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Behaviour of a Watertight Anchored Retaining Wall in Soft Soil Conditions

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ABSTRACT

A watertight prestressed anchored retaining wall was used in an excavation in Marmaris, a town located on the Southwest coast of Turkey due to presence of high water level and soft soil conditions. Following a detailed geotechnical investigation an analysis of the retaining system was performed by Plaxis Finite Element Program. The analysis consisted of stage construction simulating the real case. The behaviour of the watertight pile wall was monitored by means of inclinometric measurements. The paper describes the overall stability problems disclosed by Plaxis finite element and Slope-W slope stability programs and their remediation and the problems encountered during construction and inclinometric measurements. The lateral displacements of the retaining wall obtained in the analyses are compared with the inclinometric measurements taken during the excavation program.

INTRODUCTION

Marmaris is a touristic town located on the Southwest coast of Turkey. An excavation with a depth of approximately 6.0m was performed by means of watertight (secant) bored pile walls due to presence of high water level and soft soil conditions. The watertight retaining wall system consisted of bored piles with a diameter of 65cm and 15cm overlapping. The wall was decided to be supported by one and two levels of prestressed anchorages having an angle of inclination of 10^0 with the horizontal at the sides adjacent to the four storey-buildings and roads respectively. In the project it was planned to socket the 15m long bored piles into dense sand-gravel layer located at about 14.0m depth from ground surface. However, during construction, piles could not be bored into dense sand due to presence of undisclosed high artesian groundwater pressure, and they were constructed with a length of 12m instead of 15m. Analyses performed by using Plaxis finite element program and Slope-W slope stability program showed the possibility of an overall stability problem at the building sides of the excavation area. Therefore the number, length and angle of inclination of the anchorages the in second level were changed so that the fixed lengths of the anchorages were kept outside the possible sliding surface. At the sides beside the roads, second level of anchorages was added to be on the safe side.

SOIL CONDITIONS

The soil profile consists of a loose silty sand layer at top and followed by a soft silty, sandy clay layer down to depth of 13.00/14.50m. The groundwater level is at 1.0m depth from ground surface. The soil layers encountered during site investigation and their average standard penetration numbers, N_{ave} are shown in Table 1.

Table 1 Idealized Soil Profile

Layer No	Soil Type	Depth (m)	N_{ave}
1	Silty SAND	0.00-5.0/6.0	13
2	Silty, sandy CLAY	5.0/6.0-13.0/14.5	6
3	Silty gravelly SAND	13.0/14.5-30.0	25

Layers no 1 and 3 have fine contents of 5%-15% and %30 respectively. Layer no 1 is in appearance of clean sand. Layer no 2 is soft silty sandy clay layer with low plasticity. Undrained shear strength of silty clay layer is found to be c_u = 25-35 kPa based on laboratory tests and field tests and literature survey.

RETAINING SYSTEM

In this project, watertight (secant) bored pile wall was selected as the retaining system due to presence of high groundwater level and soft soil conditions. There were four-storey buildings without basements in the both left and right sides and roads in front and back sides of the excavation area. The general layout of the site is illustrated in Fig.1.

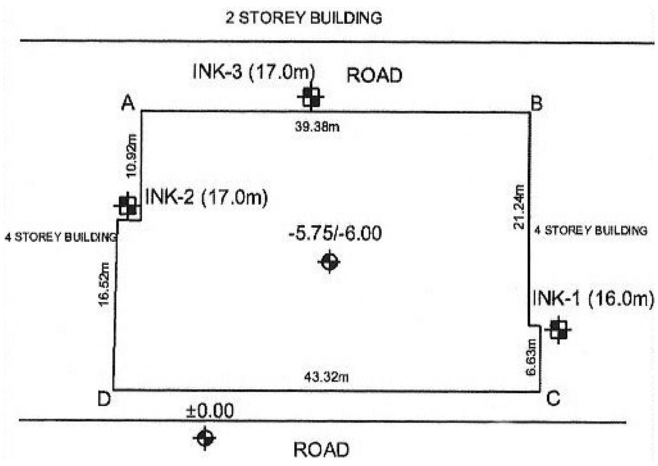
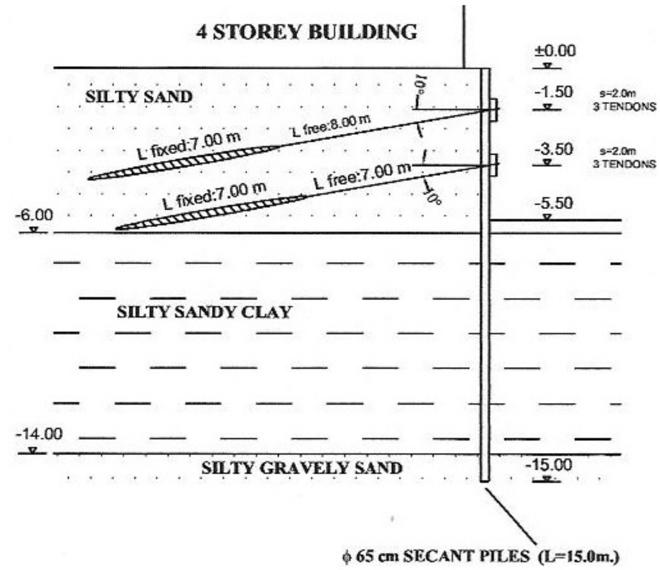


