Failure of Waste Fill Buried within a Soft Clay

Rupture d'un Remblai de Tout-Venant Encaissé dans une Argile Molle

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SYNOPSIS A large waste fill was placed in a swamp, near an important railroad. The fill was buried in the very soft organic clay of the swamp, under stable conditions. For two months heavy earth-moving equipment was run over the fill without any trouble. Subsequently, additional layers of waste material were dumped adjacent to one margin of the initial buried earth-fill, and this caused a gradual elevation of the swamp mud adjacent the margin. As a consequence an uncommon type of failure occurred, unexpectedly, in presence of the Author. It gave a chance for a reconstitution and posterior analysis of the phenomenon to verify the most probable causes and the mechanics of the failure. Stability calculations confirmed a three-dimensional rupture, which started probably by a translational movement, followed by spreading and a complete immersion of the waste fill in the swamp.

INTRODUCTION

Frequently the stability analysis of earth-fills built in swamp areas have been restricted to the classic case of a fill spread upon weak soil. The analysis is therefore performed under consideration of a superficial loading, susceptible of undergoing a general sinking (Fig.1-a) or a lateral (rotational) sliding (Fig.1-b and 1-c).

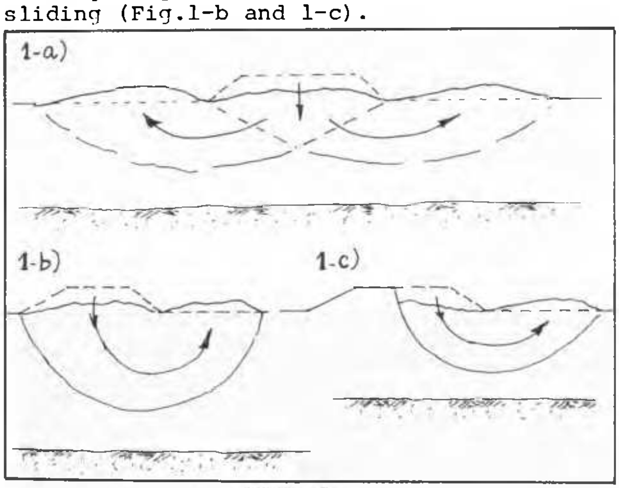

Fig. 1

In the present case, the failure occurred with a waste fill buried within the swamp soil, originating from a displacement of the soft clay foundation. The fill had remained stable during two months. The failure happened unexpectedly. The Author had the fortune of to be walking on the fill at the quite moment of its failure.

GENERAL CHARACTERISTICS OF THE AREA

The area consists of a large swamp within a fresh water lake (30 meters over sea level), at km 104 of the Vitoria-Minas Rail-Road, State of Espirito Santo, Brazil. This important rail-road belongs to COMPANHIA VALE DO RIO DOCE and is the main corridor of transport and export of iron ore from the State of Minas Gerais.

The swamp is located within a wide valley, surrounded by hills, which are constituted mainly of residual soils (gneissic in origin). The organic clay of the swamp is quite recent in origin (Holocene Age) and has a very uncommon soft consistency.

A re-location of the existent rail-road, will result in a larger platform, requiring a deep cut in the adjacent hills. The earth material (of sandy soil) resultant from this cut will be partially used in the new rail-road fill across the swamp. The clayey material of the cut is being wasted and was dumped in the swamp, outside the existent rail-road. This is the origin of the waste-fill whose failure is the main topic of this paper.

DESCRIPTION OF THE FAILURE

The Author visited the place to see the beginning of the construction of the new rail-road fill. While taking a walk over the waste-fill, acompanied by other engineers, the failure occurred. Many cracks appeared suddenly and advanced rapidly in numbers and openings. The extreme side of the waste fill had opened in a few seconds, giving way to a large stream of retained water (See Fig. 2).

New cracks continued arising and opening up, rather like an earthquake (See Fig. 3), across a long portion of the waste fill, which displaced vertically and laterally. As a result, some vehicles became isolated (See Fig. 4) during some minutes, but were removed

Fig. 2

Fig. 3

Fig. 4

in good time along a way prepared quickly by a bulldozer.

Besides the photographs taken on the waste-fill during the failure, the Author took the opportunity of photographing panoramic views one before (See Fig. 5) and the other after the failure (See Fig. 6). Such views were taken from a hill located 40 meters above the swamp area.

PROBABLE MECHANICS OF THE FAILURE

The Author searched to investigate the main and probable causes of the failure and its mechanics. An stability analysis demonstrated that the failure was due to an increase of earth-pressure arising from a mud surcharge risen adjacent to the fill (See Fig. 7). The sketch in Fig. 8 shows the most probable sequence of events and movements during the failure. The phenomenon may be classified as a Composite Rupture, started by a translational slide which was followed by spreading and a final and complete immersion of the fill

Fig. 5

Fig. 6

Fig. 7

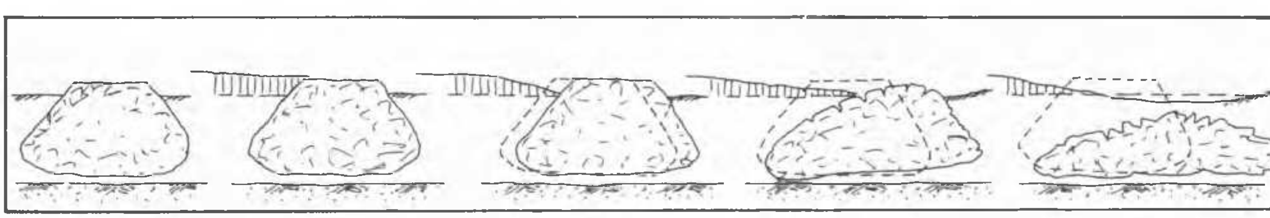

Fig. 8

in the swamp.

