and also to the particular construction stage in any one job, from initial excavation stage, excavation at final panel depth and preparation for concreting to finally concreting of the panel.Whilst in the author's opinion the first three items, mud density, wall cake and stabilising arching are the major factors, some mention should be made of the fourth item, the effect on granular soils of the mud penetration of the ground at the sides of the trench.

Muller-Kirchenbauer reported at the Madrid conference that stability analysis of the potential failure wedge at the slurry trench sides showed a 50 per cent reduction in factor of safety when the effect of mud penetration into this wedge was made. Correlation was shown between the cake thickness and the penetration of the mud into the soil with the volumetric content of solids in the mud and the porosities of cake and soil respectively.

Measurements of mud penetration into gravel at the time of bulk excavation and correlation with overbreak are limited although avoidance of this penetration by design of the mud appears very desirable. Some evidence exists, however, of the increase of strength of granular subsoil by the intrusion of the mud and subsequent gelling.

*Contracts Manager, A. Waddington & Son Ltd.

Mud pressure

Considering the first factors listed by Fernandez Renau, the principal purposes of the mud are to provide, firstly, a wall cake of low permeability (between 10⁻¹⁰ and 10⁻¹⁵ cm/sec) and secondly a fluid which exerts an opposite pressure to the soil at the trench wall. The value of this mud pressure will be a function of the mud density which is constituted from the density of both the mud and soil contaminants held in suspension. Fernandez Renau mentions that horizontal pressure does not necessarily occur hydrostatically from the contaminated mud because of the effect of impulses set up between the colloidal particles in that fraction of the mud but concludes that from practical considerations hydrostatic pressure distribution from the mud may be assumed.

Mud density is therefore an important stability factor. It can be varied intentionally by the addition of weighting materials although contamination with exca-
vated soil is more usual.

The practical range of such specific gravity will vary from approximately 1.03 for the fresh suspension to 1.30 when fully laden with, say, fine sand. An increase in mud density from 1.03 to 1.30 would thus increase the calculated horizontal mud pressure on a 20m deep panel from 2.06kg/m² to 2.60kg/m². Considering the whole diaphragm wall construction procedure, however, the use of weighted muds may remedy excavation problems only to cause difficulties in concrete.

Lined sand content muds are therefore desirable but mention should be made of the considerable risk of slurry trench instability when large mud losses occur during the excavation of a panel. Such large losses can produce exaggerated stresses in chalk, although not necessarily so.

Recently the author’s firm experienced such trouble in the excavation of the first panel of a basement wall at Maidenhead, Berkshire, through 5m of medium dense sandy gravel into approximately 5m depth of soft chalk. At the interface between gravel and chalk more than 12,000 gallons of mud were lost from the panel within a few seconds.

The mud being used was a 4 per cent bentonite solution and only by increasing this to an 8 per cent solution was mud loss controlled on subsequent panels. Further minor mud losses did occur and on one panel a loss of 1,000 gallons was measured into the gravel above the chalk.

The oil drilling technique of throwing whole bags of powdered bentonite into the panel suffering severe mud loss, the bags being broken in the panel by the excavating tool is not to be recommended except in cases of emergency! Obviously major mud loss is most serious when the panel excavation is surcharge-loaded by existing structures.

Often the principal pressure from the sub-soil adjacent to the panel is caused by ground water and experience has shown that a differential head of at least one metre must be maintained by the mud to avoid instability by the groundwater influence. In cases where diaphragms are installed from a working platform below original ground level, with de-watering techniques applied to reduce ground water pressure, an adequate system of piezometers is advised to monitor the effectiveness of the de-watering operation and the maintenance of a differential between mud and groundwater levels.

Impermeable mud cake

The second stabilising factor listed by Fernandez Renau was the formation of a satisfactory, relatively impermeable mud cake on the trench walls. At a given depth within a panel with area, mud pressure and viscosity constant, flow through the cake is a function of cake thickness and permeability. Excessive filter cake thickness is itself disadvantageous and may cause high overbreak especially with excavation methods which require the continual vertical passage of excavating grab past the cake.

Permeability of the cake, however, will be influenced by the size and distribution of solid particles in the cake itself and filtration control chemicals are used to fill the voids and interstices between the dispersed bentonite particles.

The most suitable filtration control agents for slurry trench work are organic cellulose polymers. API filter tests give comparative values of fluid loss and cake thickness, and tests on a standard 4 per cent bentonite mud have shown a decrease in filter loss of over 50 per cent by the addition of 0.4 per cent by weight of organic polymer.

Chemical mud thickeners are also used to control filtration and although not as efficient as polymers they are usually less expensive. Reference to Table 1 shows the comparative effect on filtration loss of the use of Dextrin a polysaccharide made by Baroid and a popular mud thinner, ferro chrome lignosulphinate.

Mud thinning is sometimes itself necessary since although viscosity and gel strength of a mud must be adequate to surround and hold the loose particles of a caving formation, very high viscosities and gels together with high mud densities cause poor concreting practice; the trimmed concrete finds difficulty in removing the mud upwards within the panel and lacks the scour action necessary to remove the mud from the steel reinfomement.

