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Geotechnical Problems in a Bridge over Corinth Canal

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SYNOPSIS The railroad bridge of Corinth Canal was founded in a stable tectonic block (horst) consisting of neogene marly limestones, marls and sands. After the last strong earthquake of 24th February 1981 an extension of existed subvertical joints, directed E-W, was observed close to the northern bridge abutment. A geotechnical study was carried out for the detection of the causes which created these phenomena and for the design of probable reinforcing measures. From the results of site investigations and laboratory tests and after considering the slope stability, it was concluded that the only risk for the abutment is the progressive change of joints apperture and their erosion due to rain water. To minimize this risk, the installation of inclined untensioned grouted dowels was proposed and the continuous monitor of joints apperture especially during future strong earthquakes.

INTRODUCTION

The Isthmus of Corinth connects the Peloponnese with the rest of Greece and the idea of crossing this dates at least from the time of Periander of Corinth, one of the Seven Sages of the ancient Greece.

He built a paved roadway, 4 m wide, called "Diolkos" to drag small ships across the Isthmus from the Corinthian to Saronic Gulf. Later, Caligula surveyed the Isthmus and Nero started the construction of the Canal in A.D. 67 using 6.000 Jewish prisoners. Few months later the work stopped and the whole construction of the canal was completed a long time later, in 1882-1893.

It is approximately 6.3 km long, 21 m wide and 8±2 m deep (ebb and flood) with slopes up to 75 m high. The canal is crossed by two road and one railway bridges.

The new railway bridge was put into circulation in 1948. Its metallic frame was designed by the American Bridge Co. and was fitted together in situ under the supervision fo the engineers Max Shubs and M. Theoloyitis. The site of abutment foundations was selected by a Greek Committee after taking into account the geological conditions and in particular the lithology and geological structure of Isthmus (Theoloyitis, 1949).

In more detail, the bridge was founded on a stable tectonic block 330 m wide and 70 m high (Figure 1) which forms a tectonic "horst" laterally limited by normal faults with an East-West main direction.

During the excavation for the construction of the abutments, deep and long seperating surfaces were revealed with an apperture 0.1 to 10 cm. These were systematic, continuous, almost vertical joints running parallel to the main tectonic faults of the region and forming an angle of 30°-40° with the axis of canal. The location of the above geological structures led in a deeper foundation of the abutments and in an increase of their dimensions.

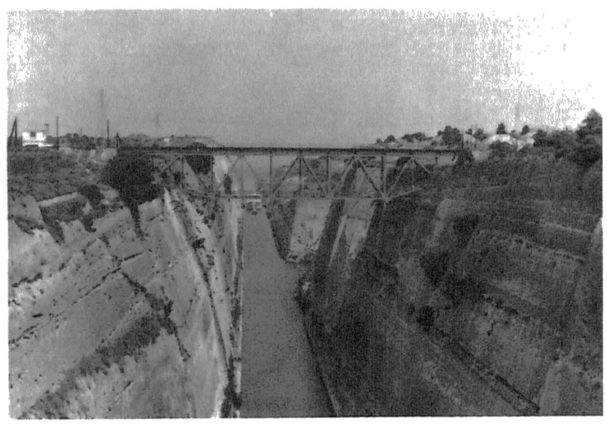


Fig. 1. Railroad bridge over Corinth Canal

After the earthquake of September 5, 1953 (Magnitude 5.5 to 6 Richter scale and local intensity 8 Mercalli scale), an extension of existed joints was observed close to the northern abutment. The same phenomenon was repeated during the main shock of February 24, 1981 (Magnitude 6.6, local intensity 9-10). After this last shock an extension of existing joints on slope was observed and small pieces of glass previously placed on joints walls were broken.

Immediately after the last earthquake of 1981, a geotechnical study was initiated in order to evaluate the risk for the railway bridge abutment and to decide for possible remedial and reinforcing measures.