Fig.1 General layout of excavation area

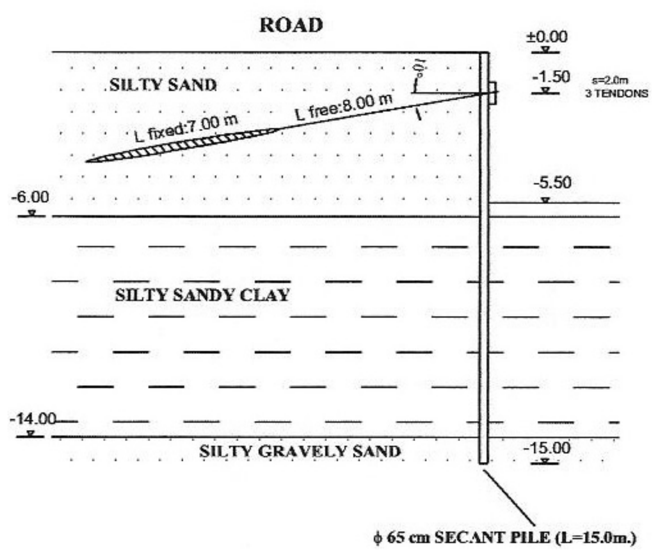
In the design stage 15m long bored piles were made socketed into dense silty gravelly sand layer located at the bottom. Building and road sections were analyzed representing excavation near adjacent buildings and roads respectively. A surcharge load of 50 kPa was taken as building load and 7 kPa due to roads in the analyses. As a result, initially it was decided to have 15m and 14m long prestressed anchorages for the first and second levels respectively in building sections. The fixed length of each anchorage was 7m. In the road section, however one level of prestressed anchorages with a length of 15m was found to be adequate. In the both sections anchorages were adjusted so that their fixed lengths were placed within silty sand layer instead of soft clay layer in order to achieve higher pullout resistance. The anchorage spacing was 2.0m. The details of the building and road sections in the initial project (before construction) are given in Fig.2

During construction, when the empty casing reached the dense sand layer, piping occurred due to high water pressure. The artesian pressure had not been reported in the soils report. Since construction had to be finished in relatively short time piles were constructed with a length of 12m. In addition to shortening in pile length, excavation depth was increased from 5.50m to 6.00m. All those changes in the project led to reanalyze the system. In addition to this, three inclinometers were placed to examine lateral deflections during excavation stages. Locations of the inclinometer tubes are shown in Fig.1.

Effects of changes in the project were examined by Plaxis finite element program. In analyses the soil parameters shown in Table 2 were used. Soil parameters were established regarding laboratory tests, field tests and literature survey. The building with one basement was decided to rest on a piled foundation. Axially loaded 0.65m diameter bored piles were spaced 3m in both directions. Construction of foundation piles were ended before the start of excavation. Therefore the effect foundation piles on stability and wall behaviour was also examined.



a) Building section



b) Road section

Fig.2 The details of building and road sections in initial project

Table 2 Soil Parameters Used in Finite Element Analyses

Soil Type	Depth (m)	γ (kN/m^3)	E (kPa)	c (kPa)	ϕ (^{0})
Silty SAND	0.0-6.0	19	14000	1.0	30
Silty, sandy CLAY	6.0-14.0	20	8000	25.0	1
Silty	14.0-25.0	19	24000	1.0	33

gravelly SAND

The analyses showed that soft clay layer could not provide adequate passive resistance in the building sections, especially in the absence of foundation piles. Secant piles had a tendency to rotate inside the soft clay layer. Shear strain formed in the soft clay in the building and road sections was 315.16% (Fig.3) and 8.53% respectively, and lateral deflection of the piles was excessive. With the contribution of foundation piles and prestressing of anchorages shear strain values were reduced to 9.53%(Fig 4) and 5.12%respectively. Lateral deflection of the piles was 0.076m and 0.057m in the building and road sections respectively.

