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## INFLUENCE OF STRUT AND ANCHOR STIFFNESS ON THE BEHAVIOUR OF DIAPHRAGM WALLS

## INFLUENCE DE LA RIGIDITE DES TIRANTS ET BUTONS SUR LE COMPORTEMENT DES PAROIS MOULEES

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**SYNOPSIS:** Following several accidents derived from excessive anchor flexibility or improper bracing stiffness, it has been detected that this is a frequent defect in current design of diaphragm walls, where attention is mainly paid to forces instead to deformations. After sensitivity analyses a case, very common in normal practice, of a diaphragm wall with a single support in a cohesionless soil has been selected. Although bending moments are favourably influenced by flexible systems, maximum deflections show a marked increase (near 100%) for any type of preloaded support combined with low stiffness walls (thickness below 0.60 m). The increase is greater than 2.5 times with passive supports and systems of low stiffness. The combined effect of strut stiffness and level of preloading on maximum deflections is clearly shown. The secondary influence on moments and deflections of the toe condition of the wall (free or hinged) and the position of the support have been also investigated.

### INTRODUCTION

More often than not diaphragm walls designed by methods of limit equilibrium behave in an acceptable manner even with very low safety factors, but the associated ground deformations (not given by conventional methods) can induce excessive settlements and horizontal displacements on nearby buildings and facilities.

For instance, in the case shown in fig. 1 a very flexible steel strut resulted in increasing negative bending moments until the creation of a hinge in a concrete diaphragm wall. The additional load transferred to the strut led to buckling failure of the same and the overturning of the wall above de excavation line. The accompanying flow of ground and water displaced a foundation pit of an inhabited building 3 m apart and seriously endangered other neighborhood foundations, fortunately without severe structural damages.



**Fig. 1.** Overturning of a diaphragm wall by yielding of the struts. Observe the displaced foundation pit (marked by an arrow).

This and other recent cases suggest an urgent necessity of introducing in geotechnical designs more strict specifications as refer to deformability of supports in diaphragm walls.

A first attempt to analyse relative stiffness of walls and tiebacks is due to Clough and Tsui (1974) who obtained, trough a FEM computation for a wall 10 m high in stiff clay, a 30% reduction in maximum deflections when using rod anchorages 10 times stiffer as cables of same capacity. A parametric study carried out by Mana and Clough (1981) for braced cuts in clay showed reductions of 20% in wall movements with a 10 times increasing in strut stiffness.

More recently Ulrich (1989) has related the maximum lateral movement of braced walls (in percent of wall height) to the stiffness of the bracing system as expressed by  $EI/L^3$ . This index stresses the importance of the unsupported length of the bracing,  $L$ . Relative deflections up to 0.2%H appear as tolerable near major buildings or structures.

### MODEL FOR SOIL-STRUCTURE INTERACTION

This clearly is a problem of soil-structure interaction where deformational properties are to be taken into account. Usually FEM computations allow a good approach to the actual behaviour, but contact conditions between wall and soil and the correct modelling of anchors remain as delicate problems. On the other hand, FEM are not very handy as a design tool because of the difficulties in changing geometrical features or the position of the supports.

This has lead to a more extended use of elastic solutions based on subgrade reaction models, mainly of Winkler type, modelling ground reactions by springs. Models using the non linear relationships between earth pressures and deflections for any depth (the so called "p-y" curves) are also widely used.

In our case a similar approach has been used, following the method suggested by Castillo (1972). Starting with at rest conditions, active or passive earth pressures in every design step are related to deflections

through previously established relationships of the non-linear type shown in fig. 2. Although  $\delta$  values found in the literature show an ample scattering, the figures given in Table 1 are deemed advisable for normal practice.

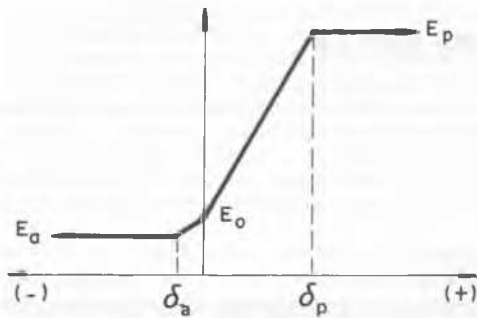


Fig. 2. Theoretical relationship between earth pressures and wall displacements.

Table 1. Proposed values for the limit active and passive values of wall displacements.