STABILITY ANALYSIS

The stability analysis was performed on the premise that a three-dimensional rupture had occurred, because the failed fill was only 50 meters long by a total height (including the buried body) of approximately 27 meters.

A typical transversal section of a buried fill is presented in Fig. 8. In the analysis however, that section was simplified to a trapezoidal shape. Two borings were perforated through the waste fill before the failure (by requisition of the Author). They indicated a remaining layer of organic clay in the bottom of the fill.

Fig. 9 shows the longitudinal and transversal sections of the failed waste fill.

The forces which come into play were:

A) Acting forces which caused the translational movement:
   a) The Active Earth-Thrust (on the upstream margin of the fill) - P_a

   b) The Lateral Force due to the Mud Surcharge - P_q

B) Resistant Forces:
   c) The Passive Earth-Thrust (on the downstream margin) - P_p

   d) The Cohesive Force in the bottom of the fill - $B.C_{u(B)}$

   e) The Shear Force in the extreme transversal section (I), the shallowest - $[A_I.s+(A_I'+A_I'').s']$

   f) The Shear Force in the extreme transversal section (I), the shallowest -

$[A_{III}.s+(A'_{III}+A''_{III}).s']$

(See Fig. 9 with areas A, A' and A")

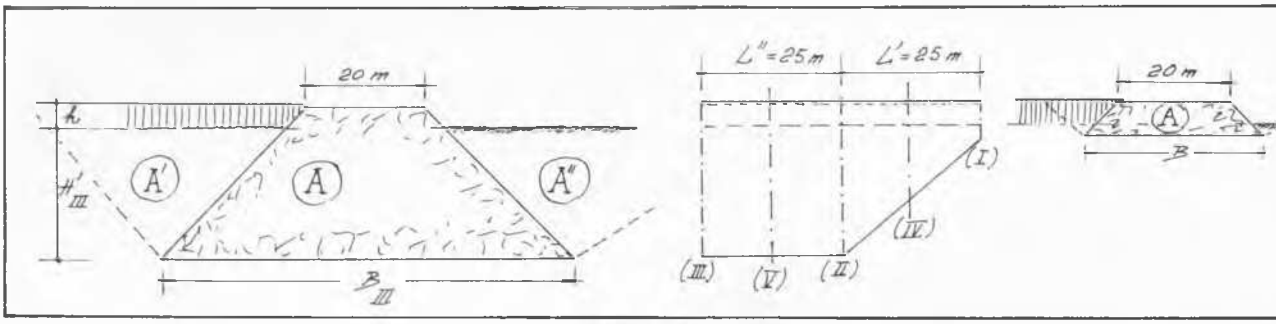

Fig. 9

Using the results of several shear tests (vane-shear, unconfined compression) for $\phi=0$ conditions, and taking account the variation with depth and remoulding effects, the following values were adopted:

C_u (remoulded, for depths between 0 and 20 meters) $\cong$ 0,25t/m² (average)

$C_{u(B)}$ (idem, for the bottom of the fill) $\cong$ 0,60t/m² (average)

$S' = C_u \cong$ 0,25t/m² (average)

S = shear resistance (average) of the fill (non performed tests)

The forces P_a, P_p and $B.C_{u(B)}$ were calculated for the average sections (IV) and (V). The surcharge height (h) was taken as constant along the fill. Therefore:

$$P_a = \frac{1}{2}.(\gamma.H'-2C_u\sqrt{2}).(H'-\frac{2C_u}{\gamma})$$

$$P_p = \frac{1}{2}.(K_p.\gamma.H'+K_{pc}.C_u).H'$$

$$P_q = H'.C.q = H'.C\gamma.h \qquad (C=1,00)$$

The stability equation (for SF=1) becomes:

$$(P_a+P_q)_{(IV)}.L'+(P_a+P_q)_{(V)}.L''=(P_p+$$
$$+B.C_{u(B)})_{(IV)}.L'+(P_p+B.C_{u(B)})_{(V)}.L''+$$
$$+(A_I+A_{III}).S+(A'_I+A'_{III}+A''_I+A''_{III}).C_u$$

where:

L'=25m; L"=25m; $B_{(IV)} \cong$ 53m; $B_{(V)} \cong$ 74m

$H'_{(IV)}$=12,5m; $H'_{(V)}$=23,0m; h=4,5m

With the formulae and values indicated, the Author arrived at a value of

$S \cong 2,30$ t/m²

for the average shear resistance of the waste fill between sections (I) and (III).

The Author also performed a calculation considering the failure as occurring exclusively along the extent L'=25m. The value obtained was $S \cong 1,28$ t/m², which is very low, taking into consideration the SPT values of the two borings in the waste fill. Besides this, the Author assumes that if S=2,30 t/m², is an average value for the extreme sections (I) and (III), it is reasonable to accept for the larger sections (as III, for example) a value of $S \cong 3,40$ t/m².

It is worth noting that at the moment of the failure, the Author observed that the whole extent of L' was the first part to displace and sink, even though all the 50 meters (L'+L") had undergone movements and cracking since the beginning. The sinking of the extent L" occurred later. It is interesting to note also the deflection undergone by the remaining part of the waste fill (See Fig.6).

CONCLUSIONS

Usually, with regard to the design of fills in swamp areas, soil engineers mainly are concerned with the stability of floating loads, i.e., of fills resting on the surface of soft soils. The uncommon and unexpected failure reported in this paper, refers to a case of a deeply buried fill (in swamp area) of large dimensions, and normally stable. The accident should be taken as a warning and a lesson about the correct method of designing and building fills buried within soft soils, and moreover it should be noted that work of this nature is becoming more commonly adopted in practice, in the construction of highway and rail-roads along swamp areas.