Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Jet grouting application for quay restoration in Tunisia

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ABSTRACT: Few years ago, the quay of Sfax harbor was made-up because of the increase of the traffic ships. After this amenity, unstopped settlements occurred in the revetment layer of the roadbed. From the soil investigation conducted near to the quay, the absence of a filter, to prevent the migration of fine particles from the material fill, was observed. Due to the presence of cavities in the soil, the measured permeability was roughly 1 cm/s. To remedy at this situation, the stabilization of the revetment wall, using the jet-grouting technique, was decided. A micro-concrete and a cement grout were jetted in boreholes, with 105 mm diameter, at depths ranging from 11 m to 13 m. A remarkable decrease of the permeability was observed after water tests carried in the stabilized quay.

1 INTRODUCTION

The trade harbor of Sfax is located at the Tunisian East coast, at 34°43' north latitude and 10°46' East longitude, where the seafloors have weak slopes. The basin of the harbor covers a total area of 65 hectares with 2600 meters of quay. The length of specialized quays is 1460 meters. Roadbeds of this harbor have a surface of 24 hectares, and include 22,700 m^2 of covered surfaces. Sfax, as second town of Tunisia, offers the harbor ensuring the most important traffic (by 30% of the general import/export traffic) composed of 63% of solid jumble, 23% of liquid jumble and 14% of various wares. The harbor was opened to the trade in 1891. To follow the evolution of the traffic, this harbor knew several extensions and amenities among which, particularly, the elongation of the trade northwest quay and the extension of the roadbeds behind.

The principal basin of the quay is limited by two quay walls. The first one, with total length of 580 m, was built by prefabricated caissons filled by reinforced concrete whose foundation rests at depth 11m hydro, and leveled at 2.5 m hydro. In 1950, the construction of the quay was done 20 m in front of the old one with a foundation at -6 m hydro. A protection of the angle of the quay, of 40 cm in width, was done by masonry and cutting stones.

Surges that reach the entrance of the basin come from the southeasterly sector. The intensity of currents tide reaches 50 cm/s at marine depth of 1.5 to 4 m.

2 DESCRIPTION OF THE TRADE QUAY

After the recent extending of the trade quay of Sfax harbor, unstopped settlements occurred in the revetment layer of the roadbed. These settlements were pronounced and localized in the revetment layer. Despite several reparations, continuous settlements took place progressively until 15 cm on average. From several borings carried out in the roadbed, it was confirmed the absence of a filter between the revetment wall of the quay and the material fill with an important percentage of fine particles. The rule of the filter, to protect the loose of fine particles from the fill, was not ensured. This process, that would be amplified by the tide phenomena, created a new arrangement of gravel and blocks from which settlements occurred.

From the diagnostic of the quay, a deposit of fine particles occurred on the joints. That confirms the assumed loose of fine particles due to the absence of a filter behind the quay.

The observed degradations in the coronation beam come from two different facts. The first one is relevant to the constitutive material of the beam. The second fact is related to the marine water effect on mortar joints. As executed in masonry quarry stones, the beam can not resist to the transmitted solicitations. As a matter of fact, if submitted to a direct or a frontal shock of ships the deterioration of cemented mortar joints can not be avoided in time. This phenomena will be aggravated because of the absence of defenses.

In addition, the mortar cement joints being thin, their desegregation becomes easy under the aggressive action of the marine water.

Even if under moderate shocks, the two mentioned facts contributed largely to the progressive deterioration of the coronation beam.

3 ANALYSIS OF THE DISORDERS

In order to clarify the origin of disorders, an investigation program was adopted. The latter included a topographic survey on a band width of 25 m behind the quay, a bathymetric survey on a band width of 20 m in front of the quay, and four boreholes executed until 15 m depth. Also, an investigation by divers was done with a video film production.

The subsidence area, where localized settlements occurred, is located at 20 m in width from the quay border. Because of that, the origin of the observed settlements could not be attributed to the compressibility of the roadbed material mainly constituted by quarry wastes. Therefore, settlements are rather due to insufficient stability conditions of the quay wall as hole, or to the loose of fine particles through voids existing between stones of the revetment wall.

