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Effects of Collapse Settlement of Fill on Reinforced Earth Walls

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SYNOPSIS

Two case histories illustrate the effects that collapse settlement of the fill forming a Reinforced Earth wall can have on the structure.

Pre-requisites for collapse settlement are inadequate compaction, compaction at too low a water content, or a combination of these. Collapse settlement occurs subsequently when the water content of the fill is increased by infiltration.

The effects of collapse settlement identified in this paper are:

- (i) a temporary release of friction on the reinforcing strips with the result that the wall facing moves outwards; and
- (ii) relative settlement between the fill and the wall facing with the result that the reinforcing strips become inclined to the horizontal and their tension increases.

EFFECTS OF COLLAPSE SETTLEMENT OF FILL ON STRIP FRICTION

A loose fill has an unstable structure that is maintained by capillary stresses. In clayey fills the structure will consist of an assemblage of clods that behaves like a granular mass. Each clod maintains its integrity by means of strength imparted by capillary stresses acting within it. The void space between clods is large relative to the void space within each clod, i.e. individual clods are compact relative to the overall soil. In sand fills the unstable structure will be maintained by capillary stresses between individual grains or groups of grains.

When water later infiltrates the fill, the capillary stresses are released. Clods lose strength and compact into the surrounding voids and sand grain assemblages break down. The net effect is a settlement of the fill that has been defined as collapse settlement. The amount of collapse settlement that occurs depends on the quantity of water infiltrating and the time-settlement relationship depends on the distribution of the infiltration with time. The transient effect of the settlement on friction between the reinforcing strips and the soil will be illustrated by a case history:

A reinforced earth wall was built at Koinaas on the west coast of South Africa. The climate is desert with an average annual precipitation of 90 mm and an annual pan evaporation of 1950mm. The wall supports a fill of uniform fine dune sand which was placed without control on moisture content and with little compaction. Shortly after a high pressure sea water hose had burst on the platform at the top of the wall, the wall abruptly moved forward a distance of 150mm to 200mm and then again came to rest.

The sand was uniform in grading, having a d_{10} size of 0.1mm and a ratio $d_{60}/d_{10} = 3.2$. An investigation in the laboratory showed that the angle of shearing resistance of the sand was high ($\phi' = 43^\circ$) although the angle of friction of the loose dry sand on the surfaces of the smooth galvanized steel reinforcing strips was surprisingly low ($\delta = 13^\circ$). When the sand was inundated in the shear box, the angle of friction increased to 19° .

A re-analysis of the stability of the wall showed that for $\delta = 13^\circ$ the factor of safety against pull-out of the strips from the fill would be as low as 1.1 at a distance of 2.5m below the top of the wall, increasing to 1.5 at 4.5m and to close to 2.0 at 6m, the base of the wall. Because the effect of wetting was ultimately to increase the factor of safety against a pull-out of the strips, it appeared that some transient phenomenon had occurred, presumably as the wetting front, arising from the burst hose, passed through the fill.

The phenomenon was modeled in the laboratory by loading a dry sand-to-galvanized steel surface in the shear box, to a factor of safety of 2 against shear failure. The sand was then inundated and the movement of the sand and the shear load were recorded on a UV recorder. A typical result of such a test is shown in Figure 1.

AB in the figure represents the stage during which the dry sand was loaded to a factor of safety of about 2 (actual $\delta = 6.1^\circ$). At B the loading was stopped and the sand inundated. At C it appears that the water reached the sand-galvanized steel interface and the shear stress reduced (C to D) to an angle of friction of less than 1° . Simultaneously the sand settled, although most