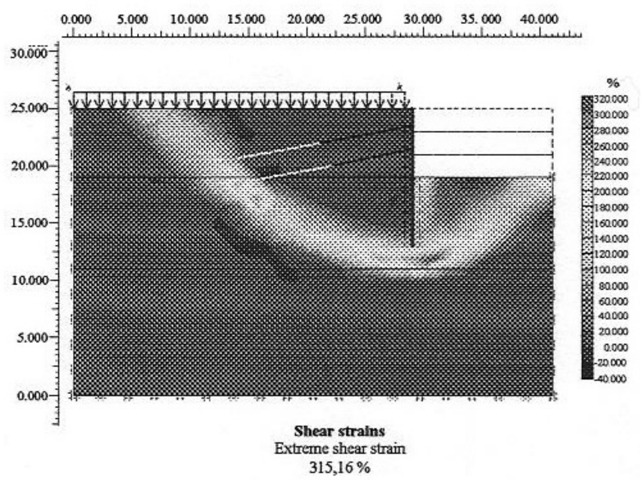


Fig.3 Shear strain in building sections in absence of foundation piles

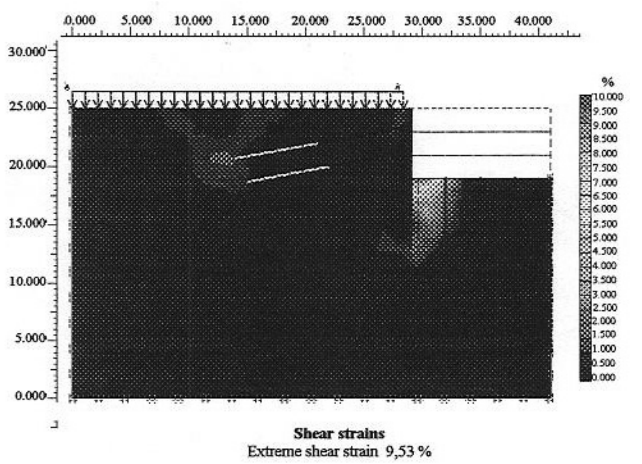


Fig.4 Contribution of foundation piles to shear strain in building sections

As a result, the possibility of an overall stability problem was recognized especially in the building sides ,and the project was modified. At all sides construction of first level of anchorages had been completed therefore some arrangements were done in the second level. In the building section, the length of the second level of anchorages was increased from 14.0m to 16.0m and angle of inclination with horizontal plane was reduced from 10^0 to 8^0. In addition, anchorages with a length of 23.0m and inclination of 5^0 were added between 16m long anchorages. Length of additional anchorages was determined considering the distribution of shear strains obtained by FEM analyses excluding the effect of foundation piles and overall stability analyses performed by Slope-W program.

Fixed length of the additional anchorages was kept outside the possible sliding surfaces shown in Fig.3 and Fig.5a.

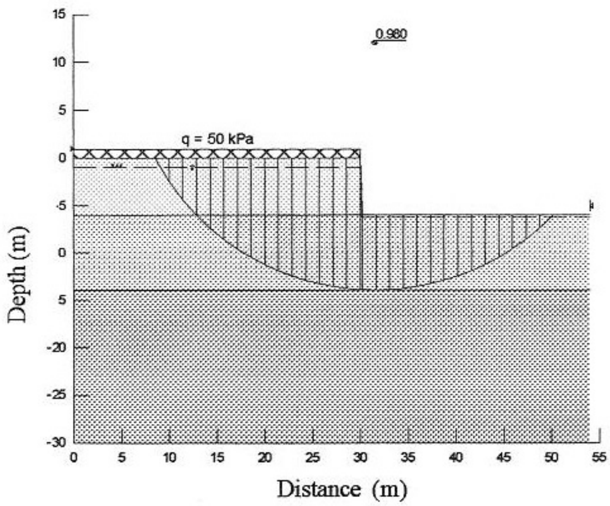
In the slope stability analyses, the following soil parameters were used.

