How a distressed quay wall could be moved back in place... using Plaxis

B. Simon, Terrasol

INTRODUCTION

Chef de Baie 1 Quay was built in 1982 in La Rochelle harbour. It is 180m long and 23.5m high. It receives ships with cargoes of bulk timber and containers. It is an essential piece of the port facilities as it receives more than 30% of all quantities of wood and other similar products which are imported into France.

DESCRIPTION

The quay is a combined wall of steel tubular piles and sheet piles with one row of tie-back anchors connected to a parallel anchorage wall. Pile spacing is 1.7m with one sheet pile between. The quay is built at the toe of an existing reclaimed fill slope.

Each tie rod, 30m long, consists of three steel pieces connected by two cast iron connecting sleeves. There is one tie rod per pile.

The whole structure is designed as an anchored frame supporting the crane rails. The front wall is designed using a subgrade reaction approach.

New fill consists of well graded limestone material up to 600 mm size.
The front wall is installed with tie rods only supported at their ends and on the intermediate pile row.

It can be established that filling operations were carried out in a rather crude way with fill material simply pushed against the front wall from the existing platform across tie rods.

DEFECTS

Defects appeared quite suddenly on 12th February 2001 between 12 noon and 1 p.m. without any witnesses. Misalignment of the rails and decimetric settlements of the platform were readily apparent. Horizontal displacement of the capping beam reached some 30 to 40cm on a 100m stretch.

Figure 2 and figure 3: Platform settlement and rail misalignment

Emergency backfilling in front of the wall could stop this progression and restore safety.

Because of the utmost importance of this quay for the operations of La Rochelle harbour, thorough investigations were started to find the cause of such defects and to be able to propose appropriate remedial works.