GEOLOGICAL SETTING

The broader area of isthmus of Corinth belongs to the Sub-Pelagonian geotectonic zone of Greece which includes:

- Limestones, sandstones and basic igneous rocks of Palaeozoic.
- Mesozoic limestones, radiolarites, shales and ophiolites.
- Plio-pleistocene, lacustrine and marine alternations of marls, sandstones, conglomerates and marly limestones.
- Volcanic rocks (Dakites).
- Fluviatile and marine sandstones and conglomerates of Pleistocene.

Especially in the site of railway bridge, under the thin recent deposits, a layer of porous marly limestone (calcarenite) of Pleistocene was located overlying the thick Pliocene marls and sands (over than 200 m thick).

Regarding structural geology, the region suffered three tectonic phases, after the formation of Corinthian Gulf by trench sinking in upper Miocene, as follows:

- an extensional phase during Plio-Pleistocene resulting in the formation of faults with an E-W direction.
- a compressional phase in lower Pleistocene which had as a result the formation of inverse faults with an E-W direction also, and
- an extensional phase from middle Pleistocene up todate with the reactivation of old normal faults or the formation of new ones with the same direction (E-W).

The great instability of the area and also the frequent manifestation of strong earthquakes are closely related with this late tectonic evolution.

Philippson (1890) in his study of Isthmus, reports that 23 main faults transverse the canal while Freyberg (1973), in a more detailed mapping of the Canal slopes, presents almost 45 faults which create a series of tectonic grabens and horsts. Finally the recent main faults of the Isthmus of Corinth were mapped by Sébrier (1977) and are presented in Figure 2.

SEISMIC REGIME

Studying shallow earthquakes manifested in the Corinth area, Ritsema (1974) found that tensional axis T is almost horizontal with a North-South direction, while axis of compression P is almost vertical. This is in good agreement with neotectonic and seismotectonic observations. From other seismicity studies it is concluded that the broad area of Corinth is seismologically very active and namely three times was suffered from distructive earthquakes during the last 130 years.

On February 21, 1858 a strong shock with a maximum intensity of 10 occurred which complet ly destroyed the old town of Corinth and 19 persons were killed (Drakopoulos et al. 1978

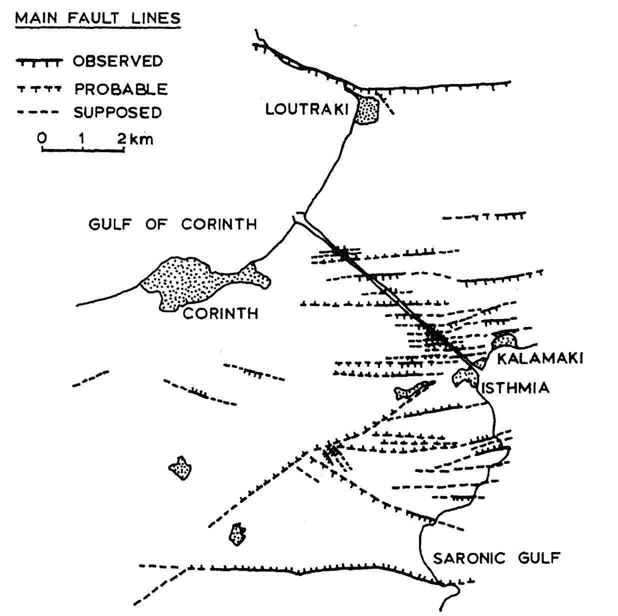


Fig. 2. Geological faults crossing Corinth Can.

Seventy years later, on April 22, 1928 another strong shock with an epicenter close to the canal (Magnitude 6.2, intensity 9-10) destroye the new town of Corinth built along the seasid

According to Galanopoulos (1968), the seismic risk expressed in return periods for shallow shocks and for a surface of one square degree is very high as it is shown in Table I.