From the soil investigation carried behind the quay, it appeared a material fill constituted by gravel and calcareous blocks. The study of stability of the recent quay wall was carried regarding sliding on its base and overturning. As shown in figure 1, stability conditions require a friction angle of the material fill equal to 37°. This condition is normally satisfied from the description of the filled material behind the quay whose friction angle is by 42°. It is then concluded that the stability of the quay wall was not compromised, Studi (1996).

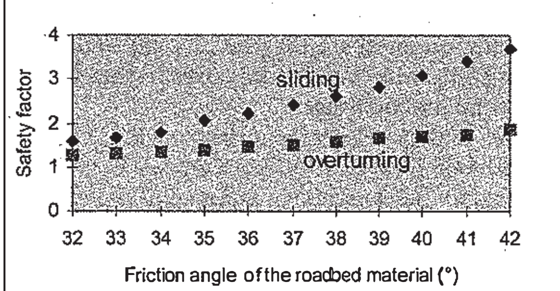

Figure 1. Computed safety factors from the stability study of the quay wall.

4 REMEDIATION

From the diagnostic and the conducted surveys above described, a solution of the quay restoration, including roadbeds and the beam coronation, should be advanced. The solution of a new quay construction is inadequate, and it should not be analyzed because settlements will not stop in the roadbeds of the existent quay whose stability was verified. By the construction of a new quay the port exploitation will be more complicated.

To remedy at this situation, with minimized disturbance of the harbor activity, repairing was the preferred solution. For the latter, two alternatives were envisaged. The first one needs the insertion of a filter, with selected materials, between the revetment wall and the roadbed. The second alternative is the consolidation of the roadbed mass using the jet grouting technique.

4.1 *The first alternative: insertion of a filter*

A geotextile film or blocks of rock (of 0 to100 kg) is the filter material to insert between the revetment wall (behind the quay) and the fill roadbed. This alternative needs to evacuate the existing fill, to execute the filter, and to replace both the excavated fill and the existing circuits. The total cost of this alternative is by 2800 thousands Tunisian dinars.

4.2 *The second alternative: grouting in the revetment wall*

By grouting a cementing agent in the roadbed behind the quay, voids will be significantly reduced. Assuming 40% of porosity in the rock blocks, the volume of grouted materials to inject is by 30 cubic meters per linear meter of the quay. Therefore, a monolithic mass will be obtained. Depending on the coefficient of permeability of the soil roadbed, the use of a cement mortar will contribute to a less restoration cost. For this reason, and to make a better estimation of this operation, the execution both of permeability and grouting (of a cement mortar) tests was recommended. The total cost of this alternative is by 2900 thousands Tunisian dinars. A comparison between the two restoration alternatives is presented in table1.

The costs of the two restoration alternatives are similar. The main technical advantage of the first alternative is a new construction of the quay. But, it needs a complete stop of the harbor exploitation (quay and roadbeds) in the area to restore. While, by the second alternative, the consolidation of roadbeds is carried without having recourse to opened excavations.

Table 1. Comparison between the two restoration alternatives.

Criteria	First alternative	Second alternative
Cost (per linear meter of quay)	2800 thousands Tunisian dinars	2900 thousands Tunisian dinars
Advantages	* The execution is relatively easy for local contractors * a complete substitution : better performances	* Without disturbance of the port exploitation * Without risk for stability of the existing foundations
Disadvantages	* The port exploitation is significantly compromised * Demolition and replacement of the existent circuits : longer time of execution.	* Difficult estimation of quantities * Risk in loose of the grouted materials * Adequate execution by few contractors * Permanent control of the execution

Because of the advantage in time execution, the second alternative was finally adopted.

5 JET GROUTING APPLICATION

The jet grouting treatment, planned in two phases, should be executed in vertical boreholes, with 105 mm diameter, along the elevation of the revetment wall of the quay. The jet grouting parameters, per meter in depth, were to reach a maximum volume of six cubic meters of the grouted material, or a maximum grout pressure of 0.2 MPa that should be maintained during one minute.

