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GEOTECHNICAL ASPECTS OF THE DESIGN AND BEHAVIOUR OF THE HIGHWAY BRIDGE OVER DRADER RIVER IN MAROCCO

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ABSTRACT: The motorway bridge on the Drader River suffered from severe floods, which occurred during its construction in 1995-1996. At this site, 8 m thick compressible soft clays layers were found during the site investigations and piled abutments were designed. During the flood, due to erosion of the riverbed under the bridge, the piled abutments were displaced and came in contact with the bridge deck. The access embankments were taken away and a new project was established for the abutments and embankments. L-shaped retaining walls prevent any contact between the fill and the abutments and hollow concrete tubes were placed in the fill in order to reduce the load applied to the ground surface.

INTRODUCTION

The motorway Rabat-Tanger is located at short distance of the Atlantic coast of Morocco (Fig. 1a) and crosses the estuaries of many rivers, the most important of which are the Oued Bou Regreg (Rabat-Salé), the Oued Sebou (Kénitra), the Oued Drader and the Oued Loukkos (Larache) (Fig. 1b). The road embankment is usually a few meters above the natural ground surface and forms a barrier against the flow of water during the winter floods. The river floor under the bridges is protected from erosion and can resist this action in service conditions.

In January 1996, during the construction of the bridge on the Oued Drader, a very heavy rain period occurred before the river bed protection was installed. Due to erosion, the piled abutments of the bridge were displaced and went in contact with the bridge deck. The existing access embankments were then taken away and a new project, accounting for what had happened, was prepared. This paper describes the techniques used for repairing the bridge and the access embankments and the observations made after the completion of the works.

THE BRIDGE OVER OUED DRADER

Description

The Drader bridge (Figs. 2 and 3) consists of two parallel bridges of a type called in French "VIPP" (post tensioned beam and slab single span bridge) (SETRA, 1996; Highways Agency et al., 1999). Each slab is borne by 4 post-tensioned concrete beams, of which the dimensions are shown in Table 1.

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Note: Discussion on this paper is open until December 25, 2000.