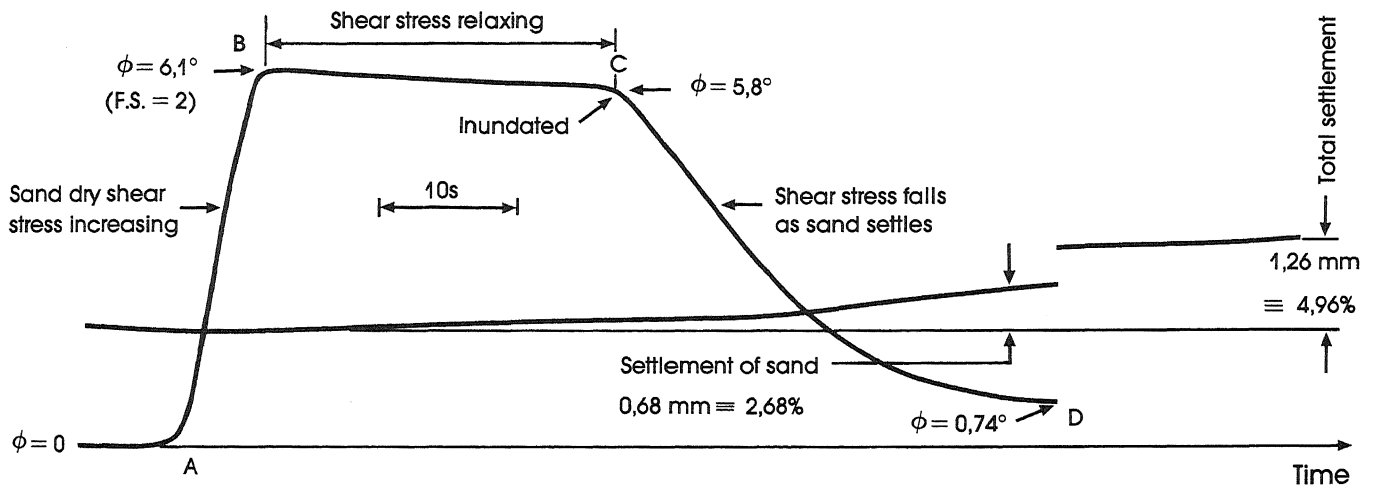


Figure 1: Variation of shear load at sand-steel interface when dry sand is inundated.

of the settlement occurred after the frictional resistance at the sand-steel interface had been lost.

It can be inferred from Figure 1 that as the wetting front moved downwards through the fill, successive layers of reinforcing strips temporarily lost their shear resistance and allowed the pressure in the fill to move the wall facing forward. As the wetting front passed, shear resistance was re-established, possibly at a greater angle of friction, and the wall facing re-stabilized.

The effect of saturating the fill on strip friction has previously been investigated by the Reinforced Earth Company. Although they found that saturation reduces the frictional coefficient between a dune sand and a steel reinforcing strip, the transient phenomenon illustrated in Figure 1 appears not to have been identified at that time.

A possible secondary effect of water entry is that water pressure may develop in the fill, thus reducing its shear strength and precipitating a rotational shear failure. In the Koningnaas case, this did not occur because the quantity of water was limited and the fill was relatively free-draining.

EFFECT OF COLLAPSE SETTLEMENT OF FILL ON STRIP TENSION

The collapse settlement of a poorly compacted fill has its effect on strip tension by dragging the reinforcing strips down relative to the wall facing. If the latter consists of concrete panels, the facing is stiff in a vertical plane, relative to the fill, once the 20mm joints between the concrete elements have closed up. This closure corresponds to 1.3% of post construction settlement of the fill.

There is also the possible secondary effect of water pressure to consider, if sufficient water enters the fill and if the fill is not free-draining.

The effect of collapse settlement on strip tension is a complex geometrical one, which depends on:

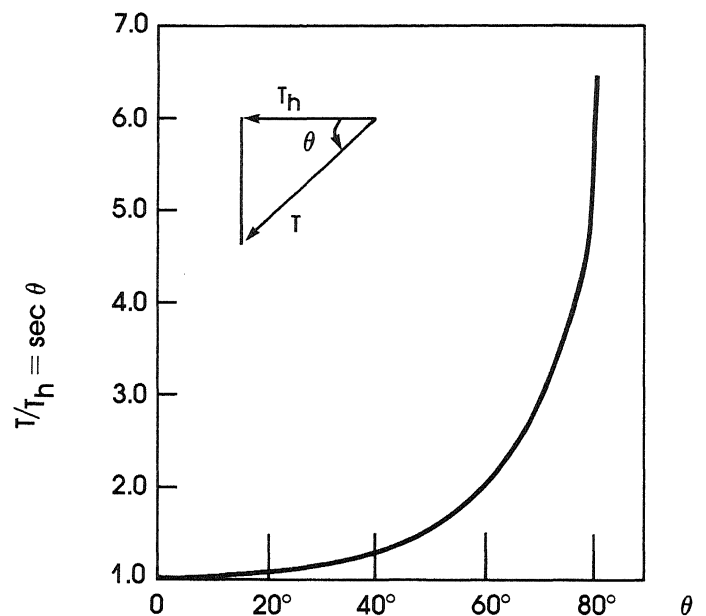


Figure 2: Strip tension T required to exert horizontal component T_h for various inclinations θ .

- the relative settlement of the reinforcing strip to the tie strip taking into account the ability of the cladding to compress in the vertical plane
- the movement of the reinforcing strip required to mobilise the friction in the loose fill along the length of the strip.

