# Use of Pullout Test Results in The Serviceability Limit State Design of Earth Reinforcement Structures

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ABSTRACT
The paper demonstrates the importance of the pullout test results in the serviceability limit state design of earth reinforcement structures. Design methods that use the strain compatibility approach (displacement or kinematic methods), are based on the hypothesis that the tensile force acting on geosynthetic anchored in the soil is a function of the displacement of the reinforcement. Therefore, in order to apply these methods it is important to get an idea of the reinforcement displacements and corresponding pullout loads that must be assigned at each reinforcement level for given conditions i.e. reinforcement length and applied effective vertical stress. In this paper the results of several pullout tests carried out varying the anchorage length and the applied effective vertical stress were analyzed in order to define the mobilized pullout resistance in correspondence with admissible displacements assumed equal to 5 mm and 25 mm. For given specimen length, the trend of the mobilized pullout resistance for a given value of displacement at the location of the first displacement transducer in soil section of the geogrid was plotted. These curves were called the iso displacement curves for the different applied vertical effective stresses. These provide the forces that can be mobilized in the reinforcement for different applied confinement pressures and for different geogrid anchorage lengths in the displacement field compatible with the serviceability limit state. Finally, these results can then be used for an appropriate choice of the admissible design pullout resistance.

## 1. INTRODUCTION

The design methods, based on the strain compatibility concept between rigid block and reinforcement (displacement or kinematic methods), assume that the geosynthetic tensile force Ti depends on the relationship:

$$T_i = f(\delta w) \quad (1)$$

where, $\delta w$ is the reinforcement displacement in correspondence with the failure surface.

Using these design methods, the solutions obtained by limit equilibrium analyses can be worked out again in order to take into account the variations of the reinforcement pullout resistance due to the different displacements mobilized at the different depths along the failure surface. These displacements are evaluated assuming the kinematic failure of the reinforced earth block. In these design methods a right displacements evaluation is important in order to determine the right geosynthetic tensile load mobilized in the anchorage zone in pullout conditions. Therefore, a pullout tests program is necessary not only to define the interface apparent coefficient of friction mobilized in the anchorage zone that must be used in the ultimate limit state analysis of the geosynthetic reinforced earth structures but also for the serviceability limit state design of these structures. This paper deals with the preliminary results of a large experimental pullout test program carried out in order to study the pullout resistances mobilized at displacement levels compatible with the serviceability limit states.

## 2. PULLOUT APPARATUS AND TEST PROCEDURE

The pullout test apparatus, shown in figure 1, is composed of a pull-out box (internal dimensions: 1500 mm x 600 mm x 640 mm), a vertical load application system, a horizontal force application device, a special clamp, and all the required instrumentation. A detailed description of the pullout test apparatus can be found in Moraci and Recalcati (2006) and in Cardile (2008). An air filled cushion applies the vertical load which is restrained using a steel plate. An electric jack applies the pullout force, which is measured using a load cell. The apparatus is capable to keep the geosynthetic specimen always confined into the soil for all the test duration. Friction between the soil and the side walls of the box is minimized by the use of smooth Teflon films. The apparatus is characterized by a clamp placed inside the soil, beyond the sleeve, in order to keep the geosynthetic specimen confined in the soil for the whole test duration.