The grouted material is a mixing of micro-concrete and mortar. As illustrated in figure 2 (dimensions are given in meter) drilled boreholes, in regular square mesh 4mx4m, will be executed respectively until 11 m depth for the external line and 13 m depth for the internal line.

5.1 *The first phase of soil treatment*

It was conducted successively along the internal and the external lines. Primary boreholes were executing by jetting a micro-concrete grout. Then, secondary boreholes were executed between the primary ones by jetting a cement grout. As illustrated in figure 3, primary and secondary boreholes are distanced 8 m.

At the end of the first phase, Lefranc water tests, Cassan 1993, and laboratory permeability tests were performed to check the efficiency of the jet grouting treatment.

5.2 *The second phase of soil treatment*

In the second phase, the grouting was achieved along the intermediate line located between those executed in the first phase, through drilled boreholes

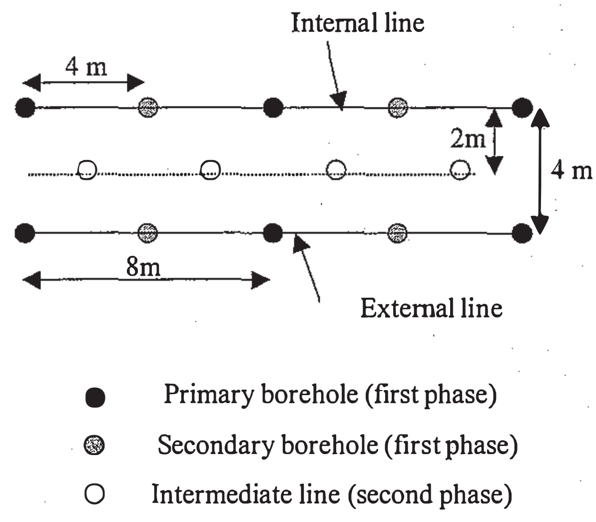

Figure 3. Adopted methodology for jet grouting treatment.

at 12 m depth. The grouted material was a cement of bentonite.

5.3 *Equipments and description of the process*

From the roadbed surface to the predicted depth, boreholes were drilled by a device SR6, using a temporary casing (wire line) with 105 mm in diameter. After, the driller device was removed, and the jet grouting string was installed within the temporary casing. From the borehole base, the temporary casing was remote on 1 m depth along which the jetting was executed at lower pressure controlled by a manometer.

The jet grouting strings, made in PVC material, had a nominal diameter larger than 26 mm. The grouting device referenced "Moyno 2000-Miro 1" pump materials such as mortar, micro-concrete, and grouts. Such pumps are equipped with devices controlling the injected pressure and the debit (or volume) of the grouted material.

The jet grouting criteria (maximum volume or maximum pressure of grout above mentioned) were adopted both during the execution of primary and secondary boreholes.

5.4 *Materials*

For the grout mixes, potable water was used from the distribution circuit of Sfax town. For micro-concrete the used sand comes from a quarry with parameters: calcareous content is 30%, sand equivalent is greater than 80% and fineness modulus ranges from 2 to 3. The cement comes from the "Artificial Tunisian Cements" factory whose characteristics comply with the French AFNOR standard.

Based on the observed decrease in volume of the grouted materials, from the internal line to the external one, an important volume of voids was filled.