Table 4 Soil Parameters Used in Slope Stability Analyses

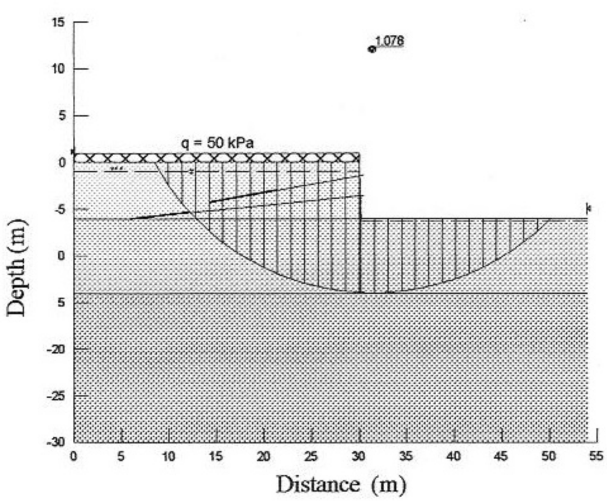
Soil Type	Depth (m)	γ (kN/m^3)	c (kPa)	ϕ (^{0})
Silty SAND	0.0-6.0	19	0.0	30
Silty, sandy CLAY	6.0-14.0	20	25.0	1
Silty gravelly SAND	14.0-25.0	19	0.0	33

The most critical sliding surface determined by means of Slope-W program is illustrated in Fig.5. The factor of safety against sliding was 0.98. The 15m and 16m long anchorages were inside this critical sliding surface. As seen in Fig.6 additional anchorages with a length of 23m and spacing of 2m increased the factor of safety from 0.98 to 1.078. Although a factor of safety of 1.078 is not adequate for the system, it was thought that in reality it would be higher with the contribution of foundation piles.

The factor of safety of the most critical sliding surface was found to be 1.308 in slope stability analysis performed for road sections. Therefore the second level of anchorages was added but their lengths were not extended. Second level of prestressed anchorages was decided to be 14m long with an inclination of 5^0 with horizontal plane.



a) Factor of safety without additional anchorages



b) Factor of safety with additional anchorages

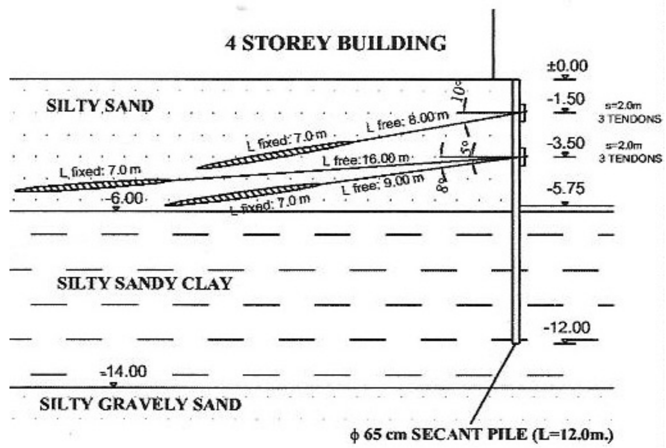
Fig.5 Slope stability analyses of building sides by with Slope-W program

The details of the modified project are shown in Fig.6. Modification in the project was controlled by means of Plaxis and it was realized that shear strain of the building and road sections were reduced to 1.23% and 4.49% respectively. In a same manner, the lateral deflection of the piles was reduced to 0.037m and 0.047m similarly (Fig 7 and Fig.8).