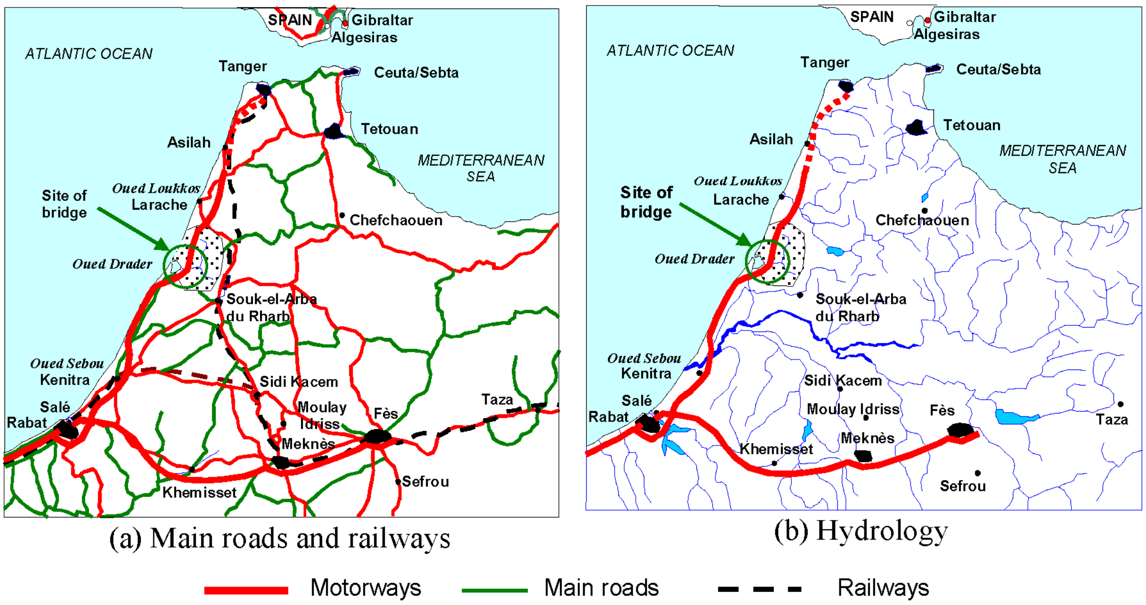

Fig. 1 Location of the Drader bridge on motorway Rabat-Tanger

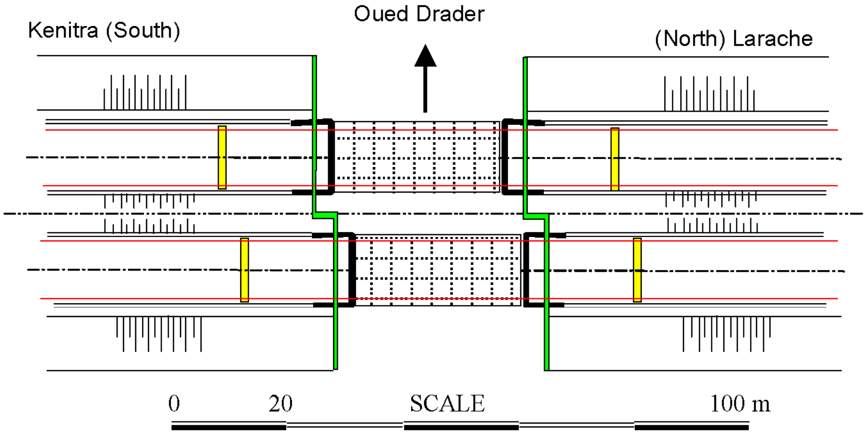

Fig. 2 Plan of the bridge over Drader river

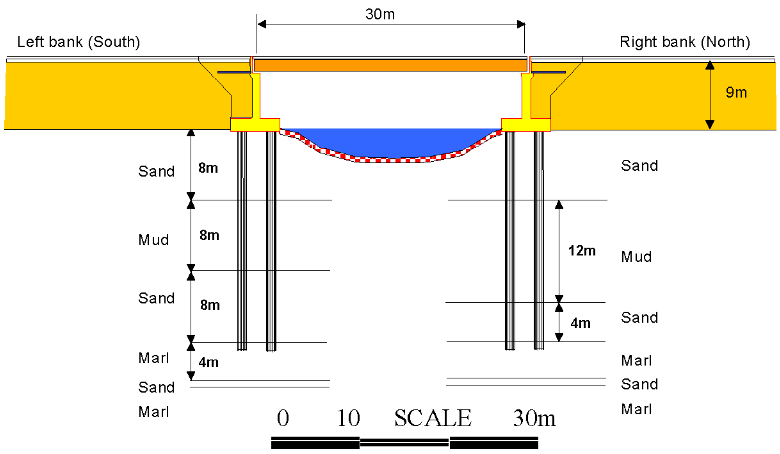

Fig. 3. Longitudinal section of the bridge over Oued Drader

Table 1 Dimensions of Drader bridge

Beam height:	1.70 m	Distance of beams:	3 m
Beam thickness:	0.2 to 0.4 m	Number of active cables:	5 per beam
Span:	30 m	Thickness of slab:	0.2 m

The abutment consists of a front wall resting on piled footings, with an abutment wall and two perpendicular sidewalls. The front walls are 5.3 m high and 1.1 m thick. The height of the abutment wall is 2.05 m.

The piled foundations of the abutments consist of a footing borne by two rows of four reinforced concrete piles:

Pile length:	30.5 m	Width of footing:	6 m
Pile diameter:	1.2 m	Length of footing:	12.5 m
Interaxial distance:	3.36 m	Thickness of footing:	1.5 m
Distance of rows:	3.6 m	Artesian water bearing layer:	17 m below NGM

Table 2 Calculation scheme for the piled foundations

Layer	q_c (MPa)	f_s (kPa)	$K_o \tan\phi'$
Fine sand 0-16m	0.2	4	0-8m 0.35 sand 8-16m 0.20 sandy mud
Dense sand 16-19m	10	80	
Dense sand > 19m	15	125	

Geotechnical Design

The geotechnical site investigations for the Drader bridge began in 1989. Two destructive soundings and two cone penetration tests were made to a depth of 25 m (one on each bank of the river). Laboratory tests were performed on samples taken from the boreholes. The first impression from these investigations was that the soils on the left bank consisted mainly of sands, with an intermediate layer of sandy marls from 12 to 14.3 m depth. The marls had a plastic limit of 11, a liquid limit of 30% and the weight percentage of fine particles (less than 80 μm) was 54%. The undrained cohesion of the marls was equal to 30 kPa. On the right bank of the river, the layering differed and a 6 m thick layer of sandy mud was found inside the sand deposits (from 8 to 16 m depth). The mud (sandy soft clay) had a plastic limit of 21%, a liquid limit of 57% and a fines (<80 μm) content of 69%. The effective shear strength parameters were equal to c'=0 and ϕ'=22 degrees. An oedometer test gave an initial void ratio of 0.8, a compression index of 0.25 and a swelling index of 0.06.

The in situ CPT tests were used to make preliminary calculations of the piled foundations, with due account for negative friction on the right bank of the river (Table 2).

At that time, no specific difficulty was foreseen for the construction of the bridge. A total settlement of 0.4 m had been estimated under the 7 m thick access embankments, with rather high consolidation rates. Each abutment was founded on six piles, with a diameter of 1.20 m and a length of 33 m. The piles would penetrate in the underlying marls by 5 to 6 m (4 to 5 times the diameter of the piles). Prior to the beginning of the construction works, additional site investigations were made, in order to define the ground water conditions for the installation of the bored piles. Two piezometers were installed on the right bank of the river at a depth of 21.3 m and 30.4 m respectively. During the installation of the piezometers, additional information was gained on the soil stratigraphy: 1 m thick fill material, covering 1.5 m of clayey mud, 15.3 m of more or less sandy mud, 12.7 m of silty fine sand, with some induration, 2.1 m of marl and a layer of fine and coarse sands. Three water bearing layers were found at –17.5 m, -21 m and –31 m below the natural ground surface. The water pressure in the lower layer was artesian (4.74 m above the ground surface). Besides, SPT tests were made in the fine sand at two depth: -24 m (N=46) and –32.2 m (N=42).

The artesian character of the permeable water-bearing layer found at –32 m depth was taken into account for the execution of the bored piles. It was decided to bore the pile holes from the top of a temporary fill, high enough to have the artesian water column remain in the casing. The contractor successfully made a suitability test for the execution procedure.

However, when the real works began, problems resumed for the installation of the piles and it was decided to limit the pile length to 25 m and to increase the number of piles (eight instead of six for each foundation).

Additional Geotechnical Site Investigations

During the floods of January 1996, the access embankments were eroded, a slide occurred in temporary humps of earth located on the left bank of the river, close to the motorway and the abutments moved towards the bridge deck. Additional site investigations were asked for, in order to check the geotechnical assumptions that would be used for the design of the repair works. Ten additional soundings (4 CPT cone penetration tests, 4 PMT Ménard pressuremeter tests and 2 field vane tests) were made in 1996. Besides, the observations made during the installation of the bored piles were analysed. The results of the in-situ investigations are shown in Figs. 4 and 5.