Type of ground	$\delta_a$ (m)	$\delta_p$ (m)
Fills and made ground	0.008	0.080
Loose Sand	0.001	0.030
Medium Sand	0.0007	0.015
Dense Sand	0.0005	0.006
Soft clays and silts	0.012	0.050
Stiff Clays	0.008	0.025
Hard Clays	0.004	0.010
Marls, weak rocks	-	0.002

Some uncertainties arise from the impossibility of taking into account the three-dimensional effect of concentrated loads (struts or anchorages) on a stiff wall, as well as the evaluation of the degree of compensation of movements already occurred when the support, prestressed or not, is applied.

## STATEMENT OF THE ANALYSIS

After performing cumbersome sensitivity analyses with a wide range of granular and cohesive soils, it became apparent that the overall conclusions of this study may be illustrated through an intermediate case with the geometry shown in fig. 3, considering a concrete diaphragm wall and a single strut or anchor. Obviously, a similar stiffness can be obtained with more flexible systems as sheet-piling, H-piles and lagging, etc. combined with several rows of struts.

Cohesion may significantly affect the pattern of deflections, moments and strut loads, although reasonable doubts exist as whether undrained conditions prevail during a normal excavation time or not. Thus cohesion has been excluded from this analysis.

The following variation has been considered in the wall and support elements:

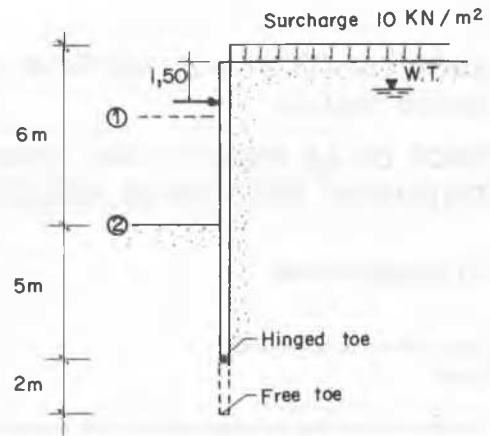


Fig. 3. Geometry used in the analyses.

### Diaphragm Wall Characteristics

- Thickness:  $e = 0.45 - 0.60 - 0.80 - 1.00$  m
- Excavation depth:  $h = 6$  m
- Wall length:  $L \approx 11$  m (toe hinged) or 13 m (free end)

In all cases a preexcavation of 0.50 m below the level of support is made in order to install the corresponding anchor or strut. In this first phase the wall behaves as a freestanding cantilever.

### Support Elements

Represented through a spring constant  $R$  of values between 5 and 150 MN/m. They can be prestressed to the full working load (active anchors) or act as passive struts.

Stiffness of commercial anchors is currently below 20 MN/m and it is difficult to increase said value without an important increase in prices, as the only solution is to reduce the working stresses in the tendons, possibly duplicating their number. Rod anchorages are obviously much stiffer than tendons, but their capacity is limited to no more than 450 kN.

Although tensile stiffness of anchors is very low, after prestressed to the maximum expected load they act as a fixed support as no additional elongation can be developed, unless the actual loads exceed those applied in advance. However, it is also well known that partial yielding of anchors due to creep of embedment soil may arise, resulting in loss of support and reduced stiffness. Local yielding of the ground when the wall is draw back is also a cause of losses in support capacity.

As refers to steel struts or lattice girders, any stiffness ( $EA/L$ ) can be achieved but the cost is very high when the unsupported span  $L$  becomes large, said above 10 or 15 m.

On the other hand, heavy steel struts are difficult to preload and they are subjected to compliance deformations in their contact with the wall which can reduce their effective stiffness to less than 10% of the ideal value (O'Rourke, 1981). Temperature effects also affect earth pressure distributions and wall movements.

**EFFECT OF THE STIFFNESS OF THE SUPPORT ELEMENTS ON THE DEFLECTIONS AND MOMENTS OF THE WALL**

With the set of values above, a number of computations have been carried out, studying the effects of several factors, as the following:

**Support Stiffness and Prestressing**

As shown in figs. 4 and 5, the support stiffness has very little influence on deflections and bending moments as long as prestressing is applied. They are simply related to wall thickness, corresponding the greater deflections and the smaller moments to the thinner walls. This is clearly in conflict with the statement of Clough and O'Rourke (1990) i.e.: "increasing the wall stiffness theoretically does not significantly reduce wall system movements".

The deflection lines represented in fig. 6 show very different shapes depending on the wall stiffness, with maximum deflections at the top for the thicker walls and closer to the bottom of excavation for the more flexible ones. Obviously the effects on nearby structures will vary according to the position of their foundations.

It is interesting to note that even with thick walls and stiff struts deflections exceed 0.45%H, well above the safe limit of 0.2%H. It is apparent that a second row of struts should be necessary to comply with said limitation.