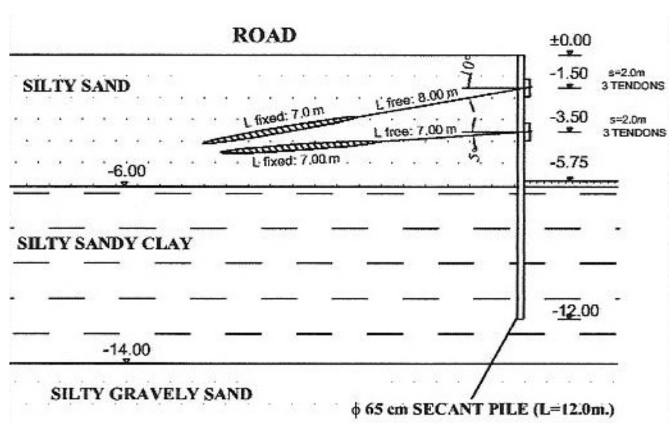
THE COMPARISION OF RESULTS OF PLAXIS ANALYSES AND INCLINOMETRIC MEASUREMENTS

INK-1 and INK-2 were installed in building sides during the construction of first level anchorages. The behaviour of the piles was observed throughout the excavation by means of inclinometers. As the construction of the piles was completed inclinometers were installed into soil besides the piles. All anchorages were tested according to BS8081and locked to their project loads. Project loads were ranging between 160-200 kN depending on the excavation side and surcharge loads.

Inclinometric measurements were compared with the results obtained from Plaxis analyses performed by applying prestressing loads. Results of analyses and inclinometric measurements for the building and road sections for the final excavation stage are given in Fig.9 and Fig.10 respectively. Because the inclinometers at the building sides were installed following the construction of first level of anchorages, lateral deflections obtained in the first anchorage level construction stage of Plaxis analysis was subtracted from the one in the final excavation stage of the program.



a) Building section



b) Road section

Fig.6 Details of the modified project

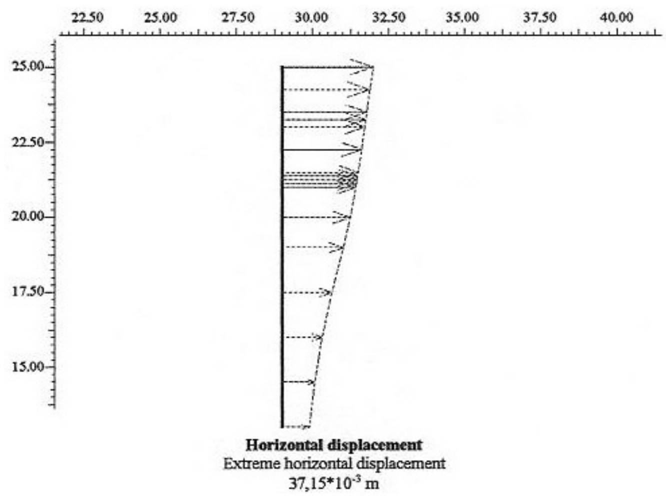


Fig.7 Lateral displacement of piles in building section

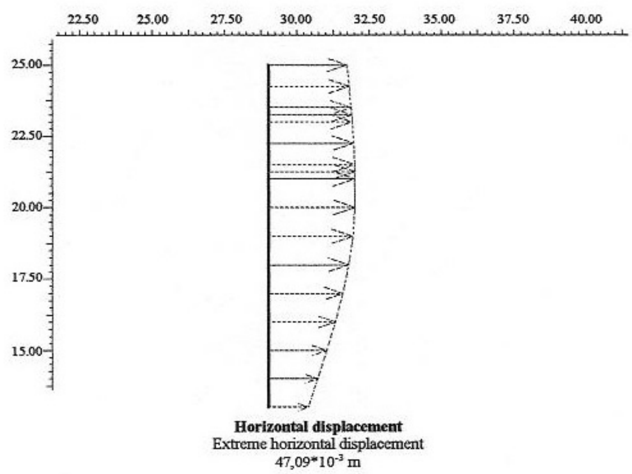


Fig 8 Lateral displacement of piles in road section

CONCLUSION

An excavation with a depth of approximately 6.0m was was made possible by means of watertight (secant) bored pile walls due to presence of high water level and soft soil conditions. The watertight retaining wall system consisted of bored piles with a diameter of 65cm and 15cm overlapping. The wall was decided to be supported by one and two levels of prestressed anchorages having an angle of inclination of 10^0 with horizontal plane at the sides adjacent to 4 –storey buildings and roads respectively. Due to difficulties in the boring of piles they were constructed with a length of 12m instead of 15m.