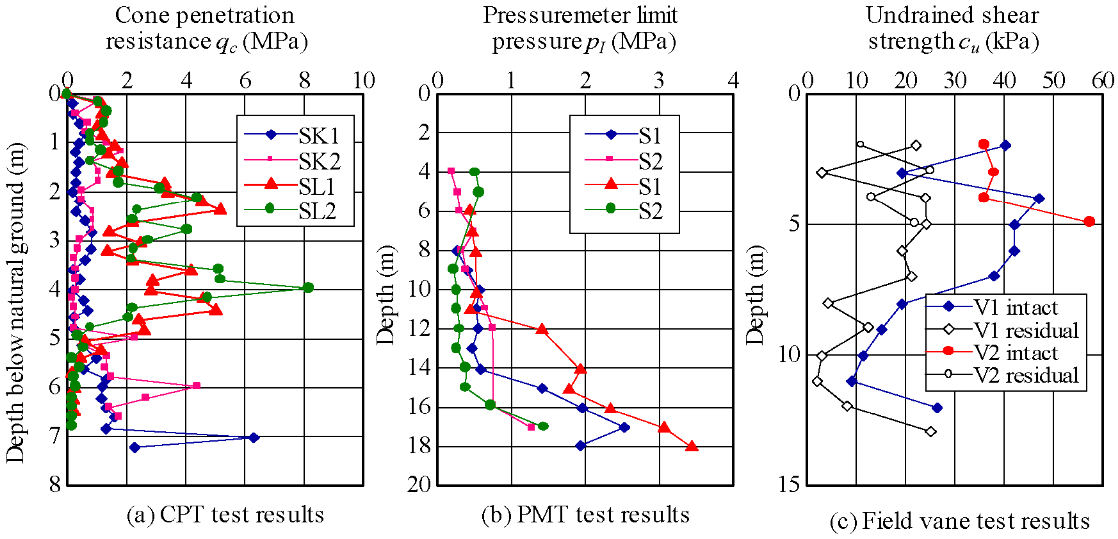

Fig. 4 Geotechnical characteristics of the soils of the Drader valley in the vicinity of the motorway bridge

Hydrology

The Oued Drader is a small coastal river with a basin of about 300 km^2 and a maximum dimension of about 21 km. It flows into a coastal pond called Merja Zerga. The mean yearly rains amount to 600 mm and extends over a five months winter period, with more intense precipitation in December and January. The winter 1995-1996 was one of the most (if not the most) rainy winter of the 20th century and was marked by a succession of floods which interfered with the motorway construction works. Hydraulic studies showed that the total discharge capacity of the bridge could be described as indicated in Table 3.

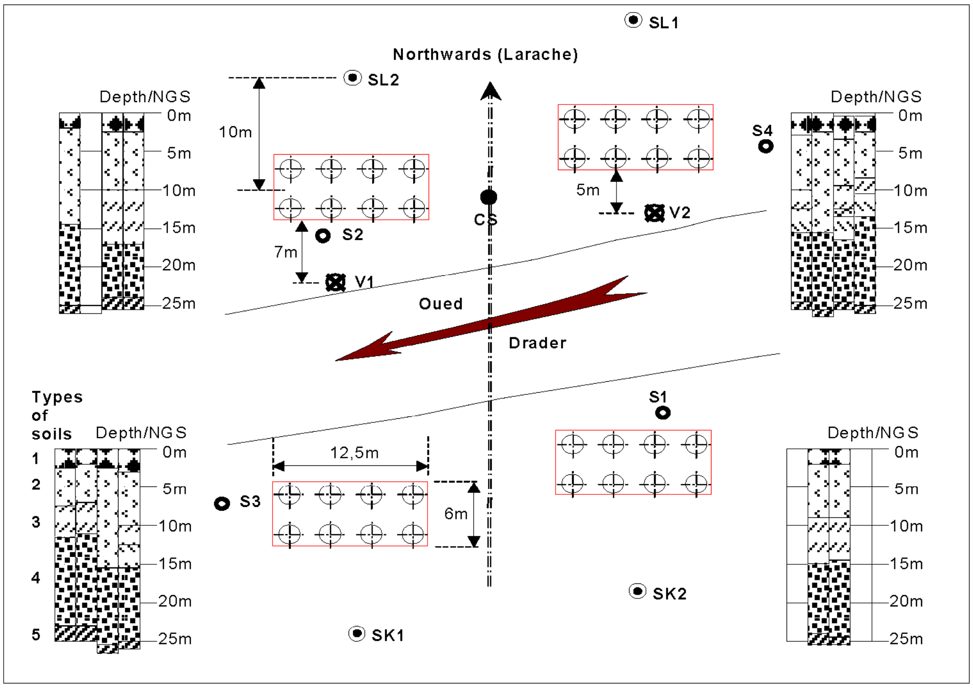

Fig. 5 Layout of the foundations and of the site investigations (Pressuremeter tests S1-S4, vane tests V1-V2, cone penetration tests SL1, SL2, SK1, SK2, core sampling CS, and types of soil found when boring the piles)
Types of soil: 1-Tirs and sandy silt; 2-Soft clayey mud; 3-Clayey marl; 4. Sandy silt, partly indurated; 5. Stiff marl

Table 3 Flow characteristics of the Drader river under the bridge

Total flow rate (m^3/s)	100	150	200	250	300	350
Water level upstream (m NGM*)	3.7	4.2	4.6	4.95	5.2	5.65
Speed of water (m/s)	1.65	2.12	2.55	2.92	3.25	3.54

* NGM : Reference level for Morocco

EFFECTS OF THE FLOODS OF JANUARY 1996

During the floods of January 1996, the estimated flow under the bridge was about 175 m^3/s, which corresponds to a mean water level of 3.82 m NGM under the bridge and a mean speed of water of 1.89 m/s. The maximum water speed could reach 2.3 m/s, with a mean deepening of the unprotected river bed by at least 4 m.