Additionally, the lignosulphonates have the ability to combat cement contamination which occurs to the mud during concreting. The presence of cement introduced to the mud causes an ion exchange within the bentonite and the result is a progressively irreversible gel together with a very marked increase in cake permeability caused by aggregation and flocculation of the bentonite particles in the mud. A further practical solution is to treat the mud with sodium bicarbonate or sodium carbonate together with a chemical thinner to reduce viscosity. In this way calcium contamination of up to 50ppm can be treated allowing considerable mud re-use.

Arching

The phenomenon of arching of soil is well known and it is the author’s view that in slurry trench stability the action is all-important, Fernandez Renau, whilst stating that the arch action is three dimensional and vault-like, maintained that the vault action actually consists of a redistribution of stresses in the soil mass caused by the movements of the trench walls, and division into horizontal and vertical arch action is an oversimplification.

Nevertheless such oversimplification does underline the importance of guide walls as a top abutment to the vertical arch and this importance is confirmed by the bad consequences of inadequate guide walls in practice. Overbreak commonly occurs immediately below guide wall level: Fig. 1 shows overbreak in a loose sandy gravel approximately one metre below the underside of the guide trench.

The theoretical analysis of soil arching adjacent to slurry trenches has been examined by several authors and these are summarised in a recent paper by Prater.

| TABLE I—EXPERIMENTAL RESULTS: API Tests |
|-------------------|-------------------|-------------------|-------------------|
|                  | Mud 1             | Mud 2             | Mud 3             | Mud 4             |
| Constituents     | 3 per cent bentonite | 3 per cent bentonite | 3 per cent bentonite | 3 per cent bentonite |
|                  | 0.3 per cent fcl   | 0.3 per cent fcl   | 0.3 per cent fcl   | 0.2 per cent fcl   |
| Filter test      | 28cc               | 22cc               | 13cc               | 13cc               |
|                  | 4.7gm              | 2.5gm              | 3gm                | 2.6gm              |

Fig. 2. Shape of failure mass as suggested by Piaskowski and Kowalewski
who examined the stability of wedges of soil in cohesive and cohesionless materials with both flat and curved failure surfaces. Piaskowski and Kowalewski had earlier examined the problem by comparison with the vault action of tunnels. They considered the limit of the failure wedge at ground level as the shape of a parabola having a rise $f = L/2$ cot $\phi$ with a chord length $L$ equal to the trench length. The shape of this mass for a trench depth $H$ is shown in Fig. 2.

Stability difficulties

The author has knowledge of stability difficulties in slurry trench excavation in apparently ideal subsoil conditions, unweathered London Clay. The collapses occurred during excavation as well as after excavation was completed and during the time preparing for concreting.

The cause of failure was connected with the large extent of fissuring of the clay. Ward, Samuels and Butler have already differentiated between fissures and "backs"—a miners' term for structural weaknesses—in the clay. Whether the failures described in the slurry trenches were connected with structural discontinuities more severe than ordinary fissures is uncertain but in the author's opinion the certain presence of a high developed joint structure prevented the formation of adequate arches within the subsoil around the panel.

A recently published note in Geotechnique by Farmer and Attwell gives measurements of ground movements adjacent to a slurry trench excavated in central London wholly in London Clay to a depth of 19.7m and 6.1m in length. The authors of this note conclude that peak earth pressures occurred in this cut at a depth of one quarter of the trench depth by the subtraction from a trapezoidal apparent earth pressure diagram of a triangular pressure diagram representing mud pressure. Horizontal arching was excluded from these considerations.

In the author's opinion collapse of stiff fissured clays may well occur at depths below guide trench level and above 5m not by maximum earth pressure considerations but purely by the inability of a vault-arch action to occur up to depths only half the length of the panel, that is 3m depth.

Lubrication of slip planes

A likely additional cause of failure in stiff fissured clays is the lubrication of potential slip planes caused by loss of fluid through the wall cake and aided perhaps by swelling caused by the action of large horizontal forces existing within such clay. Such swelling might possibly be influenced by bulk excavation of a site to a working platform lower than ground level prior to the installation of the diaphragm.

The remedies to avoid such instability may therefore include the avoidance of such pre-excavation, the use of panels of restricted length and the use of mud of minimum fluid loss characteristics.

Where gravel overlies stiff fissured clays (in the author's experience on contracts in London and Oxford) diaphragm walls have been built, of course, with virtually no overbreak in the clay, although again in some instances substantial overbreak has occurred immediately below guide trench level, perhaps by lack of vault action.

Excavation of secondary panels, between previously concreted panels, in troublesome soils such as loose open gravels can be undertaken with less risk than primary panels, between adjacent subsoil faces. This experience may stem from the ability of an arch to form horizontally from unyielding concrete abutments.

A further cause of trench instability can occur in saline conditions in both cohesive and non-cohesive formations. The phenomenon of osmosis can cause non-saline water from the mud to be attracted into the ground formation to dilute the saline ground water, leading to swelling of the trench walls, instability and caving of the trench. The addition of salt to the mud to balance the salinity in the formation overcomes the osmotic force or alternatively fcl may be used as a preventative to fluid loss.

References