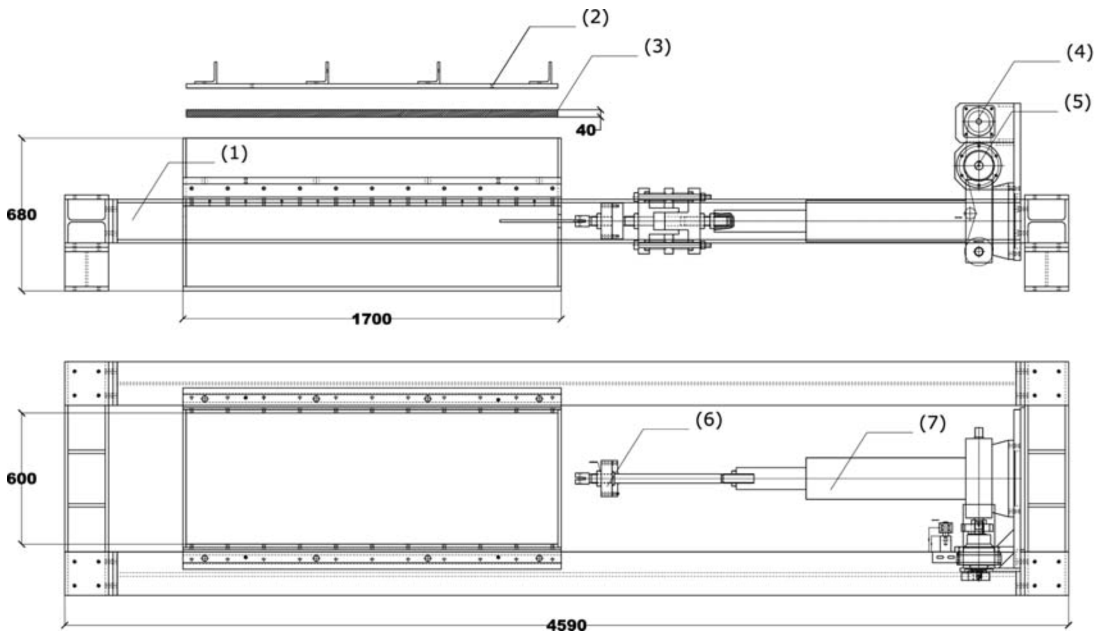


Figure 1 - Scheme of pullout test apparatus: 1) frame; 2) steel plate; 3) air bag; 4) electric engine; 5) reducer; 6) load cell; 7) electric jack (Moraci and Recalcati, 2006).

For each test condition, the friction between the clamp and the test soil has been evaluated by performing the test without the geogrid. The pullout force values for the clamp alone have been subtracted, at each displacement level, from the pullout forces measured in the tests with the geosynthetics at the same displacement in the same test conditions.

The pullout tests have been performed on a granular soil compacted at 95 % Proctor. The soil was classified as a uniform medium sand with uniformity coefficient $U=d_{60}/d_{10}$ =1.5 and average grain size $d_{50}$=0.22 mm. Standard Proctor compaction tests gave a maximum dry unit weight $\gamma_{dmax}$=16.24 kN/m$^3$ at an optimum water content $w_{opt}$ =13.5%. The peak shear strength angle $\phi'_p$ of the soil, changes between 48° (for $\sigma'_v$ =10 kPa) and 42° (for $\sigma'_v$=100 kPa). The shear strength angle at constant volume $\phi'_{cv}$ was 34° (Moraci and Cardile, 2008).The geogrid used in this research was an HDPE extruded geogrid (called GGE). The tensile properties of GGE geogrid are shown in table 1.

Table 1 - Wide width tensile test results (according to EN ISO 10319)

| Geogrid | $T_F$ (kN/m) | $J_{2\%}$ (kN/m) | $J_{5\%}$ (kN/m) |
|---|---|---|---|
| GGE | 120 | 1800 | 1440 |

At this phase of the research twelve pullout tests have been performed varying the geogrid length ($L_r$ = 0.40, 0.90 and 1.15 m) and the applied vertical pressures (equal to 10, 25, 50 and 100 kN/m$^2$). The pullout tests were carried out at constant rate of displacement equal to 1.0 mm/min.

## 3. TEST RESULTS

For any anchorage length and applied vertical stress the pullout resistance mobilized for geogrid displacements, measured in the section attached to the clamp, equal to 5 mm and 25 mm was evaluated. The results of these analysis are shown in table 2. On the base of these results it has been noticed that, for short reinforced length ($L_r$ = 0.40 m), the pullout resistances mobilized in corresponding with a fixed admissible displacement of 5 mm increase with the increase of the applied vertical confining stress. In particular, the mobilized pullout resistances were equal to 3.96 kN/m, for the lower vertical confining stresses (10 kPa), and equal to 11.80 kN/m, for the higher vertical confining stresses (100 kPa). Moreover, in the same test conditions ($L_r$ and $\sigma'_v$) the mobilized pullout resistances increase with the increase of the fixed admissible displacement. In particular, for a fixed admissible displacement equal to 25 mm, the mobilized pullout resistances were equal to 7.07 kN/m (for 10 kPa) and to 35.47 kN/m (for 100 kPa).The same analysis, carried out for the longer reinforcement ($L_r$ = 1.15 m), showed, also in this case, that the mobilized pullout resistances, increase with the increase of the applied vertical confining stress and with the increase of the fixed admissible displacement, varying from 11.45 (for 10 KPa) to 16.05 kN/m (100 kPa) for a fixed admissible displacement of 5 mm, and from 20.33 kN/m to 53.71 kN/m for a fixed admissible displacement equal to 25 mm.