The erosion of the fine sand under the bridge had unfavourable effects on the bridge:
- horizontal movement of the abutment towards the river : 2 to 5 cm;
- fissuration of the abutment walls;
- distortion of the bearings by about 40 mm;
- residual deepening of the riverbed of about 4 m, due to scour;
- erosion and failure of the access embankments next to the abutments.

The state of the bridge after the flood period is shown in Fig. 6.

REPAIR WORKS

Just after the floods, the embankment material was taken away on both sides of the bridge. The origin of the displacements of the abutments was clearly the river floor erosion, but it was not possible to back calculate the displacements of the abutments because no precise deformation characteristic of the soils was known, the maximum depth of the riverbed during the floods was unknown and the displacements of the abutments and of their piled foundations, which had been limited by the bridge slab, were unknown, too.

The definition of the repair works was thus based more on experience than on predictive calculations and could be better described as an application of the observational method.

The best and maybe only way of controlling the horizontal movements of the existing abutments consisted in limiting the pressures on the retaining wall (front wall) and on the piles. This was obtained by two measures:

- the construction of an additional retaining wall behind the abutment, which will suppress any contact between the embankment and the abutment;
- the replacement of the standard fill material by a lighter one.

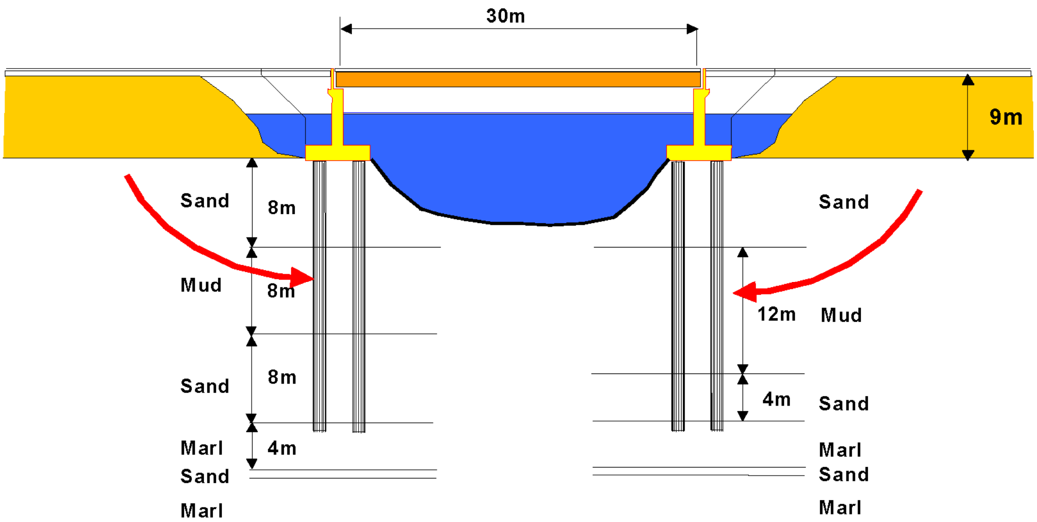

Fig. 6 Longitudinal section of the bridge after the flood and river bed scouring

In order to suppress the pressures against the front wall of each abutment, an L-shaped wall with a deadman anchorage consisting of a smaller wall located at 15 m distance of the abutment was erected.

The technique adopted for decreasing the weight of the embankments was selected from a list of techniques including:

- the use of ultra light weight materials (such as expanded polystyrene),
- the use of low weight materials (such as expanded clay),
- the insertion of piles under the embankment (piled embankment),
- adding one additional span on each side of the bridges,
- inserting hollow structures in the embankments (reinforced concrete frames, large culverts, concrete pipes).

Since the construction works had been interrupted and the completion of the motorway had to be achieved as soon as possible, it was felt that the availability of concrete pipes made this solution the most adequate one. Two types of pipes, 1.6 m and 1.0 m in diameter, were selected and placed in three layers on both sides of each bridge (Fig. 7). The mean weight density of the embankments was thus decreased by 22%. The lower pipes were kept open, in order to facilitate the flow of water during the floods, whereas the pipes of the upper two layers were closed by means of concrete plugs. Two views of the completed embankment are presented in Figs. 8 and 9.

OBSERVATIONS MADE ON THE BRIDGE

Since the design of the repair works was mainly based on experience, some importance was given to the monitoring of the vertical and horizontal movements of the foundation soils and embankments. On each side of the river, the instrumentation consisted of (Fig. 10):
- five hydraulic settlement-probes installed at the natural ground surface level under the embankment,
- one inclinometric tube (on the axis of the motorway),
- 22 topographic marks (spits) placed on both sides of each lane.

Some typical results are presented in Figs. 11 to 20.

