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SYNOPSIS

The Stability of large T cross-section excavations under bentonite suspension is examined by measuring concrete absorption during pouring. Such measurements are correlated to the specific weight of the mud, tidal level and excavation modalities. Finally, some informations are given on the verticality of trenches.

INTRODUCTION

The study on the behaviour of large trenches is becoming of great importance as a consequence of the tendency, in the last years, to replace caissons and gravity walls with reinforced concrete diaphragm walls in harbour works specially in case of deep seabeds. This paper reports the results of stability analyses on T cross-section trenches carried out under static bentonite suspensions. They refer to the harbour wharfs of the Commercial Ports of Gioia Tauro - Italy (over 220,000 sq. m. walls) and Bandar Abbas - Iran (over 110,000 sq. m. walls, construction still in progress).

STABILITY OF TRENCHES

Before starting with the analysis of job-site data we will list herein the principal causes influencing trenches stability. They can be divided as follows:

(i) Problems related with the intrinsic stability of trenches:
- Cake formation
- Specific weight of the mud
- Soil region penetrated by the mud
- Shear strength of the mud itself
- Arch effects
- Osmotic effects due to the mud.

(ii) Influence of drilling tools on stability:
- Drilling tool dimensions
- Shape of trenches
- Drilling tool speed
- Excavation modalities.

MEASURES ELABORATION TECHNIQUES

Hereinafter, both job-sites will be examined separately. For each of them, a representative number of panels was considered (300 panels at Bandar Abbas site and 250 at Gioia Tauro Site). The study on the stability of trenches was performed analyzing typical absorption diagrams similar to the one shown in Fig. 1.

![Fig. 1 Typical absorption diagram](image-url)
The absorption ratio, defined as the actual absorption of concrete as compared to the theoretical one, is reported as a function of depth. A graph of this type is prepared for each panel. The following data are also shown on the graphs:

- Excavation modalities
- Tidal level
- Specific weight of the bentonite suspension before the pouring of concrete.

Such data were chosen because, in our opinion, the principal parameters influencing the stability of excavations are:

- Water table level
- Specific weight of mud
- Arch effects
- Excavation modalities.

The specific weight of mud after desanding has been accounted with in the following analyses.

**BANDAR ABBAS SITE**

**Nature of Soil**

The sub-soil investigations carried out in the Port area shows a substantially uniform stratigraphy which can be summarized as follows:

(i) Stratum I - medium dense silty sand (3 to 11.5 m. thick)

(ii) Stratum II A - soft to firm clayey silt (4 to 6 m. thick)

(iii) Stratum II B - firm clayey silt with some sand lenses (6 to 11 m. thick)

(iv) Stratum III - very dense silty sand with hard clay lenses (over 30 m. thick)

The natural soil profile level varies smoothly between 0.0 m. and - 2, - 2.5 m. as referred to m.s.l. hence a sandy gravel fill was placed to obtain in the area a working elevation of + 2.5 m., with a final wharf top elevation of + 3.2 m. from m.s.l. In particular, the following average thicknesses for the above-mentioned strata were encountered in correspondence with the studied panels (from + 2.5 m.).

(i) Fill, with variable th. between 3 and 5 m.

(ii) Transition stratum, between fill and natural soil, having a th. of about 0.50 m. and constituted by soft soil and prospective intercalations of mud.

(iii) Stratum I, with variable th. between 6 and 8 m.

(iv) Stratum II, with a th. of 10 m.

**Bentonite suspension**

The iranian bentonite "Hygel" mixed with a "Plastoclay" polymer at a concentration of 0.075 % was used. The suspension was prepared with a concentration of bentonite at 5 %. The correspondent mud characteristics were:

- Flocculation, practically negligible
- Marsh viscosity, 43 to 53 sec.
- Cake th. approx. 2 mm.

Particular tests were carried out to obtain informations on the influence of chloride concentrations up to a maximum of 0.2 kN/m3 on the mud viscosity and volume of filtrate. For the maximum chloride concentration examined, we obtained:

- Marsh viscosity, 40 to 43 sec.
- Volume of filtrate, 50 cm.3

At the job-site:

(i) mud tank, stabilized condition (mud ready to be used)
- specific weight, 10.1 to 10.5 kN/m3
- Marsh viscosity, 34 to 38 sec.