Both building and road sections were analyzed by means of Plaxis finite element program, and it was realized that foundation piles of the building contribute to passive resistance of soil against rotation of the wall considerably. They reduced shear strains in the soft clay from 315% to 9.53% at the building sides and from 8.53% to 5.12% at the road sections. However, this contribution was not sufficient especially at the building sides to prevent overall instability problem. Therefore at the sides adjacent to the buildings the number, length and angle of inclination of the second layer of anchorages planned in the project were changed so that fixed lengths of the anchorages were kept outside the possible sliding surfaces determined by Plaxis and Slope-W slope stability analyses. At the road sections a second level of anchorages was added but lengths were not extended. Modification in the project led to a reduction of shear strains from 9.53% to 1.23% at the building sides and from 5.12% to 4.49% in the road sections. In a similar manner, the lateral deflection of piles was decreased from 0.076m to 0.037m and from 0.057m to 0.047m respectively in the Plaxis analyses.

The results of Plaxis prestressing analyses were compared with the measurements of inclinometers installed into soil beside the piles. It was observed that they were in accordance.

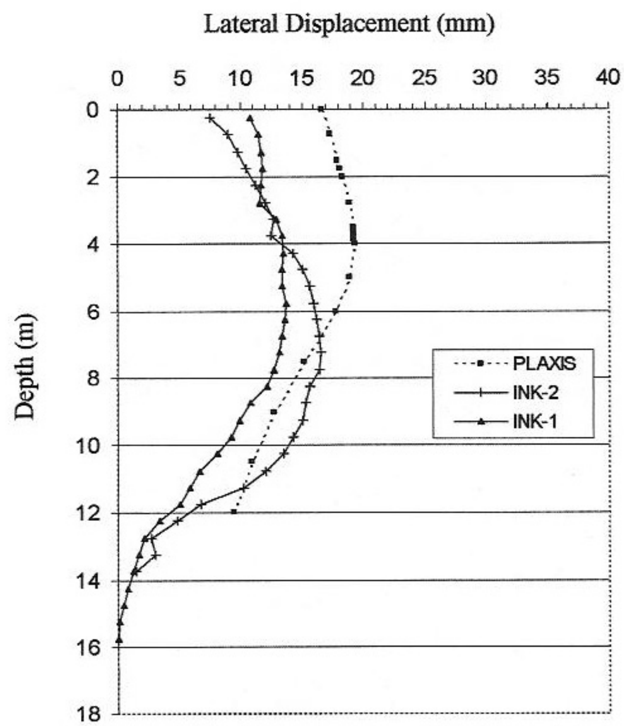


Fig 9 Comparision of Plaxis analysis and inclinometric measurements for the final stage of construction in building sides

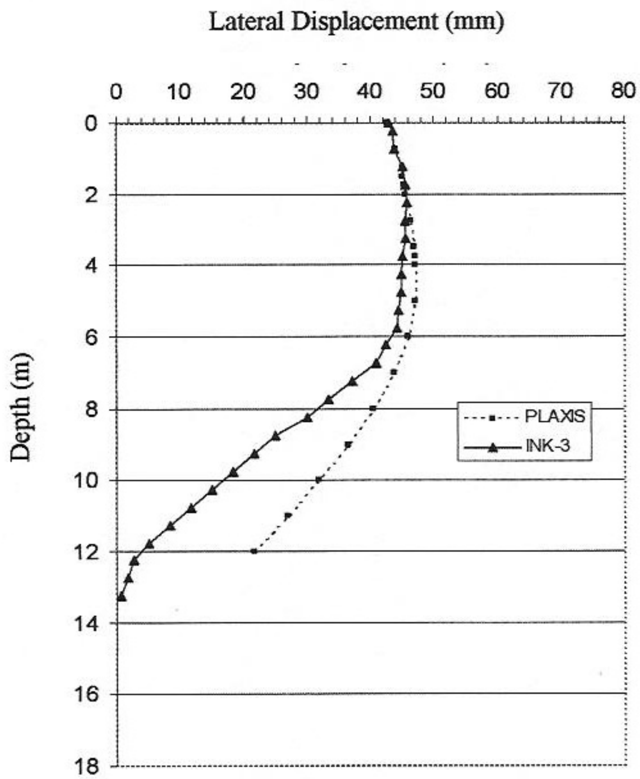


Fig 10 Comparison of Plaxis analysis and inclinometric measurements for the final stage of construction in road sides

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Plaxis 7.2. *"Finite Element Code for Soil and Rock Analyses"*, User Manual

Plaxis 7.2.[2001]. *"International Course on Computational Geotechnics"*, Istanbul, Turkey