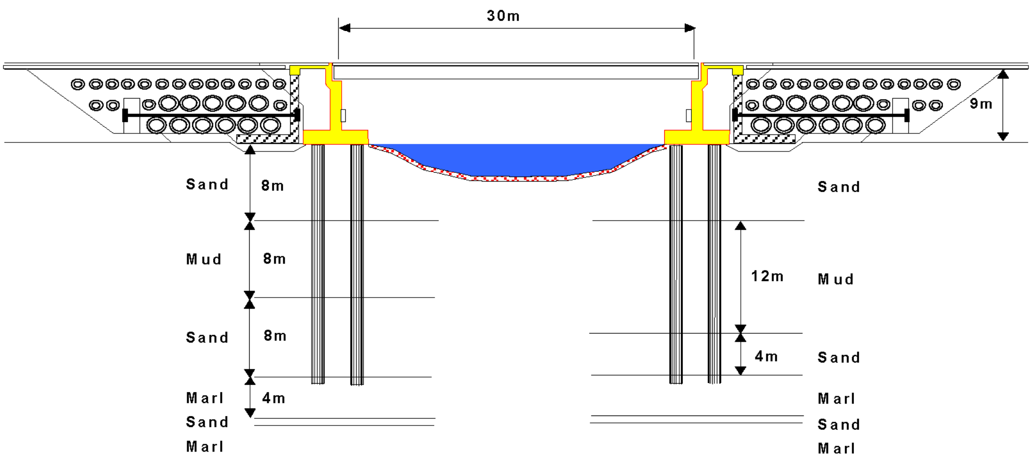

Fig. 7 Longitudinal section of the bridge over the Drader river after the repair works

Fig. 8 Side view of the bridge over the Drader river (from the downstream side)

Fig. 9 View of the three rows of concrete pipes aimed at decreasing the weight of the access embankments of the bridge over the Drader river

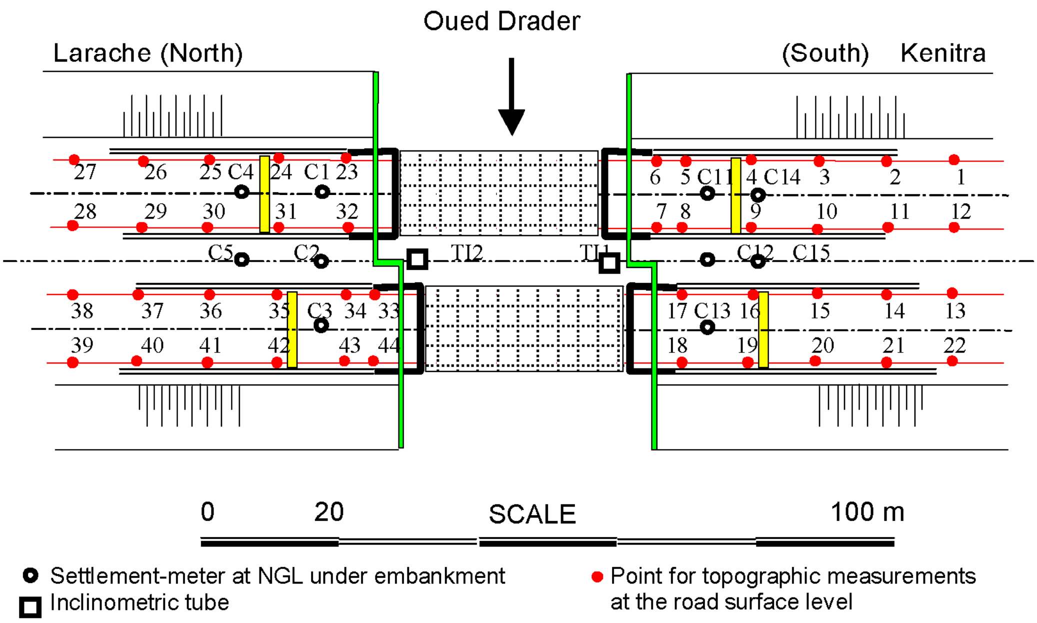

Fig. 10 Location of the instruments used for monitoring the ground movement

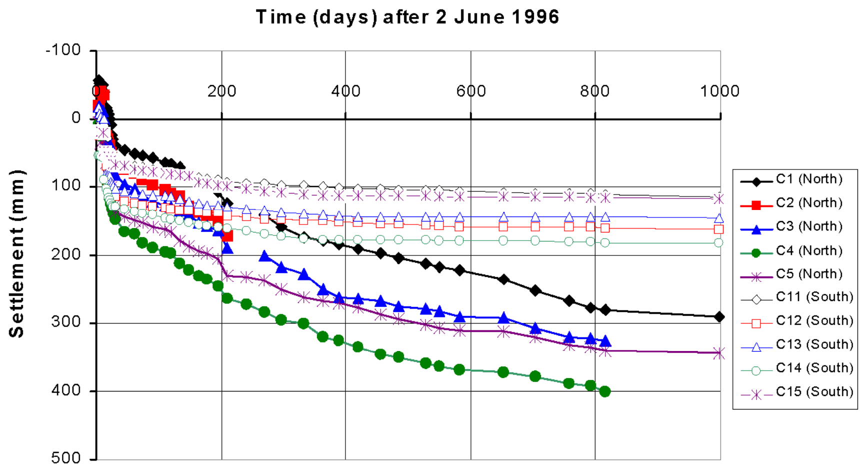

Fig. 11 Settlement of the ground below the embankments (Linear scale)

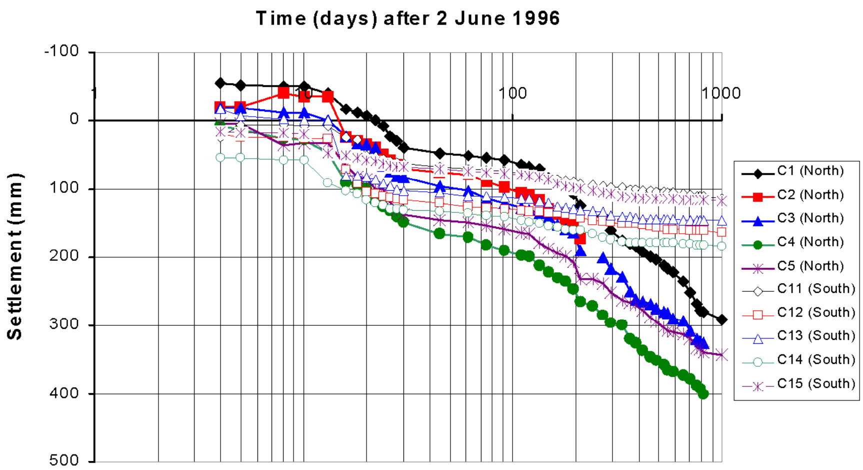

Fig. 12 Settlement of the ground below the embankments (Logarithmic scale)

