Design, Construction and Monitoring of a Mixed Soil-Reinforced and Anchored Retaining Wall in Expansive Soil

Conception, construction et surveillance d'un mur mixte de sol renforcé et ancré dans un sol gonflant

Abramento M.
CEG Engenharia and Escola Politécnica da USP

Fujii J.; Cogliati B., Assakura V.
Yamamichi and CEG Engenharia

ABSTRACT: Due to traffic volume increase a large strecth of a major highway linking São Paulo and Campinas City, Brazil, has recently been widened. In order to achieve the construction of additional lanes, a construction of a mixed-type retaining wall became necessary. This mixed-retaining structured consisted of a 5m high anchored wall at the bottom and a 5m high steel-reinforced retaining wall at the top, totalling a 10m high retaining wall. The bottom wall was built in a cut slope in a stiff, highly expansive, clayey soil. The steel-reinforced retaining wall was built over the lower anchored wall with both faces aligned. Anchor loads at the bottom wall were applied in stages in order to account for the increasing loads during the construction of the top wall. In order to correctly design the bottom anchored wall several undisturbed soil samples were obtained from the stiff clay. Laboratory tests included complete caracterization, shear strength and expansion pressure determination. The retaining system was monitored during all construction stages. This paper presents details on the laboratory tests results, design of the retaining walls, construction steps and monitoring.

RÉSUMÉ : En raison du volume de trafic une portion d'une route importante reliant São Paulo et Campinas, au Brésil, a récemment été élargie. Afin de réaliser la construction de voies supplémentaires, une construction d'un mur de type mixte devenait nécessaire. Cette structure mixte consistait en un mur ancré de 5m de haut en partie basse et un mur en sol renforcé en partie haute, pour une hauteur totale de 10m de soutènement. La paroi en partie basse a été construite dans une pente en déblai dans un sol argileux raide et très expansif. Le mur en sol renforcé t a été construit sur la paroi inférieure ancrée avec les deux parements alignés. Les charges d'ancrage de la paroi en partie basse ont été appliquées par paliers afin de tenir compte des charges croissantes au cours de la construction de la paroi supérieure. Afin de concevoir correctement le mur ancré plusieurs échantillons de sol intacts ont été prélevés sur l'argile raide. Les tests de laboratoire incluent la caractérisation complète, la résistance au cisaillement et à la détermination des pressions de gonflement. Le système de soutènement a été suivi pendant toutes les étapes de la construction. Cet article présente des détails des résultats des tests de laboratoire, la conception des murs de soutènement, la construction et le suivi des mesures.

KEYWORDS: Reinforced wall, anchored wall, expansive soil, monitoring

1 INTRODUCTION

Due to traffic volume increase a section of approximately 3km of a major highway linking São Paulo and Campinas city, Brazil, had to be widened. In order to achieve the construction of additional lanes, and due to geometric constraints, a mixed-type retaining wall became necessary. This mixed-retaining structured is shown in Figure 1 and consists in a 5m high anchored wall at the bottom and a 5m high steel-reinforced retaining wall at the top, totalling a 10m high retaining wall.

This paper presents details on the laboratory tests results, design of the retaining walls, construction steps and monitoring, as well as a comparison of measured and predicted displacements and loads at the top and bottom retaining walls.

2 SITE INVESTIGATION AND LABORATORY TESTS

SPT borings show that the local soil consists of a superficial colluvial soil characterized as a soft porous silty clay 2 to 3m thick and with blowcounts varying from 2 to 3, followed by a medium, stiff and hard clay with blowcounts larger than 15 and reaching up to 40. A picture of this last layer is shown in Figure

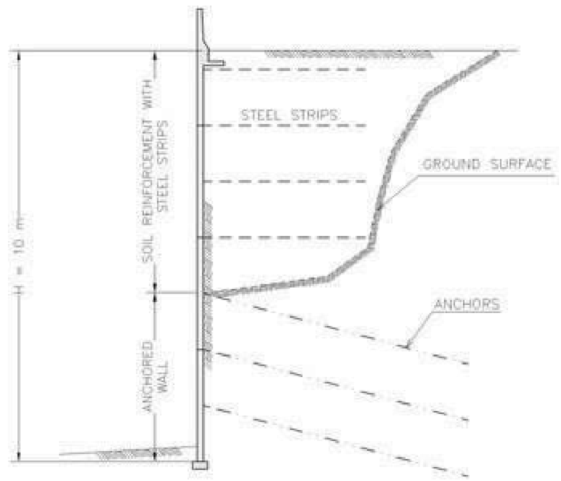

Figure 1. Typical cross-section of mixed reinforced fill-anchored wall.