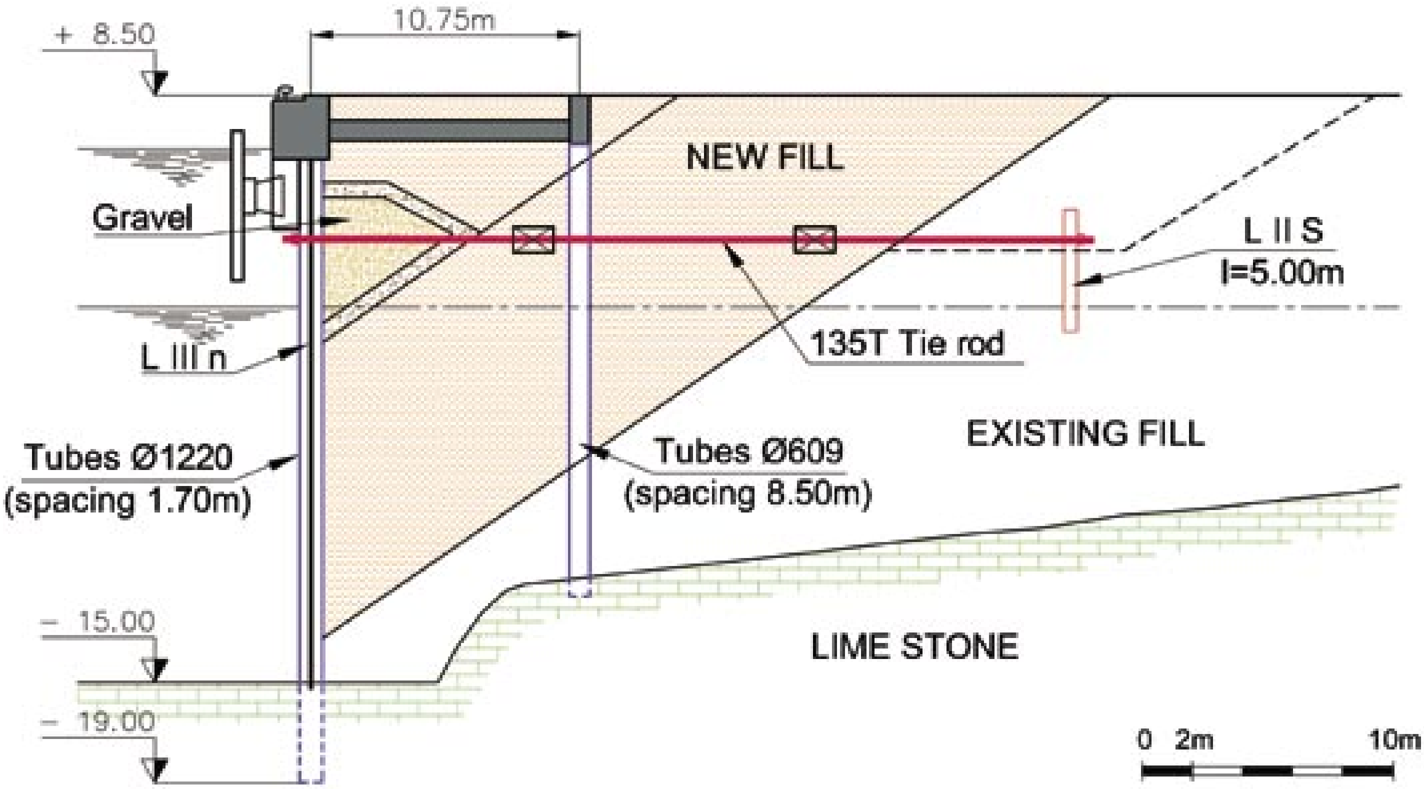


Figure 1: Schematic quay cross section (CM: datum at lowest astronomical tide)

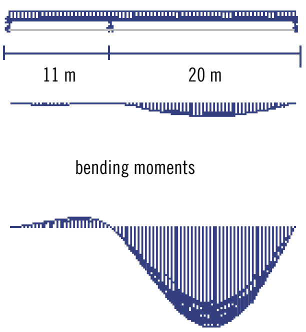
It could be observed that some tie rod caps were in loose contact with their piles while others had punched and torn up the pile envelopes.

Excavation of the quay platform made clear there was no difference of piezometry between fill and basin at low tide.

This course of action combined historical survey and specific geotechnical borings. It led us to ascertain without any doubt, and in less than four months, that the defects were caused by accidental breakage of a few of the anchor tendons which had sustained excessive stresses for a time period back to construction. The construction procedure had created the conditions for quite erratic tensions between adjacent anchors, some of them having probably failed since that very early stage without anybody noticing it. A cast-iron piece connecting two elementary tendon pieces was recovered and inspected to confirm it broke a long time ago.

ANALYSIS WITH PLAXIS OF THE CAUSES OF THE DEFECT

At first, it was decided to check the stresses in the tie rods before filling, when they simply hung between the front and back wall with one temporary support line in between. Only updated mesh analysis provides reliable results as can be seen in figure 4 where they are compared to results from standard analysis. Updated mesh analysis demonstrated that tie rods could be submitted to significant tensions, which combined with the bending stresses led to stresses as high as 20% of the tendon yield stress. A significant strength amount had thus already been consumed in that preliminary stage and this clearly should not have been neglected in the design.



Plaxis model

tendon 80 mm under its own weight

Updated mesh analysis

y = 0.15 m

M = 1.18 kNm T = 103 kN

$0.2\sigma_e$

Standard analysis

y = 0.08 m

M = 13.0 kNm

Figure 4: Hanging rod analysis

A complete and rather simple model of the quay (including the emergency fill) was prepared. It comprised 347 6- noded elements.

Mohr Coulomb model was used for all layers. Fill strength parameters were derived from the results of Menard pressuremeter tests carried out following the disorder. Limestone Young's modulus could be ascertained from the results of one pile lateral loading test carried out during the construction, which was partially documented.

	γ/γ_{sat}(kN/m³)	c (kPa)	ϕ (°)	ψ (°)	E (MPa)	ν
Fill	18/21	5	35	5	50	0.25
Limestone	18/21	500	0	0	1000	0.20

Table 1 Model parameters.

R_{inter} value was set at 0.5 for all layers.

The filling operations (slope in limit equilibrium) could be properly modelled by activating clusters laid parallel to the initial slope (this feature could not be incorporated in the initial design by the subgrade reaction approach).

A comparison was made between Plaxis calculations assuming tie rods acting either as node to node anchors or as geogrids with the same axial stiffness per ml. In the first case no interaction is assumed between fill and tendons while the latter assumes a complete interaction where tendons are carrying the full weight of overlying fill. The model neglecting fill/tie rod interaction led to less horizontal displacement with higher stresses found in the front piles.

	Ymax (cm)	M+ (kNm/ml)	M- (kNm/ml)	T (kN/ml)
Subgrade reaction model	8.4	1820	2280	650
Plaxis model				
without interaction	9.4	1480	2160	623
with interaction	7.5	1265	1820	771

Table 2 Results.