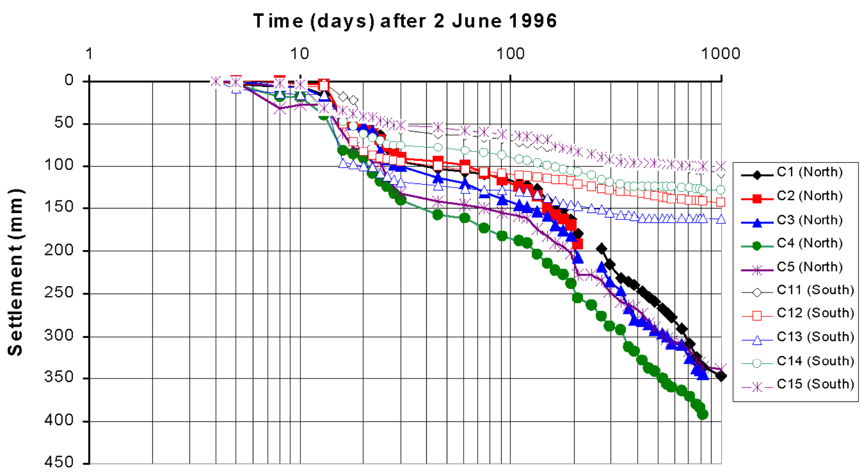

Fig. 13 Settlement versus logarithm of time (corrected values, all equal to zero for t=4d)

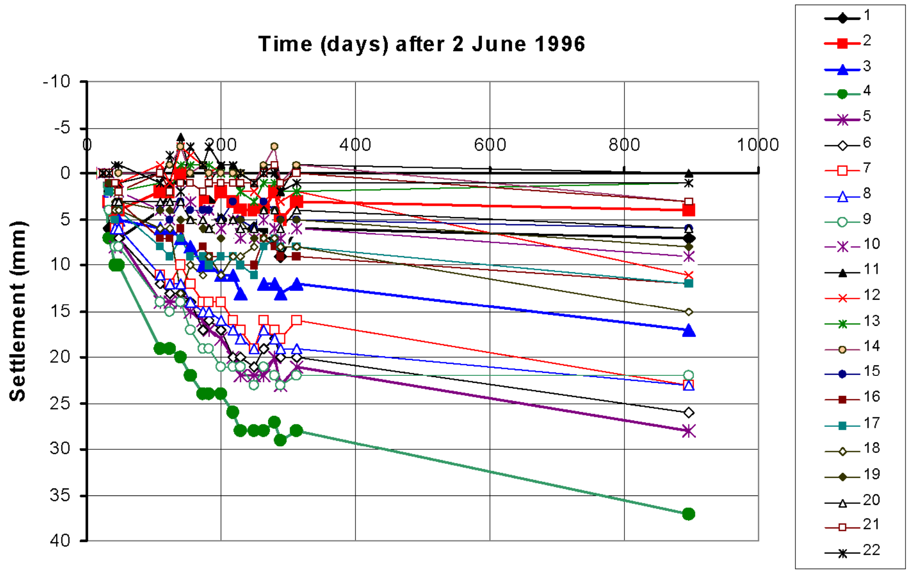

Fig. 14 Settlement of the road surface on the left (Southern) bank of the Drader river

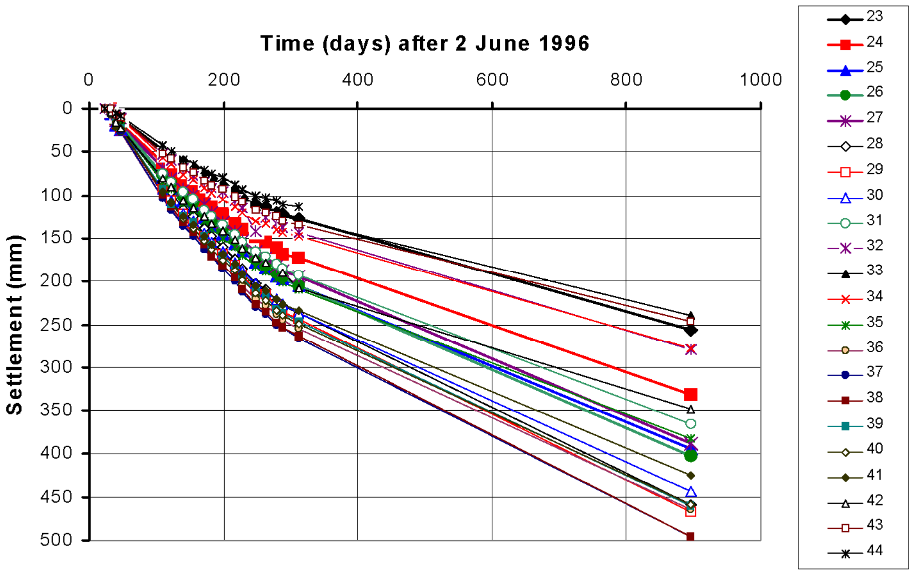

Fig. 15 Settlement of the road surface on the right (Northern) bank of the Drader river

Settlement Analysis

The settlements measured at the natural ground surface under the embankments are presented in Figs. 11 (linear time scale) and 12 (logarithmic time scale). The settlements of the left bank embankments (C11-C15) are clearly lower than those of the right bank (C1-C5) and the consolidation period was much shorter, too. The quasi stabilisation of settlements on the left bank agreed with the data obtained from the site investigations (less compressible soils). Therefore the settlements of the left bank access embankments did not receive further attention.