2. Figures 3 and 4 show typical SPT borings results for two of the wall sections. This stiff clay layer receives the load from the

reinforced fill and had to be cut and anchored in order to widen the roadway.

Therefore, this layer was fully investigated with:

- Several SPT borings.
- Laboratory tests: direct shear and expansion tests on undisturbed samples and characterization.
- Pullout tests on anchors.

Moreover, compaction and direct shear tests were carried out on fill materials.

Figure 2. Stiff to hard silty clay layer to be cut and retained with anchored wall and surcharged with reinforced soil fill.

3 TEST RESULTS – STIFF TO HARD CLAY

Table 1 presents results from direct shear tests. It is worth noting the large drop in shear strength for large displacements (residual conditions). Peak strength typically occurs for very small displacements, in the range of 1mm.

Table 1. Direct shear test results.

Sample	*Specimen*	*σ* (kPa)	*τ máx* (kPa)	*τ res* (kPa)
Natural	CP-1	51	232	32
	CP-2	154	305	22
	CP-3	306	419	92
Saturated	CP-1	51	228	77
	CP-2	151	264	72
	CP-3	304	304	34

Table 2 presents results from expansion tests carried out on the horizontal and vertical directions. The expansion pressure is very high in the vertical direction, whereas the expansion pressure in the horizontal direction is around 6% of the vertical pressure, showing the marked influence of clay structure on its behavior (Figure 2).

Table 2. Expansion pressure for vertical and horizontal directions.

Direction	*Expansion Pressure (kPa)*
Vertical	440
Horizontal	30

Table 3 presents results from pullout tests on anchors 10cm in diameter and 6m long as a function of injection pressure. Anchors 202, 207 and 212 had, respectively, one, three and two functioning pressure valves. Therefore, adhesion values varied significantly from 25 to 45kN/m, demonstrating marked influence of injection pressure on adhesion.

Table 3. Pullout tests on anchors.

Segment	*Adhesion (kN/m)*	*Injection Pressure (kgf/cm²)*
202	25	ϕ/ϕ/20 (1 valve)
207	45	50/20/30 (3 valves)
212	30	ϕ/30/20 (2 valves)

4 DESIGN PARAMETERS

The following design conditions and strenght parameters were considered for design:

- End-of-Construction (EOC): peak shear strength parameters and natural water content, with and without expansion pressure.
- Long-Therm and Peak Condition (LTP): saturated peak shear strength parameters, with and without expansion pressure.
- Long-Therm and Residual Condition (LTR): saturated residual shear strength parameters, with expansion pressure.

A possible decrease in adhesion due to soil saturation was also considered in adhesion. Increase in anchor loads due to expansion pressure was taken into account for anchor design.

With basis on the laboratory and field tests, and following the procedures outlined in ABNT NBR 11.682 – Slope Stability, the parameters presented in Table 5 were used in wall design.

Table 5 – Design parameters.

		Condition/			
Parameter		EOC	LTP	LTR	MSE*
Soil unit weight (kN/m³)		20	20	20	20
Cohesion intercept (kPa)		60	40	0	30
Friction angle (º)		30	18	18	25
Anchor adhesion (kPa)	Average	100	90	125	
	Maximum	140	125		
Same with expansion (kPa)	Average	70	65		
	Maximum	100	90		
Puncture anchor head (kN)			430		-

*MSE :Soil Parameters for Mechanically Estabilized Earth Wall

5 DESIGN AND CONSTRUCTION OF ANCHORED WALL

A limit equilibrium program was used to design the anchored wall, considering the reinforced wall on the top and a traffic surcharge of 25kPa. Potential failure surfaces were always very close to the anchored wall face. As a result, the free section of the anchors were short, in the order of 3.0m. This is the minimum length accepted by ABNT NBR 5629 – Anchored Walls. Anchor length was varied in order to achieve minimum Safety Factor of 1.8 for EOC, 1.5 for LTP, and 1.2 for LTR conditions, resulting the following anchor distribution:

- Cable anchors, 5x12,7mm 190RB, yield stress= 1708MPa
- Working load = 430kN
- Testing load = 760kN
- Minimum spacing = 1,6m
- Maximum spacing = 2,0m
- Inclination with horizontal = 20 degrees
- Free length = 3,0m
- Anchored length = varying from 6.0 to 9.0m
- Anchor diameter = 100mm

Water table close to the base of the anchored wall was found in several SPT bores. Therefore, horizontal drains 15m long were installed every 2.4m along the wall base.