As a result of the relative settlement, the strips become inclined adjacent to the wall. For an inclined strip to exert a horizontal tension component T_h , the tension in the strip has to be (see Figure 2)

$$T = T_h \sec \theta$$

monitored over a period of five months. The observed movement was only 1mm and hence measurements were stopped. The observed movements of the north wall over the period 1979 to 1984 are illustrated in Figure 4. The 1984 measurements seem to show that the rate of movement of the wall had been almost constant with time.

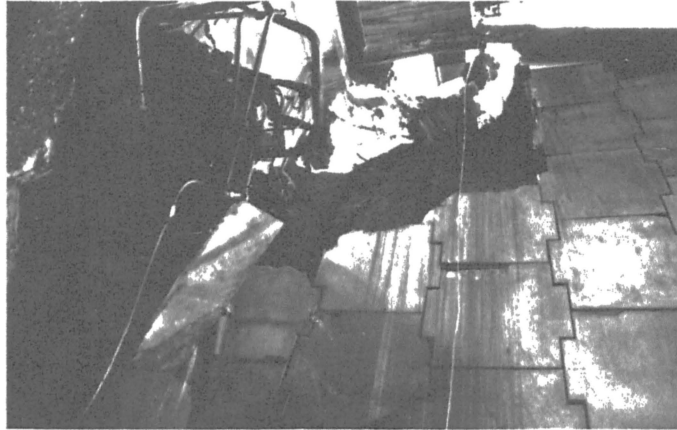


Figure 3: Frontal view of the failure at Grootgeluk Mine

As shown by Figure 2, T increases rapidly with increasing θ . If the design factor of safety against yield of a reinforcing strip is 1.6, a strip inclination of 51° will cause yield. If the factor of safety against tensile fracture is 2, an inclination of 60° will result in fracture.

The occurrence of this effect of fill settlement will also be illustrated by a case history:

At the Grootgeluk Coal Mine in the north-west Transvaal province of South Africa, the two arms of a U-shaped crusher complex were constructed of Reinforced Earth walls.

The walls support the earth ramps that provide access for 250T haul trucks to tip their loads from the base of the U into a primary crusher. Eight years after construction one of the side walls (the south wall) of the U failed, a wedge of fill sliding out together with a section of the concrete panel facing. The height of the section that failed was 16m. A view of the failure is shown in Figure 3.

Early in the life of the wall complex there had been concern because the facing of the north arm of the U had been found to be moving outwards. The movement of the wall was monitored for fifteen months, but when the rate of movement was seen to be moderate (between 10 and 20mm per year), measurements were stopped. At the same time, the wall that ultimately failed was

An examination of the failure showed the following:

- (i) A water pipe in the failed area had been leaking for an unknown period, discharging water into the fill.
- (ii) The fill consisted of a sandy gravel which contains a considerable proportion of clay. It was certainly not free-draining but had an estimated permeability of only 1m/year. Penetration of water into the fill by infiltration of rainwater would have been slow. Equally, water fed into the fill by the leaking pipe would not readily have dispersed.
- (iii) Several reinforcing strips had never been placed in the wall. For example, one facing panel was attached to four instead of the required six strips. In other cases 60mm x 3mm strips had been used instead of 80mm x 3mm strips.
- (iv) Strips in the wall adjacent to the failed section were found to be inclined at steep angles to the horizontal. Inclinations as steep as 80° were found. It is surmised that a similar situation applied to the section of wall that failed. Figure 5 shows a row of inclined strips uncovered in the post-failure examination.