The settlements observed on the northern side of the river were still going on in 1999, about 1000 days after the completion of the construction works. The experimental data showed some scatter, which might come from the installation of the pipes and of the fill next to the settlement probes. In Fig. 13, the curves are referred to a common initial state (zero settlement) on the 6th of June (the pavement was completed three weeks later). The linearity of the curves shows that primary consolidation still did not come to its end. Besides, the settlements observed in the zone where more pipes were placed (between the L-shaped wall and the deadman wall) are lower than in the intermediate zone (C4, C5).

No information can be obtained from Figs. 11 to 13 about the settlements away from the bridge, where the initial ("normal") embankment was kept. The measurements made on the pavement (Figs. 14 and 15) provide some information on this matter. These measurements began on the 26th of June 1996.

The surface settlements of the motorway are clearly different from one side of the river to the other. On the left (Southern) bank, they are all less than 4 cm. This confirms the conclusions drawn from settlement probes installed under the embankments (Figs. 11 to 13).

On the right (Northern) side of the river, the settlements vary from 25 to 50 cm and are still not stabilised. The large scatter of the curves of Figure 15 can be further analysed if the position of the points is taken into account. This was done in Figs. 16 to 18:

- next to the abutments, in the zone with the lowest loading (Fig. 16), the settlements vary from 25 to 35 cm and are similar to those of Fig. 13;
- behind the deadman wall, in the transition zone from the lighter embankment to the normal one, the settlements range from 35 to 45 cm (Fig. 17);
- away from the bridge, they vary from 40 to 50 cm (Fig. 18).

Thus, a significant reduction of the settlements was obtained by placing the pipes in the embankments.

The estimated primary consolidation final settlement, using Asaoka's method and curve fitting, was about 10cm more than the last measured values on the right side of the river, behind the L-shaped wall. It is expected to be reached in Year 2001 or 2002. Measurements are still going on on this side of the river.

From the point of view of the observational method, the observed behaviour of the foundation soils was satisfactory and no additional measures are necessary to ensure the serviceability and stability of the bridge.

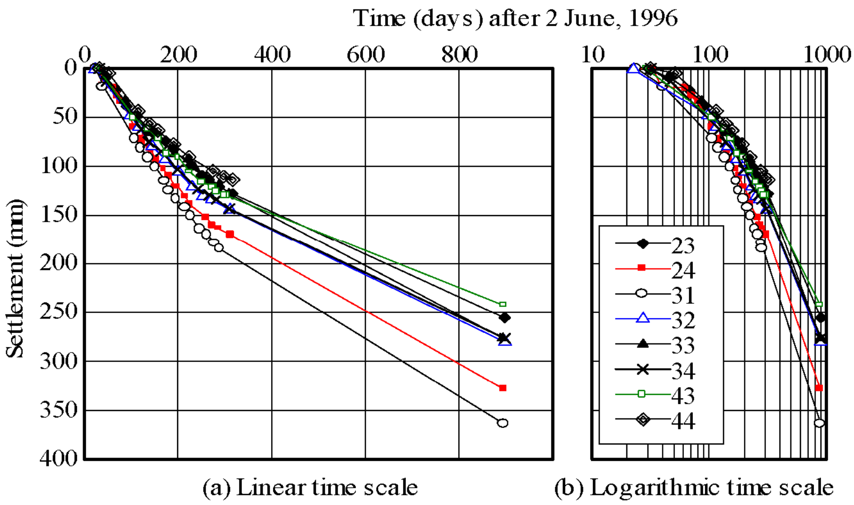

Fig. 16 Settlements measured in the zone of lowest loading (Right/Northern bank)

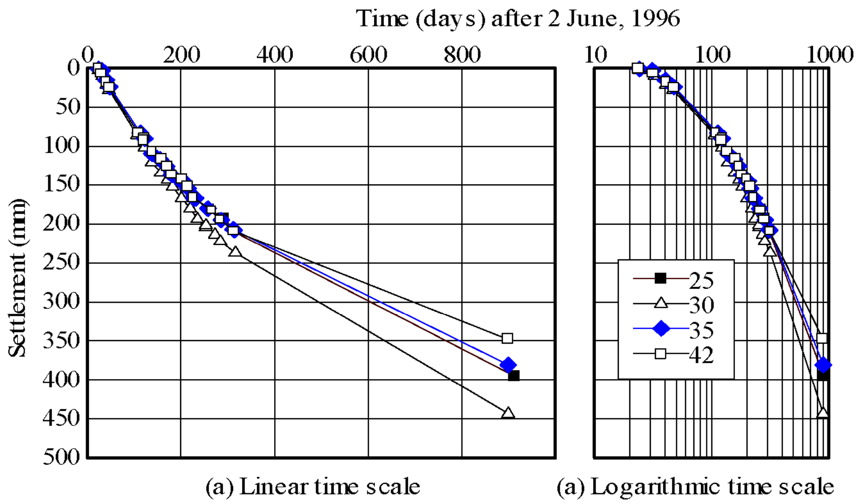

Fig. 17 Settlements measured in the zone of intermediate loading (Right/Northern bank)