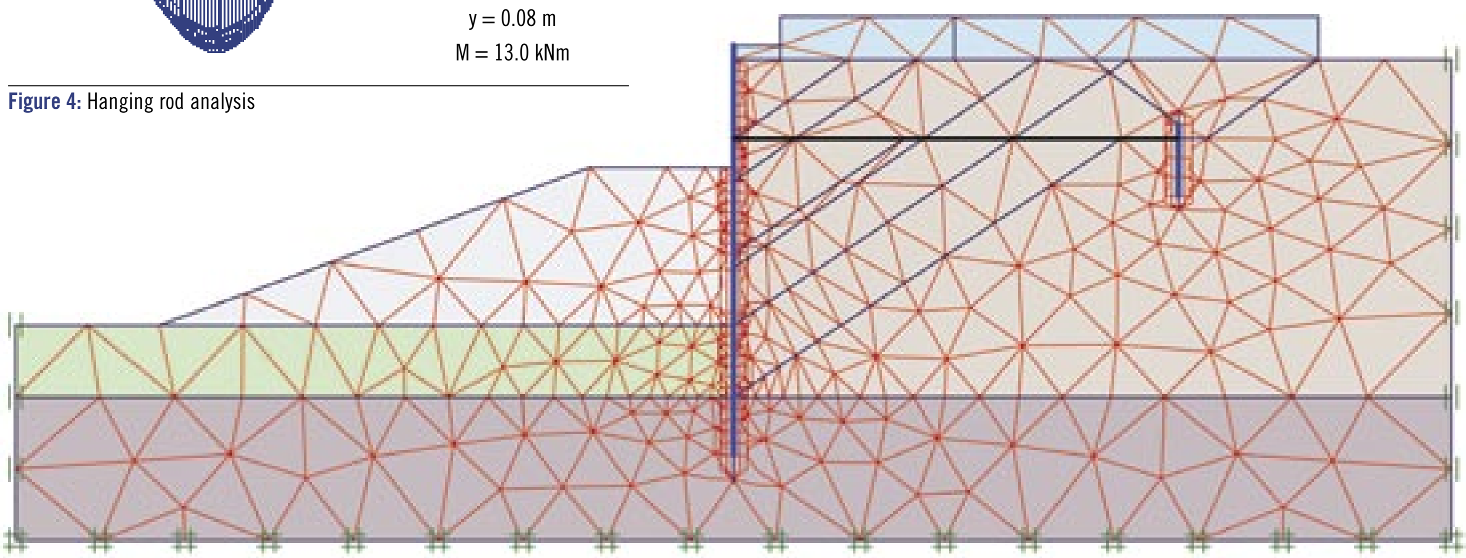


Figure 5: Plaxis model of the quay

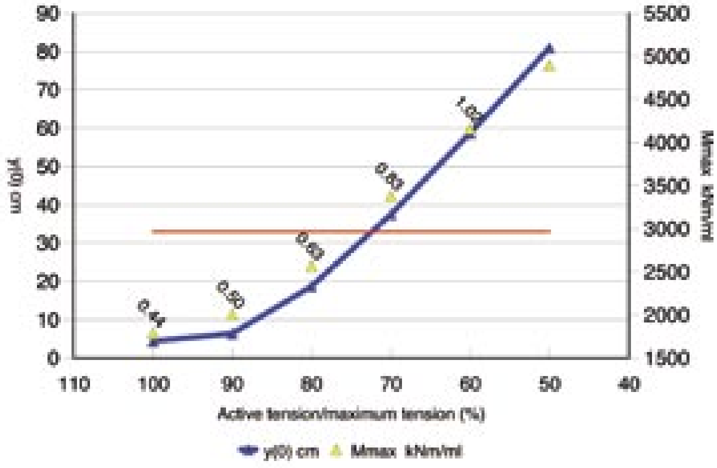


Figure 6: quay displacement and bending moment versus remaining tie-rod capacity

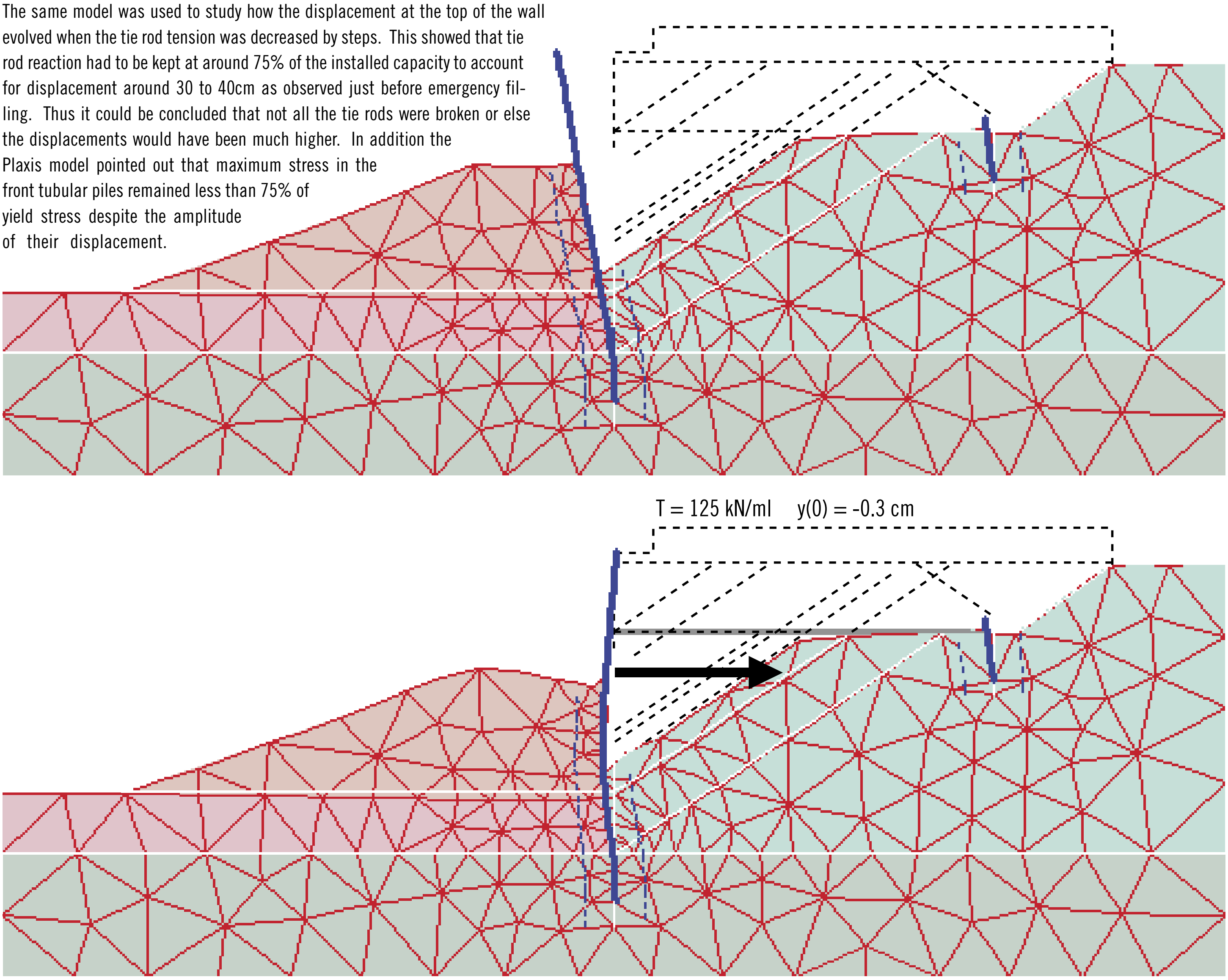
These piles could then still be reused. Checks of the structural integrity of other quay components led to the conclusion that the concrete capping beam could also be reused while the transverse and rear beams which suffered too much cracking had to be rebuilt.

USE OF PLAXIS MODEL TO EVALUATE REPAIR SOLUTIONS

The agreement found between the numerical model and the recorded displacements led us to consider that the model could help exploring various solutions for moving back the wall. This complementary study proved the wall alignment could be restored by combining controlled excavation behind the wall, down to elevation -7.6 CM, and pre-stressing the temporary tie anchors. Tension forces varied between 125 kN/ml and 145 per ml to move the front line between 0.6cm and 1.8cm back its theoretical initial position.

The Plaxis model greatly helped convincing the Owner that realignment of his quay was feasible!

The same model was used to study how the displacement at the top of the wall evolved when the tie rod tension was decreased by steps. This showed that tie rod reaction had to be kept at around 75% of the installed capacity to account for displacement around 30 to 40cm as observed just before emergency filling. Thus it could be concluded that not all the tie rods were broken or else the displacements would have been much higher. In addition the Plaxis model pointed out that maximum stress in the front tubular piles remained less than 75% of yield stress despite the amplitude of their displacement.