Table 2 - Mobilized pullout resistance for different admissible displacements and different applied vertical stresses.

| $L_R[m]$ | $\sigma'_V[kPa]$ | $P_{5mm}[kN/m]$ | $P_{25mm}[kN/m]$ |
|---|---|---|---|
| 40 | 10 | 3.96 | 7.07 |
| 40 | 25 | 6.12 | 12.27 |
| 40 | 50 | 7.43 | 17.95 |
| 40 | 100 | 11.80 | 35.47 |
| 90 | 10 | 8.93 | 15.36 |
| 90 | 25 | 13.30 | 28.93 |
| 90 | 50 | 17.78 | 44.73 |
| 90 | 100 | 17.79 | 52.29 |
| 115 | 10 | 11.45 | 20.33 |
| 115 | 25 | 12.50 | 34.28 |
| 115 | 50 | 14.53 | 45.36 |
| 115 | 100 | 16.05 | 53.71 |

The figure 2 shows the iso-displacement curves obtained, for admissible displacements equal to 5 and 25 mm (measured in the first geogrid confined in soil section), by means of the analysis of the different pullout tests performed on GGE specimens of the same length, equal to 0.4 m, varying the applied vertical confining stresses from 10 to 100 kPa.

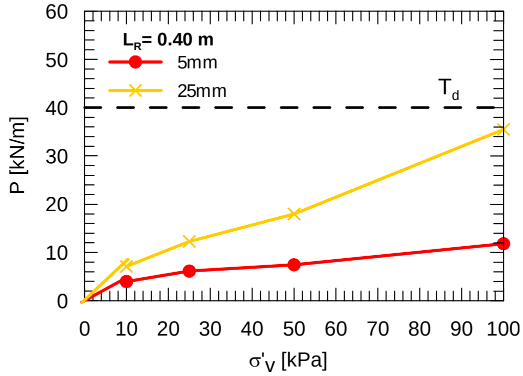


Figure 2 - Iso displacement curves for reinforcement anchorage length equal to $L_r$ = 0.40 m.

In the figures 3 and 4 the same iso-displacement curves (for 5 and 25 mm) were obtained for the specimens length respectively equal to 0.9 and 1.15 m.

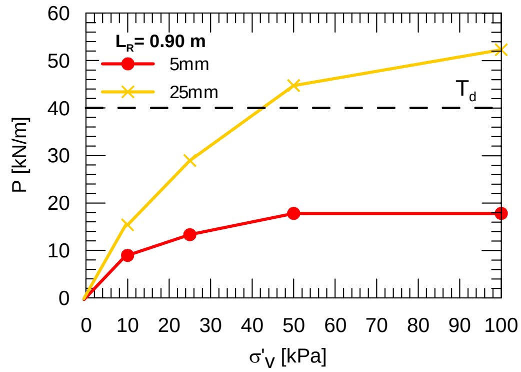


Figure 3 - Iso-displacement curves for reinforcement anchorage length equal to $L_r$ = 0.90 m.

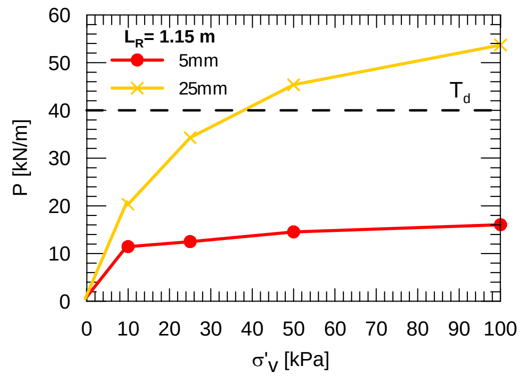


Figure 4 - Iso-displacement curves for reinforcement anchorage length equal to $L_r$ = 1.15 m

These curves represent, for fixed admissible displacements (compatible with the serviceability limit states), the trend of the mobilized pullout resistances as a function of the applied vertical confining stress.

Furthermore, the figures 5 and 6 show, for a fixed admissible displacement respectively equal to 5 mm and 25 mm, the iso-displacement curves as a function of the applied confining stress and of the specimen anchorage length ($L_r$ = 0.4, 0.90 and 1.15 m).