Suppression of prestressing clearly affects the values of moments and deflections for stiffness below 20 MN/m, as shown in figs. 6 and 7. As pointed out by Mana and Clough (1981) this effect should increase with poorer soils or greater earth pressures.

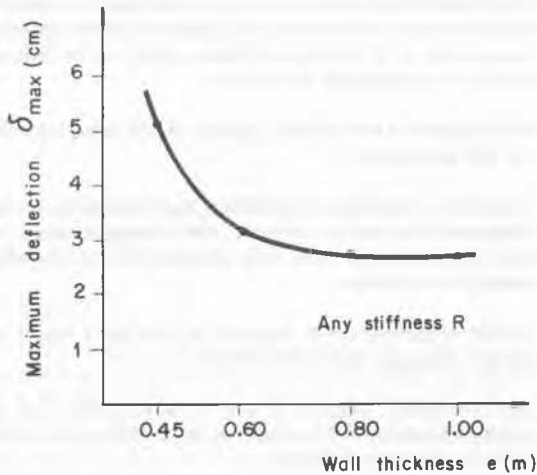


Fig. 4. Influence of the wall stiffness on the maximum deflection. Prestressed supports.

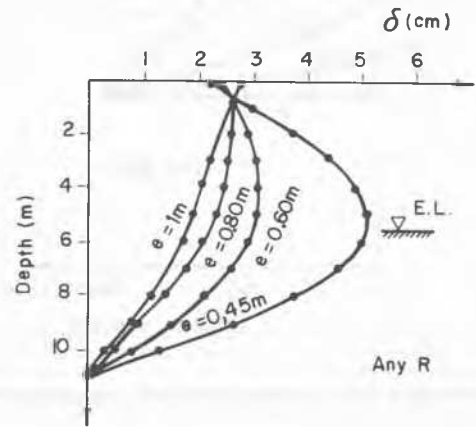


Fig. 6. Shape of the deflection line for varying wall thickness. Hinged toe and prestressed support.

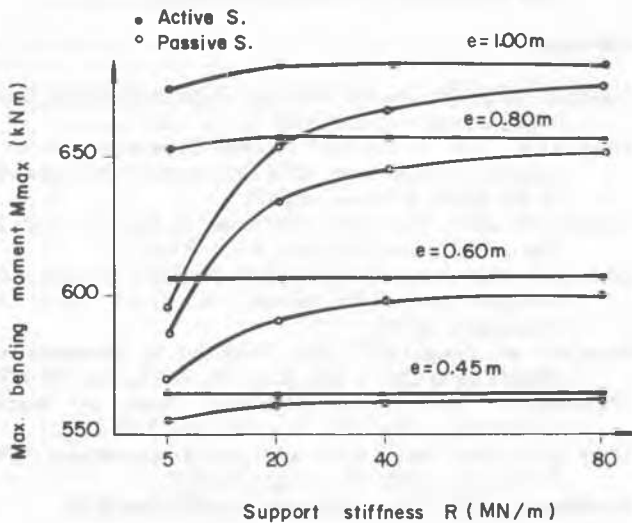


Fig. 5. Maximum bending moments versus wall and support stiffness.

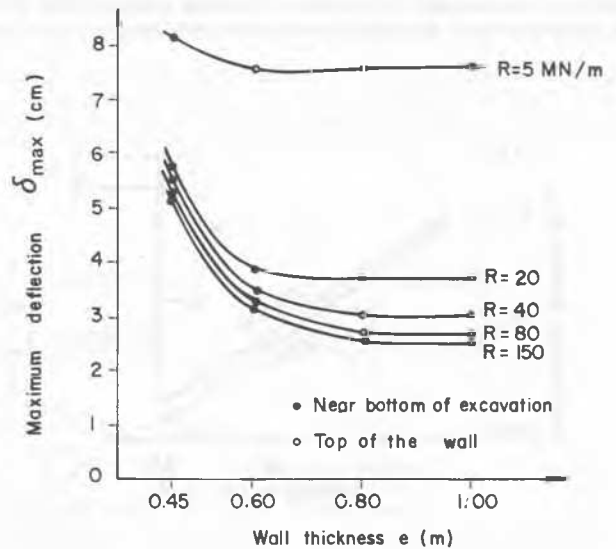


Fig. 7. Influence of wall and support stiffness on the maximum deflection. Passive support.

Comparing figs. 4 and 7 it is interesting to observe that for  $R > 40$  MN/m prestressing of the struts is of little value as refers to reduction of deflections, being more important the effect of the wall thickness. This agrees with the suggestion of Xanthakos (1979) of prestressing of the struts not being necessary unless the excavation is unusually wide.