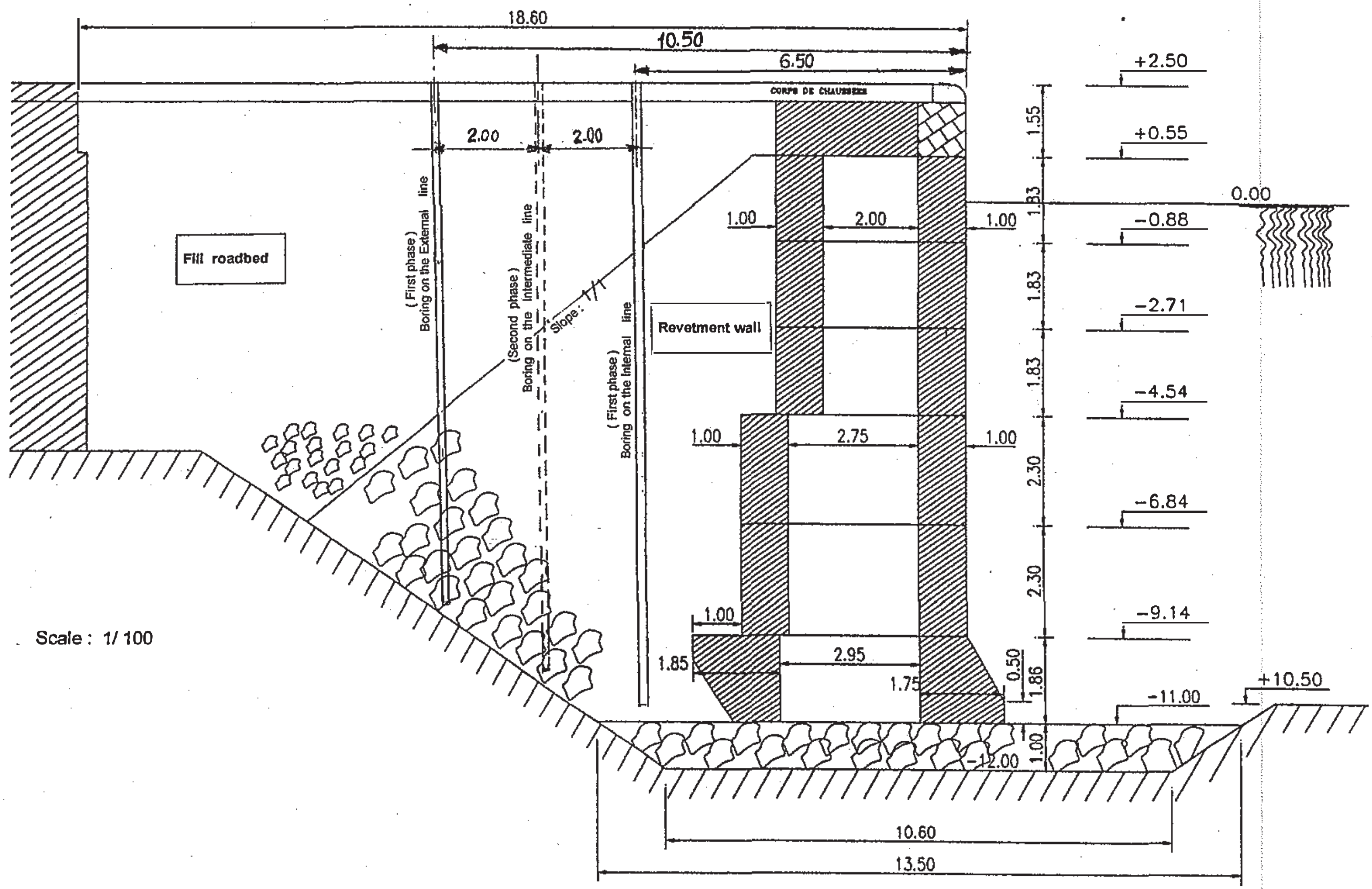

Figure 2. Illustration of the jet grouting alternative.

6 CONCLUSIONS

From the quay restoration experienced in the trade quay of Sfax harbor, two main remarks should be hold.

1) Based on recorded results, a remarkable decrease of the injected volume of micro-concrete or cement grout was obtained following the treatment sequences.

2) From laboratory and in-situ permeability tests, conducted in the treated soil, the measured coefficient of permeability was by 10^{-4} cm/s. That was enough lower regarding the required value by the technical specifications for the quay restoration.

Finally, the recourse to the jet grouting technique was a successful operation to restore the quay of Sfax harbor without stopping the trade activity.

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