(ii) before desanding:
- specific weight, 11.3 to 12.3 kN/m3 with sand content between 12 and 20 %

(iii) after desanding:
- Specific weight, 10.1 to 10.8 kN/m3
- Marsh viscosity, 33 to 41 sec.
- Sand content, 1 to 5 %.

**Intrinsic stability of trenches**

As mentioned before "T" cross-section trenches are considered in the project with the following overall dimensions 3.5 x 3.5 (flange and web) x 0.8 th. m., and a total depth of approximately
Two zones can be defined in the considered wharf length after examining the absorption diagrams:

(i) Zone 1: Where actual absorptions were far greater than normally expected for these types of works.

(ii) Zone 2: In which absorptions of concrete were near the normal range of values.

In each zone, the analysis of the absorption exceeding the theoretical volume has been done considering the variability of specific weights and tidal levels, defined as "high", "medium" and "low" as shown in Fig. 2. The graphs in Fig. 2 result from a weighted mean extended on the heights "H" where excess of concrete absorption was recorded as well as the average absorption itself. The division of the total depth of trenches in three segments, as indicated below, was considered significative:

- Segment I: from 0.0 to 6.0 m. including the fill and the transition stratum.

- Segment II: from 6.0 to 21.0 m.

- Segment III: from 21.0 to 29.0 m.

The results concerning the first two segments are given in Fig. 2a and 2b. Only the absorptions exceeding 1.15 are considered in the graphs for the computation of the height "H", as 1.15 was assumed as a normal value for these particular trenches. By examining Fig. 2a and 2b we can observe the influence of the tidal level on the absorption ratio for a given specific weight of mud. Conversely, for a constant tidal level the reduction of the absorption ratio appears evident with the increase of specific weight. Some discordances as to the last observations can be found in the first segment, between 0.0 and 6.0 m. According to us, such discordances depend on the fact that the surface absorptions are practically due to earth slides into the trenches as a consequence of:

- Small arch effects
- Soft soil inclusion in the transition stratum.

The predominant influence of the water table is shown in Fig. 3. The results of the analysis on panels included in "Zone 1" where the water table was lowered of nearly 4 m. through the installation of well-points clearly demonstrate the beneficial effect of the reduction of the water table elevation. From their observation, the results in the third segment (between 21 and
29 m.) appear to be independent from the tidal level, the specific weight and the examined zone. Such behaviour can be explained considering that in this segment the arch effects are predominant as compared to all other factors. Anyway, an absorption ratio of 1.26 for a height of H=3m. was observed in only 27% of the panels. In addition such absorption is found in correspondence with the interface between stratum IIB (clayey silt) and stratum III constituted of very dense silty sand. The formation of overbreaks at the interface region between soils having different properties was also observed by other authors.

**GIOIA TAURO SITE**

**Nature of Soil**

According to the sub-surface investigation carried out up to 45 m. below g.l., the upper strata can be classified in fine sands with gravel lenses. Some silty lenses can be found at more than 20 m. below g.l. According to the electric static penetrometric tests, relative densities are estimated between 70 and 90%. In particular, in the areas in which measurements have taken place the stratigraphy results as follows:

(i) **Stratum I**: at +2.5 m. above m.s.l. (corresponding to the working level) dense fine sands, about 7 m. thick.

(ii) **Stratum II**: gravel in very dense sand, about 8 m. thick.

(iii) **Stratum III**: fine sands with silty fine lenses from dense to very dense, up to the max. depth of the boring.

**Bentonite suspension**

The Italian "Laviosa B.120" bentonite at 5% concentration has been used. The corresponding mud characteristics were:

In laboratory:

- Flocculation practically negligible
- Marsh viscosity, 39 to 42 sec.
- Cake th. approx. 1.5 mm.

At the job-site:

(i) Mud tank, stabilized condition (mud ready to be used):
- Specific weight, 10.1 to 10.4 kN/m³
- Marsh viscosity, 33 to 36 sec.