The stiff clay layer was carefully excavated to install the anchors and build the reinforced concrete face 30cm thick. For each anchor level the anchors were loaded to 50% of the working load. Construction of the reinforcef fill started after the completion of the anchored wall. When the reinforced fill height reachedd around 70% of the final fill height the anchors were re-loaded with 100% of the final working load.

6 WALL MONITORING

In order to monitor wall behavior a monitoring system was installed along the wall. It consisted of:

- 3 inclinometers 15m deep installed
- 3 load cells installed at selected anchor heads
- 20 displacement pins

Inclinometers were installed in boreholes along the front face of the anchored wall, and extended upwards during placement of the reinforced fill.

Several readings were obtained during construction of the lower anchored section and continued durgin construction of the upper reinforced fill section.

7 MONITORING RESULTS

Figures 3 and 4 show inclinometers results for 2 of the instrumented sections: Section I-200 and Section I-205. The results show that:

- The displacements increase continuously with construction of the lower anchored wall and the upper reinforced soil wall.
- Displacements of the lower anchored wall were generally small, in the range of 5 to 10mm.
- Small face displacementes were expected for the stiff clay layer. However, for these displacements level it is possible that residual conditions may be attained by the clay layer during wall construction.
- For the upper reinforced fill, however, face displacements were relatively high. Measured displacements varied from around 10mm at the bottom up to 70 to 80mm for the upper part of the fill.

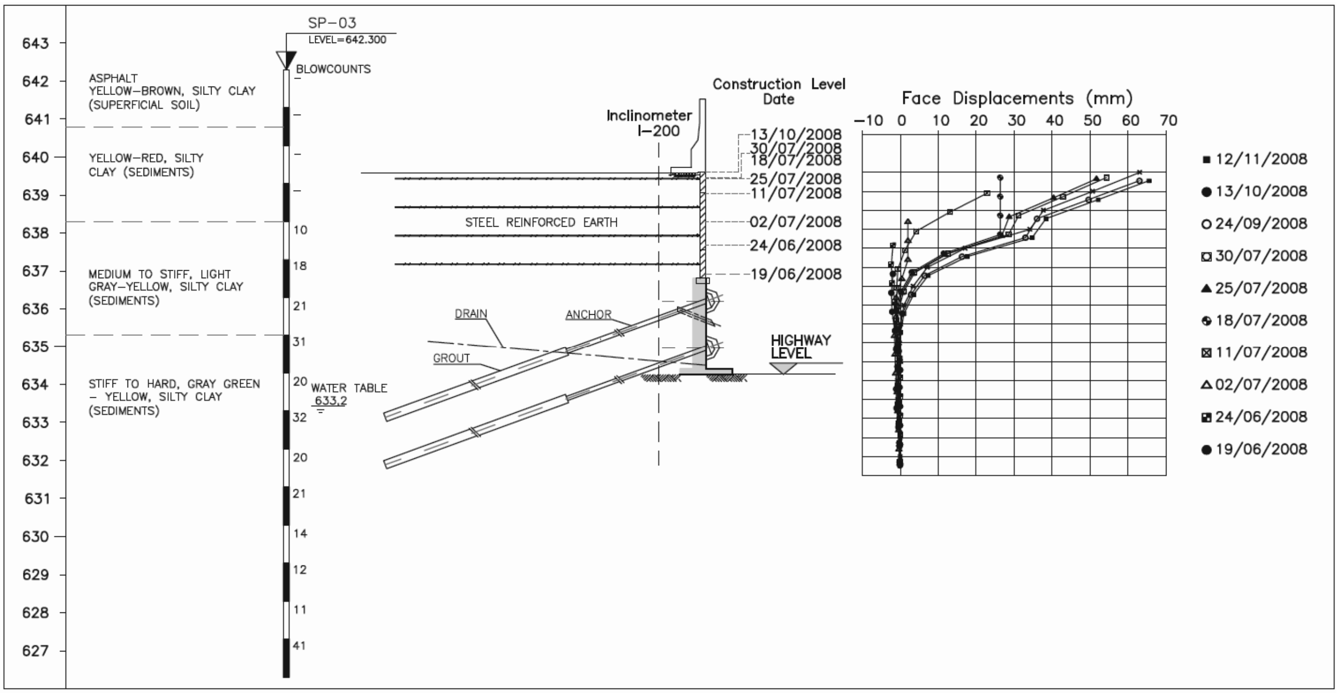

Figure 3. Inclinometer results in Section I-200.