TABLE I. Return periods of shallow earthquakes in Corinth area

1 shock with M≧7	every	135-170	years
1 shock with M≧6½	every	55- 70	years
1 shock with M≧6	every	23- 28	years
1 shock with M≧5½	every	9- 12	years

GEOTECHNICAL INVESTIGATIONS

Immediately after the first local inspection o the abutment towards Athens and the study of existing geological and geotechnical data, an investigation program started, including:

- Excavation of two trial trenches to study joints characteristics (strike, dip, frequence, apperture, persistence and roughness of joint walls).
- Installation of crack displacement transducers connected with a measuring instrument in order to monitor relative movements of joint walls with time or after loading (static or dynamic) of abutment.

- Drilling of five boreholes for sampling, location of discontinuities in depth and measurement of secondary permeability.
- Laboratory testing of undisturbed and disturbed samples.

Trial Trenches

As it was previously mentioned, the main direction of the joints close to the abutment is E-W, the same as that one of the normal faults. The frequence of joints was approximately one joint per two meters of length.

In order to study the joint characteristics and their persistence as well, two trial trenches were excavated as they are presented in Figure 3.

In the first trench, which was almost parallel to canal axis, after the excavation of about one meter of loose recent deposits, a hard layer of porous marly limestone was revealed. This limestone was crossed by subvertical joints with an E-W mean direction.

In Figure 4, a characteristic joint is shown, having a dip direction of 8° and a dip of 88°.

Fig. 4. Characteristic joint in marly limestone

Its maximum apperture was 5 cm filled with loose sandy clay. The joint walls were smooth, undulated with a wave-length of 2.5 m and an amplitude of 20 cm, without the appearence of any slickenside or other lineation of mechanical origin.