Figures 7a and 7b: Modelling the repair actions

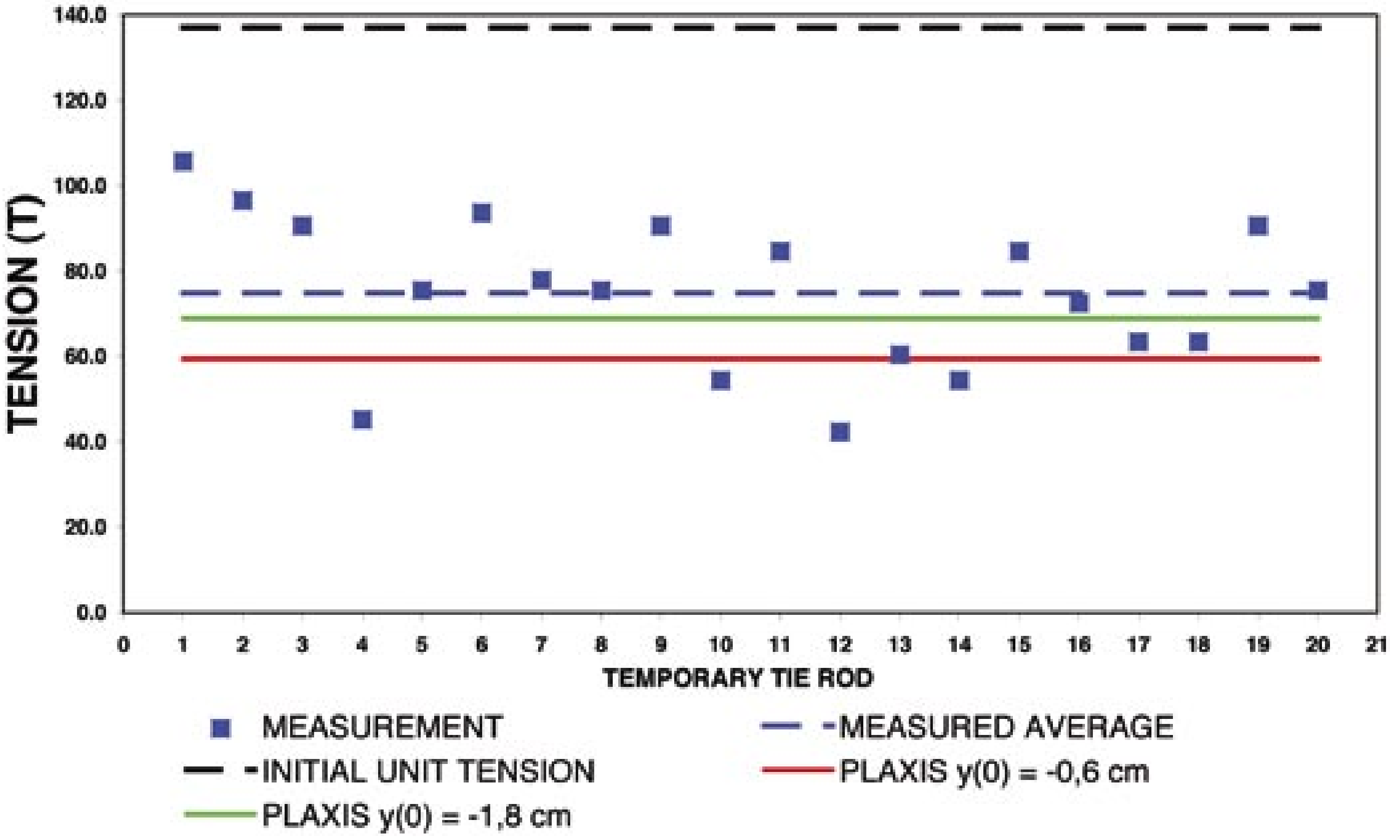


Figure 8: measured tensions in the temporary tie-rods

REPAIR WORKS AND COMPARISON WITH PLAXIS PREDICTIONS

From then on the detailed design of these remedial works could be prepared by a team set up by the Owner with one structural expert and one geotechnical expert. This included a detailed description of all successive stages. Tenders were asked of specialised contractors in the same way as for a new structure.

Works started in May 2003 less than 26 months after the accident with the following steps:

- Temporary fill to improve passive thrust in front of rear anchoring wall
- Temporary tie rods (2 tie rods every 5 piles : one per 4.75 ml)
- Controlled excavation down to -7.6 CM together with tensioning of the temporary tie rods (in successive runs)
- Rebuilding the rear beam (piles and transverse beams)

The quay could be moved back along its initial alignment with accuracy less than a few centimetres.
Measured tensions in the temporary tie rods at final stage are plotted in figure 8. Average value is slightly higher than the estimated tension for a final displacement of 1.8cm beyond the theoretical line. Since achieved displacement was slightly more (between -2 and -3cm), Plaxis predicted tension values match closely the observations.

CONCLUSION

This case illustrates quite remarkably how a numerical model supported by careful in situ observations, specific borings and historical survey can help decision making: decisions about either restoring safety soon after the accident or choosing the most appropriate remedial solution later on.