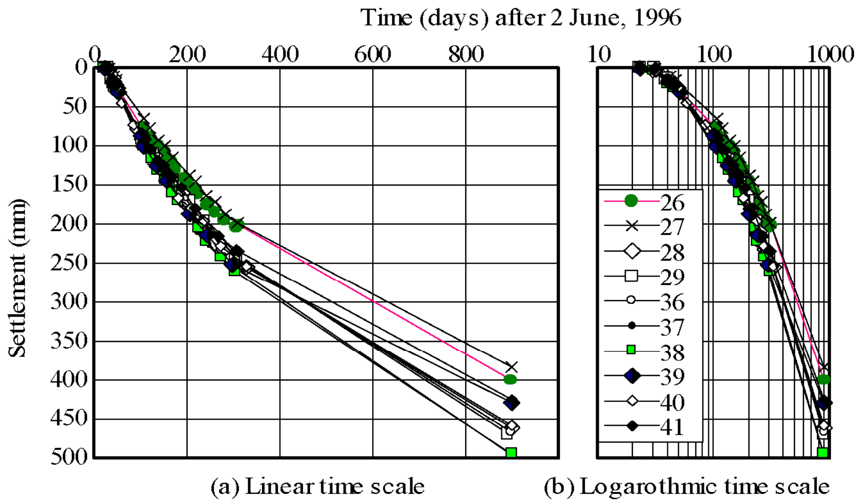

Fig. 18 Settlements measured under the initial embankment (no pipes) (Right/Northern bank)

Horizontal Movements

The horizontal movements of the ground on both sides of the river, as measured in the two inclinometric tubes TI1 (Left/Southern bank) and TI2 (Right/Northern bank), are shown in Figs. 19 and 20. The movements are not parallel to the bridge but perpendicular to the riverside (Fig. 10). The maximum horizontal movement was observed at a depth of 5.5 m on the right bank (8 cm) and 4 m on the left bank (2.2 cm). Much of the movement occurred during the construction period (3.5 cm and 1.5 cm, respectively). During the next four months, the horizontal displacement amounted to 2.5 cm (0.5 cm), whereas the corresponding settlement of the embankment was in the range 7-10 cm (1-1.5 cm) (Figs. 15 and 14, respectively). The ratio of the horizontal to the vertical displacements was thus close to 30% during that four months period. During the following 21 months (until August 1998), the maximum horizontal displacement was equal to 2 cm (0.2 cm) and the settlement to 20 cm (3 cm). The ratio of horizontal to vertical displacements was therefore lower (10% or even less for the left side of the river). Over the 1000 days elapsed from the beginning of the construction period, this ratio is close to 20%. For embankments built on soft soils (Leroueil et al., 1990), the ratio of horizontal to vertical movements is usually close to 17% but the present layering slightly differs from the usual one because of the existence of a thick layer of sand below the ground surface, on top of the soft soils. Besides, the erosion of the riverbed during the floods may have influenced the state of the foundation soils next to it.

Another important information obtained from the inclinometric measurements is the depth of the lower limit of the more compressible soils: 12-15 m on the right bank and 7-8 m on the left bank. This confirms the conclusions of the geotechnical site investigations.

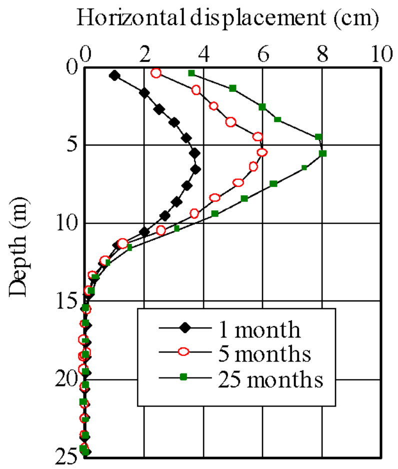

Fig. 19 Horizontal displacements (TI1) (Left/Southern bank)

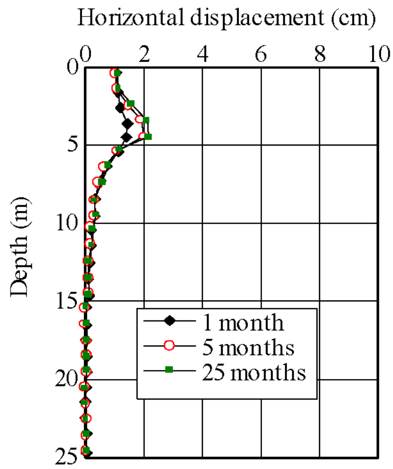

Fig. 20 Horizontal displacements (TI2) (Right/Northern bank)

Detailed Inspection of the Bridge in 1999

In 1999, a detailed inspection of the bridge and its access embankments was organised in order to check their behaviour since mid-1996 and their present state. Except for a few localised disorders at the contact of the walls and the abutment, and some internal erosion of the fill material behind the L-shaped wall, no problematic event was discovered. The various part of the abutment/access embankments system worked as foreseen. In particular, the L-shaped wall settled by about 40 cm without influencing the abutment itself.

CONCLUSION

The reconstruction of the access embankments to the bridge on the Drader river was successfully completed by mixing two techniques: the protection of the frontwall of the abutment from the fill material pressure by means of an L-shaped wall isolated from the abutment and the inclusion of large diameter concrete pipes in the embankment, in order to decrease the load applied to the ground surface. The available knowledge of the geotechnical conditions at the site, where the layers of sandy and muddy soils had varying thickness, did not allow making precise calculations for the project. The repair works were therefore based on experience and a detailed monitoring of the vertical and horizontal movements of the ground, the fill and the abutments was organised. The analysis of the measured displacements of the ground led to the conclusion that the repaired structure behaved as foreseen.

The case history of the bridge on the Drader river shows that practical problems can be solved reliably, without complicated calculations, even without due knowledge of the details of the varying soil stratigraphy, provided the experience gained from the practice of soil mechanics is carefully implemented and the solution is checked by monitoring the behaviour of the ground and the structures.

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