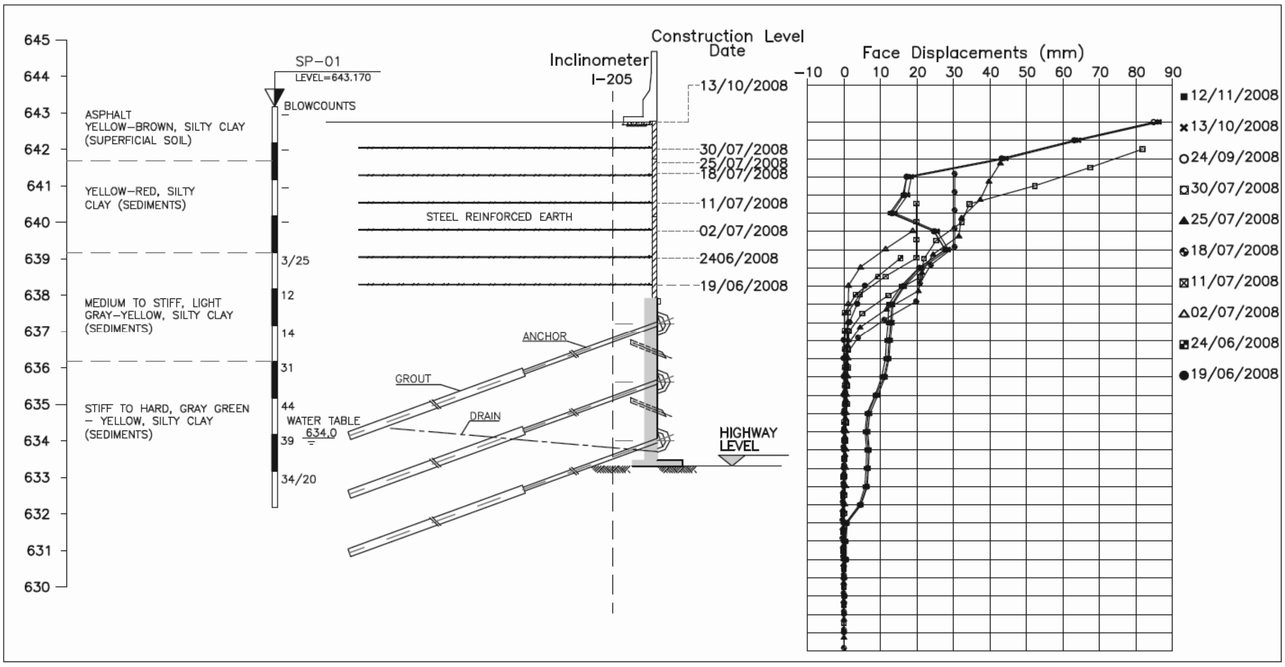

Figure 4. Inclinometer results in Section I-205.

8 CONSTRUCTION CONDITIONS

Figures 5 and 6 show construction conditions, especially the upper part of the reinforced soil fill with the reinforcing steel strips and the face of the anchored wall face at the bottom.

Figure 5. General view of the top part of the reinforced soil fill.

Figure 6. General view of the highest section of wall.

9 CONCLUSIONS

The following conclusions can be summarized:

- The stiff clay layer has relatively high strength parameters for peak conditions.
- Residual conditions are achieved for relatively low displacements, around 1mm.
- Due to structural conditions the stiff clay has relatively high vertical expansion pressures, around 440kPa, whereas horizontal pressures are relatively low, around 30kPa.
- Displacements of the lower anchored wall were generally small, in the range of 5 to 10mm.
- These small face displacementes were expected for the stiff clay layer. However, for these displacements level it is possible that residual conditions may be attained by the clay layer during wall construction.
- For the upper reinforced fill, however, face displacements were relatively high. Measured displacements varied from around 10mm at the bottom up to 70 to 80mm for the upper part of the fill.

10 ACKNOWLEDGEMENTS

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11 REFERENCES

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