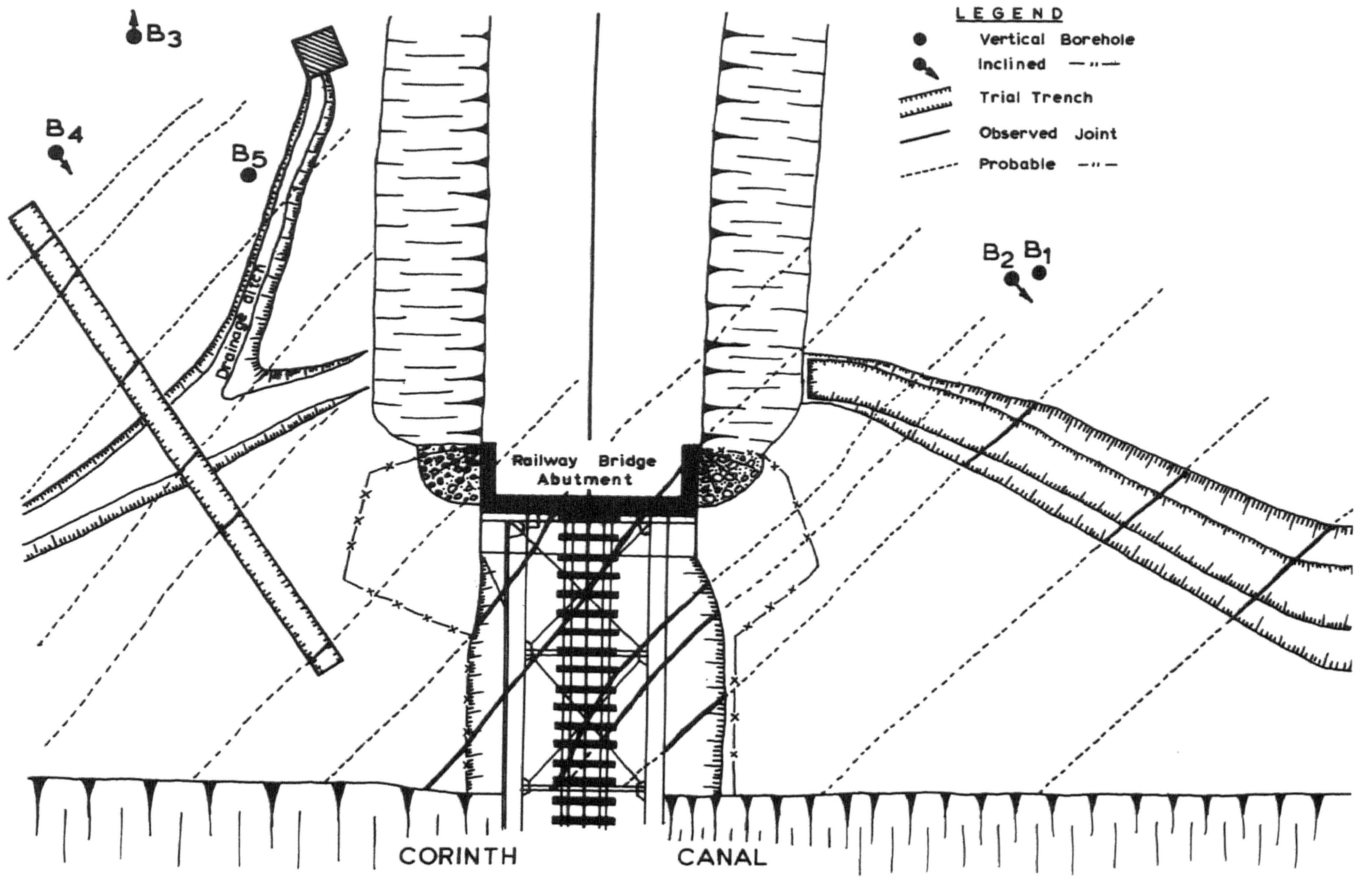


Fig. 3. Site investigations in the region of northern abutment of railroad bridge

TABLE II
Joints Characteristics

Joint No	Deep	Deep Direction	Apperture	Fill material	Roughness of walls	Wall geometry
1	88°	008°	5 cm	Sandy Clay	Smooth	Undulated
2	90°	350°	4 cm	"	"	"
3	90°	350°	Closed			Planar
4	82°	352°	"			"
5	86°	005°	6 mm	Calcite	Smooth	"
6	70°	358°	3 cm	Sandy Clay	"	Undulated
7	88°	005°	2 cm	"	"	"
8	85°	010°	3 cm	"	"	Almost Planar
9	90°	012°	10 cm	"	"	"

These joints were mapped (Figure 3) and it was verified that these were extensions of the joints located close to the abutment.

Furthermore, joints of the same origin and similar characteristics were revealed in the porous marly limestone after the excavation of the second trench, 2 m deep directed NNE-SSW (almost perpendicular to joints strike).

As it was measured, the mean frequency of joints close to the site of bridge abutment was one joint per four meters of length. The characteristics of revealed joints after the excavation of the two trial trenches are listed in Table II.

Monitor of Joint Walls Relative Movements

In order to measure probable movements of different rock blocks limited by existing joints, five crack displacement transducers were installed on the walls of joints close to the abutment. These transducers were connected with the portable measuring instrument through a 12-channels switch box.

In Figure 5 a transducer, covered for protection with a metallic box, installed on the walls of a joint is shown. The relative movements of joint walls started to be monitored immediately after the installation of the measuring system and the recorded values in certain dates are presented in Figure 6. As the figure illustrates, the deviations from the initial readings are very small (max. value 0.285 mm). Also there was not any continuous opening or closing of joints walls observed, but only an alternating increase and decrease of the initial appertures.