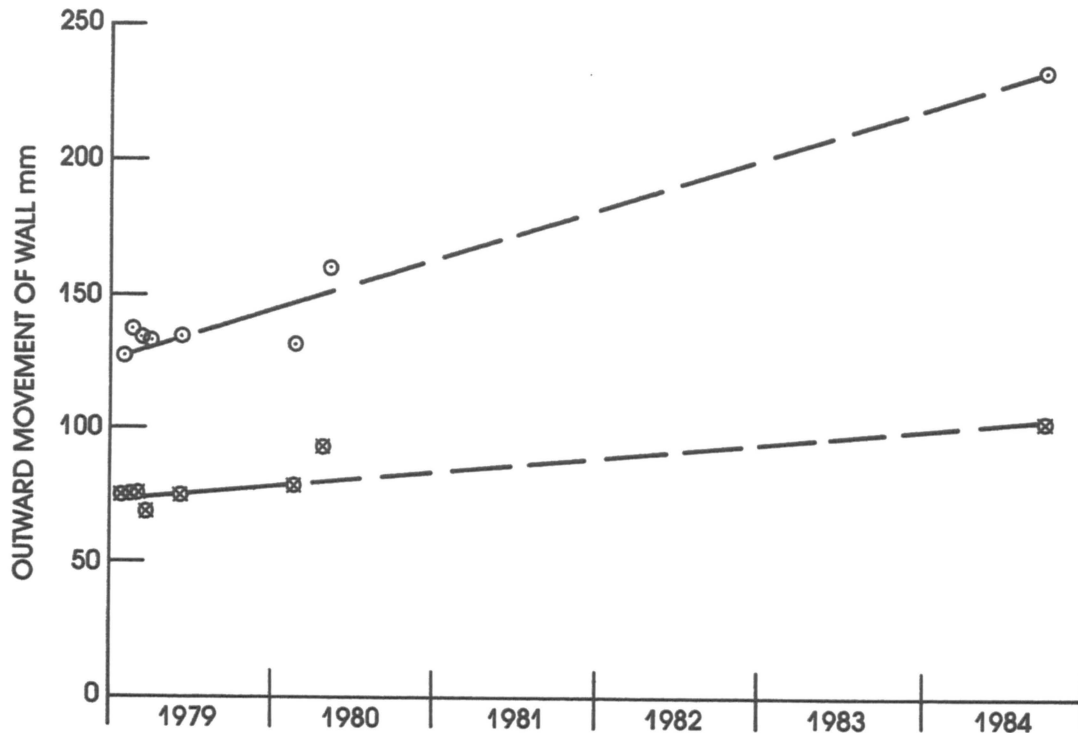


Figure 4: Observed movements of north wall at Grootgeluk Primary Crushing Plant.

The inclination of the strips may have resulted from setting the facing slabs too far ahead of the fill with the result that the unsupported reinforcing strips drooped down to rest on the fill surface. On the other hand, the observed progressive movements of the north wall were probably caused by a similar mechanism, involving collapse settlement, to the movement of the

Koningnaas wall. Because of the relatively low permeability of the fill, the process of progressive release of friction would have taken place slowly over the years as each seasonal wetting front progressed through the fill. The same process was probably taking place on the south wall, but was unobserved.



Figure 5: Inclined reinforcing strips uncovered during post-failure examination

- (v) A deep rut in the surface of the fill showed that a heavy wheel load had been applied to the surface of the failed area shortly before the failure occurred.
- (vi) Several of the strips supporting the failed section had clearly broken some time previously, as the fracture surfaces had rusted.

An engineering failure seldom stems from a single cause. It is usually the concatenation of a number of circumstances that results in a failure. The Grootgeluk failure was obviously no exception. All the above factors would have pushed the condition of the wall nearer to failure.

Accepting the various construction errors mentioned above, a likely scenario for the failure is the following:

Because of progressive collapse settlement and construction errors, the factor of safety of the section of wall that failed may have been close to unity before the water pipe started to leak. The penetration of the fill by water from the leak would have resulted in further collapse settlement and an increasing inclination of the reinforcing strips in this zone. Simultaneously, the accumulation of water would have reduced the shear strength of the fill. The last straw may have been the straying of a heavy vehicle onto the surface of the fill above this zone, now in a critical state. As often happens in engineering failures, there was no coherent eye-witness account of the failure.

Observations at Grootgeluk indicated that reinforcing strips were dragged down over a distance of 500mm to 750mm back from the wall facing. If one sets the acceptable angle of inclination at 37° (a 25 per cent increase in strip tension), then the maximum permissible settlement of the backfill relative to the wall facings is 375mm. Hence the limitation on settlement or misplacement of strips in elevation is not severe. Relative displacements of less than 375mm over a fill height of 16m should be easily possible with good supervision and careful compaction.

CONCLUDING REMARKS

The case histories described above, illustrate the importance of applying the usual control norms during the construction of Reinforced Earth structures, as well as the necessity for adequate compaction of the fill. As shown by measurements on Reinforced Earth structures, the tensions in reinforcing strips at a particular level can vary widely (Blight, Dane and Smith (1)). Circumstances that result in increasing strip tensions may cause certain strips to break, thus reducing the overall factor of safety of the structure. Recognition of these facts will lead to the building of safe, durable structures.

ACKNOWLEDGEMENTS

The information on the Koningnaas wall is published by kind permission of the Anglo American Corporation of South Africa Limited.

The Grootgeluk case history is published by permission of Iscor Limited.

REFERENCES

1. Blight, G.E., Dane, M.S.W. and Smith, A.C.S., "The progressive deterioration of a Reinforced Earth wall complex", submitted to Geotechnique, 1987.