(ii) Before desanding:
- Specific weight, 10.4 to 11.2 kN/m³
- Sand content from 5 to 11 %

(iii) After desanding:
- Specific weight, 10.1 to 10.5 kN/m³
- Marsh viscosity, 32 to 37 sec.
- Sand content, 0.3 to 3.5 %

**Intrinsic stability of trenches**

Trenches were T-shaped, 3 m. x 2.5 m., thickness 0.8 m. and depth of about 30 m. In the
750 m. of wharf, no area appeared to behave differently because of its soil nature. Furthermore, variations in tidal level are here negligible. Therefore, the analysis has been carried out in function of only the bentonite mud specific weight. In this case, the trench depth has been divided into two significative segments:

- Segment I: between 0.0 and 5.0 m.
- Segment II: between 5.0 and 30.0 m.

The influence of specific weight on the trench stability is clearly evidenced on Fig. 4. In this particular very dense soil, absorption ratios are, in the second segment, far below the acceptable value of 1.15.

INFLUENCE OF DRILLING EQUIPMENT ON STABILITY

Two excavation methods have been applied in both job-sites. The first one foresees the use of the traditional grab (two jaws) for the T-shaped trench excavation while, in the second, the excavation takes place in one single stage with a three jaws hydraulic grab. (Soil Mec BPH / S). Both methods show similar influences on the trench stability. A greater productivity and improved verticality of the trench are instead obtained using the three jaws hydraulic grab.

MEASUREMENT OF DEVIATIONS FROM VERTICALITY

Deviation from verticality has been studied at Gioia Tauro job-site. With the equipment used, deviation from verticality is due to the combination of an error of the grab guide, the clearance between the guide and the sliding kelly and the elastic deformation of the kelly due to the lateral thrusts of the soil on the jaws and guiding shoes. The kelly initial verticality can be rectified by hydraulic pistons, and can be checked in the cab with an electric inclinometer.
Measurements were carried out in 12 panels executed with a three jaws grab and in 9 panels executed with a standard grab. The above mentioned measurements were carried out using an accelerometric bi-axial inclinometer. The deviations were calculated in function of the inclination readings every 2 meters. The deviations from verticality are shown in Fig. 5. From these measurements, such deviations are found to be perpendicular to the wharf axis (direction y Fig. 5) while in the x direction they are negligible.

CONCLUSIONS

The following conclusions can be deduced from the analysis of all the above mentioned data:

- When fillings are necessary, it becomes important to provide for a good degree of their compaction, in particular, the muddy strata covering natural soils must be perfectly removed to avoid transition soils having poor characteristics as in the case of Bandar Abbas, because it is the principal cause of superficial cave-ins.

- The guide wall heights must be about 1/2 the excavation length (in this case it is of about 1.8 m.) to help the stability of the trench as this is always critical because of the lack of the arch effect.

- As can also be deduced from the observation of the influence of tidal levels on the stability of excavations (see fig. 2 and 3), a difference of at least 1.5 meters between the mud and the external water table levels, is recommendable.

- The specific weight of mud is extremely important; as already seen it is one of the basic elements for stability. Therefore, it is important to keep specific weight equal or above 10.3 kN/m3 and a sand content not below 2 % (except the occasional addition of fine materials). This makes it also possible to reduce desanding and therefore excavation opening times with less risks for its stability. It can be interesting to note that in case of excavations with these dimensions and under conditions at the limit of stability as in the case of Bandar Abbas, the closing speed of the trench walls is of about 0.5, 0.6 mm./h. (this date was obtained through studies still in progress). In any case specific weight must not be higher than 11.3 kN/m3 during casting, specially if it is due to the addition of sandy materials, because of the well-known inconveniences of sand inclusions during casting.

- Even in optimal conditions, for the excavation of quite large trenches, average absorptions of about 1.10 to 1.15 times the theoretical one must be foreseen.

- At the top of the trenches, overbreaks and cave-ins are very frequent, therefore if smooth surfaces are needed, an adequate shuttering must be used. Overbreaks can also occur in transition regions between two types of soils.

- Deviations from verticality of about 1.5 % must be considered for the panels themselves.

REFERENCES


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