Fig. 5. Installation of a crack displacement transducer on joint walls

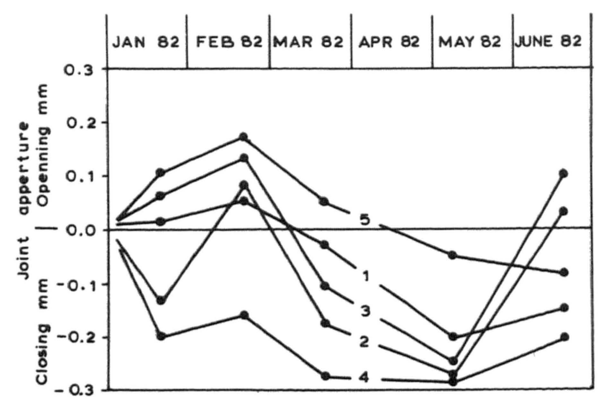


Fig. 6. Recorded values of joints apperture measured by displacement transducers

Situ and Laboratory Tests

ve boreholes were drilled, as they are shown Figure 3, B1, B5 (vertical) and B2, B3, B4 nclined), in order to:
)etermine the stratigraphy below the abutment foundation.
ocate discontinuities of rock mass in depth.
)btain undisturbed samples and
Estimate secondary permeability due to joints presence.

ring the drilling and every 1.5 to 2 meters pth, Standard Penetration Test (SPT) was rried out, while sampling with thin wall oes (SHELBY) was almost impossible for the st of the cases, because of marl stiffness.

nison samplers were carefully used to obtain disturbed samples of marl, although the vance was very slow and unsteady, resulting some cases, in a relatively little sturbance of samples.

e porous marly limestone, of the upper six ters was sampled using rotary core drilling.

certain places and depths, especially in rly limestone, some joints were revealed ring drilling of inclined boreholes, having e same orientation as these which were served in excavated trial trenches. In these ses a total loss of drilling water was served and a mean value of the order 10^{-3} to $^{-4}$ cm/sec for the coefficient of secondary rmeability was estimated (Lugeon tests).

Undisturbed specimens of marl were tested in unconfined and triaxial (consolidated-undrained) compression. The unconfined compressive strength varied between 0.15 MPa and 0.70 MPa, with a mean value of 0.3 MPa, while the mechanical parameters c' varied between 0.06 and 0.18 MPa and Φ' from 28°to 32°.

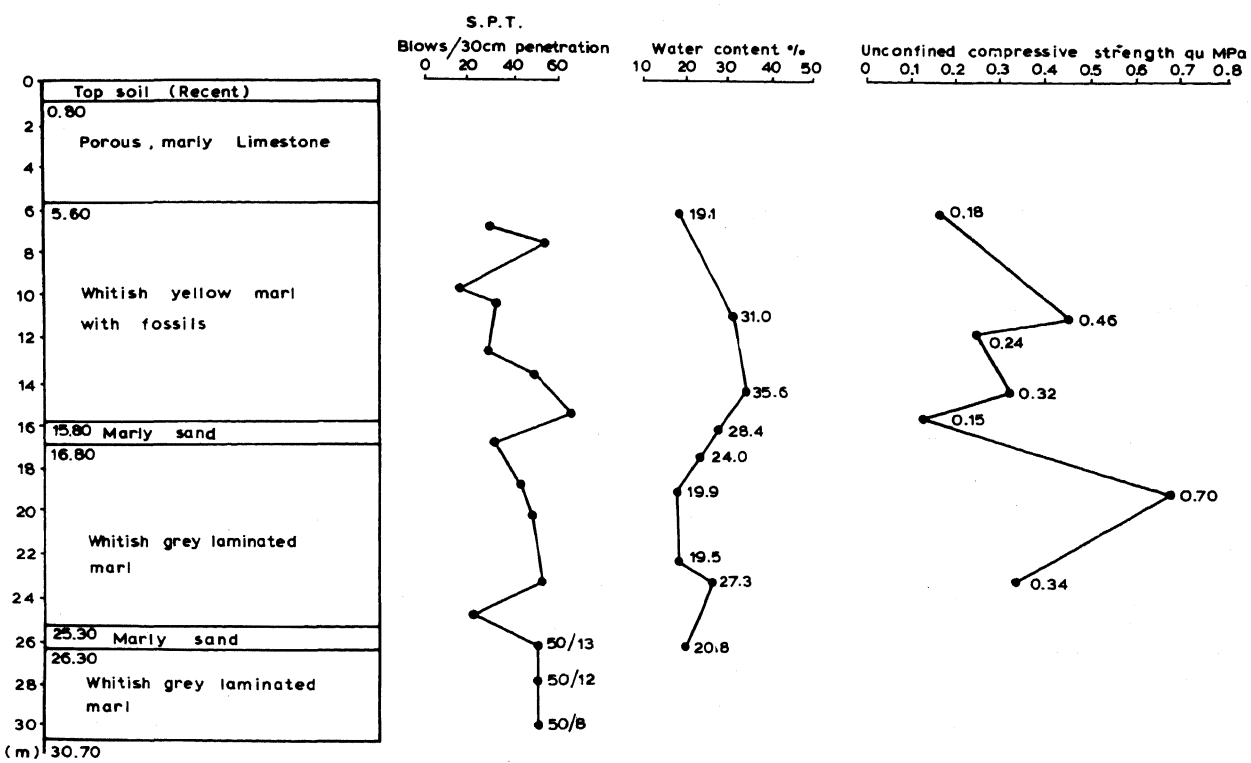
The uniaxial compressive strength of porous marly limestone ranged from 10 MPa to 20 MPa while its tensile strength between 0.35 MPa and 0.96 MPa.