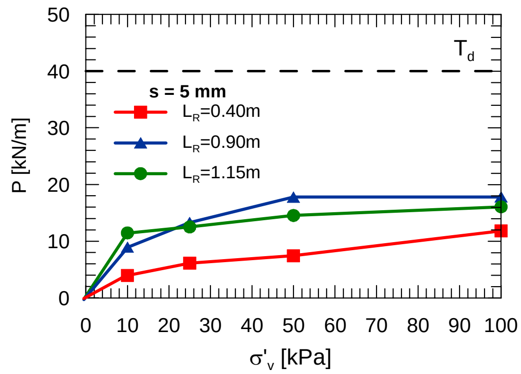


Figure 5 - Iso-displacement curves for an admissible displacement equal to 5 mm for different reinforcement lengths.

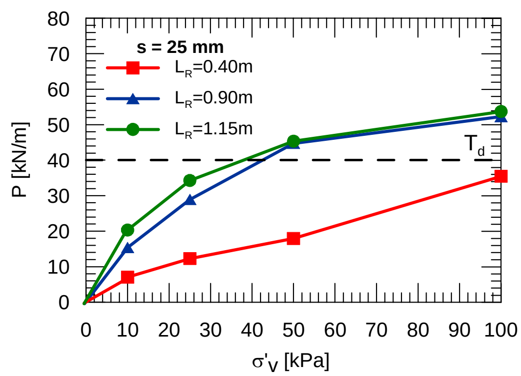


Figure 6 - Iso-displacement curves for an admissible displacement equal to 25 mm for different reinforcement lengths.

In all the graphs (figures 2 – 6), a line corresponding with the long term tensile design resistance $T_d$, evaluated applying a safety factor equal to three at the in isolation tensile resistance (according to EN ISO 10319), is drawn. The ratio between the mobilized pullout resistances, in the serviceability conditions, and the long term tensile design resistance is showed in table 3.

Table 3 - Ratio between the mobilized pullout resistances, in the serviceability conditions, and the long term tensile design resistance.

| $L_R[m]$ | $\sigma'_V\ [kPa]$ | $P_{5mm}/T_d$ | $P_{25mm}/T_d$ |
|---|---|---|---|
| 40 | 10 | 0.10 | 0.18 |
| 40 | 25 | 0.15 | 0.31 |
| 40 | 50 | 0.19 | 0.45 |
| 40 | 100 | 0.29 | 0.89 |
| 90 | 10 | 0.22 | 0.38 |
| 90 | 25 | 0.33 | 0.72 |
| 90 | 50 | 0.44 | 1.12 |
| 90 | 100 | 0.44 | 1.31 |
| 115 | 10 | 0.29 | 0.51 |
| 115 | 25 | 0.31 | 0.86 |
| 115 | 50 | 0.36 | 1.13 |
| 115 | 100 | 0.40 | 1.34 |

The analysis of the test results shows that the iso-displacement curves can be used not only in order to evaluate the serviceability limit states but also, in the limit equilibrium analysis, for a careful choice of the long term design pullout resistance. In fact, it's possible to notice that for short reinforcement length ($L_r$ = 0.40 m) the mobilized pullout resistances corresponding with the admissible displacements, for the different applied confining vertical stresses, were always lower than the long term tensile design resistance. In particular, the mobilized pullout resistances corresponding with the admissible displacements are in range from 10% to 18% of $T_d$, for the lower vertical effective stress, and from 29% to 89% of $T_d$, for the higher vertical effective stress; where the lower percentages refer to admissible displacement of 5 mm, while the higher percentages refer to the superior limit of admissible displacement equal to 25 mm. For the long reinforcement ($L_r$ = 1.15 m), the ratio between the mobilized pullout resistance and long term tensile design resistance varies from 25% to 55%, for the lower $\sigma'_v$, and from 40% to 134% ,for the higher applied effective vertical stresses ($\sigma'_v$= 100 kPa).

Therefore, this analysis showed that the design of earth reinforced structures based on the long term tensile resistance, may be not conservative for the lower applied vertical confining stresses (10 and 25 kPa). In fact, the long term design tensile resistance will be mobilized only for displacement incompatible with the serviceability of the structure.

## 4. CONCLUSIONS

The analysis of the pullout test results described in this paper showed that the iso-displacement curves can be used in the design methods that use the strain compatibility approach (displacement or kinematic methods) in order to evaluate the serviceability limit states of the earth reinforced structures. Moreover, these curves can be used also in the traditional design methods, limit equilibrium analysis, in order to choose the long term design pullout resistance. Finally, this analysis showed that the design of earth reinforced structures based only on the long term tensile resistance, may be not conservative for the lower applied vertical confining stresses (10 and 25 kPa). In fact, in these conditions the long term design tensile resistance will be mobilized only for displacement incompatible with the serviceability state of the structure.

## 5. REFERENCES

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