In Figure 7 a typical geotechnical section of the region close to the railway bridge abutment is given.

SLOPE STABILITY ANALYSIS

From consolidated-undrained tests on specimens of marl, average values of $c'=0.1$ MPa and $\Phi'=30°$ were taken and used subsequently in the slope stability analysis. The corresponding mechanical parameters for marly limestone were taken (conservatively) from existing local experience and data of tests on similar rocks as $c=0.25$ MPa and $\Phi=35°$.

By using the simplified Bishop method of slope analysis, for dry slopes (very low phreatic horizon), a factor of safety F=1.05 was obtained in the case of no earthquake. On the other hand, considering stability with seismic forces and



. 7. Typical geotechnical section of the region close to the railroad bridge abutment taking $\alpha=0.10$ g, where α is the horizontal acceleration due to earthquake forces, a factor of safety of the order F=1.0 was estimated.

It must be mentioned, that these values of the mechanical parameters obtained for the marl, mainly referred to specimens, taken with a Denison sampler, which represent the softer parts of the marl. So the values used in slope stability analysis actually constitute lower bounds of the mechanical parameters of the whole marly mass.

Even though, using these conservative values, the factor of safety is close to unity and it must be considered as a satisfactory value for slope stability in the case studied.

According to the above mentioned data, it seems that the only risk for abutment stability is the probable relative movement of rock blocks, limited by subvertical joints, due to a progressive opening of joints with time or after an intense seismic activity.

In order to minimize this risk, Panet (1982) proposed, as a reinforcing measure, a series of untensioned grouted dowels inclined 45° and directed normal to joints strike (Figure 8), which are now under construction.

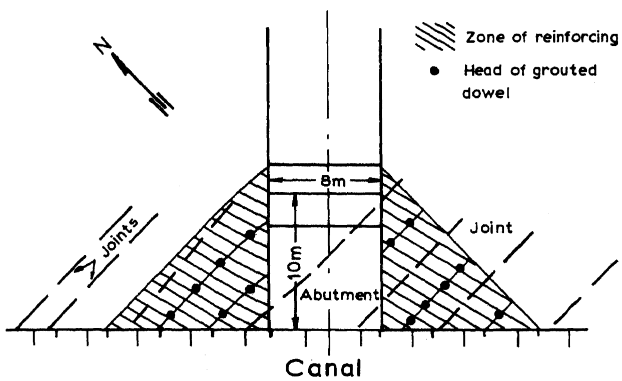


Fig. 8. Installation of grouted dowels

Finally, the photo-surveying of the region, close to the abutment, and the continuous monitor of probable changes of joints apperture in the future and especially during strong earthquakes, were undertaken.

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