The effect of prestressing is analysed in more detail in fig. 8, corresponding to a wall 0.60 m in thickness.

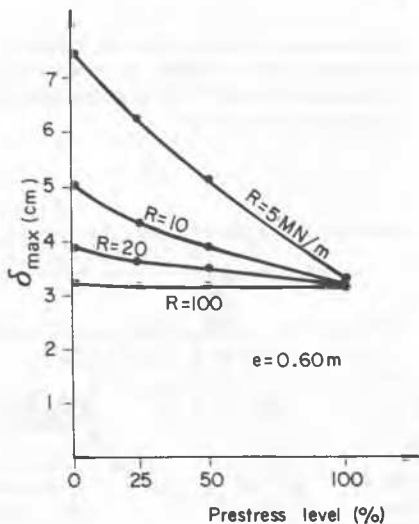


Fig. 8. Influence of the prestressing level on the maximum deflection.

### Toe Condition

The computations have been performed with a hinged toe wall (as achieved in rock). Equivalent free-end walls result in 25 to 40% greater deflections accompanied by reductions of bending moments up to 25% for the thicker walls, due to the smoother deflection line.

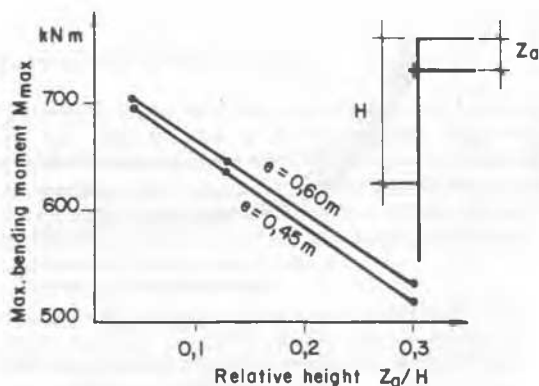


Fig. 9. Influence of the support position on the bending moments (Prestressed support of  $R = 20$  MN/m ; free end).

### Position of the Support

Placement of the support close to the top of the wall may reduce its deflections as a cantilever but has little effect in decreasing the maximum deflection at the mid-span. However the resulting greater unsupported height causes a marked increase in bending moments (fig. 9).

Although there is interest in locating the first row of struts as close to the ground surface as possible in order to keep movements to a minimum, it is convenient to avoid very shallow positions because there is a risk of local ground failure when prestressing the tie-backs.

### CONCLUSIONS

From the analysis above, the following conclusions can be drawn:

- For limited deflections, active anchors combined with thick walls should be used. For achieving the same results with steel struts, these should be of very high stiffness, which can be difficult to assure with spans above 10 or 15 m.
- With supports of low stiffness, absence of preloading may double the wall movements.
- Irrespective of the support conditions, rigid walls show increasing deflections from the toe upwards, with maximum values at the top, whereas flexible walls show maximum deflections near the bottom of excavation.
- Greater deflections can be expected in short walls hinged at the toe than in longer walls with free ends.
- With prestressed supports at a low position (said 0.30 H) a significant reduction of the moments (up to 25%) can be achieved without increasing deflections.
- Design of support elements should always take account of tolerances of nearby structures to displacement. The combined effect of support and wall stiffness allows to assure the desired maximum deflection at a predefined position but, below a certain limit, several rows of struts may be necessary.

### References

- Castillo, E. (1972). Discussion to the Session IIIa of the 5th Europ. Conf. SMFE, Madrid, Vol. 2, 361-363.
- Clough, G.W. and O'Rourke, T.D. (1990). Construction induced movements of insitu walls. *ASCE Geot. Special Publication No. 25*. Ed. Lambe & Hansen. 439-470.
- Clough, G.W. and Y. Tsui (1974). Performance of Tied-Back Walls in Clay. *ASCE J. Geot. Eng. Div.*, Vol. 100, Dec.
- Liñán, C.R. (1985). Desarrollo de un método de Cálculo de Pantallas de Hormigón Armado (In Spanish). Ph. Thesis. *E.T.S. de Arquitectura*. Sevilla.
- Mana, A.I. and Clough, G.W. (1981). Prediction of Movements for Braced Cuts in Clay. *J. Geot. Eng. Div. ASCE*, June, 759-777.
- O'Rourke, T.D. (1981). Ground Movements Caused by Braced Excavations. *J. Geot. Eng. Div. ASCE*, Sept., 1159-1178.
- Ulrich, E.J. (1989). Tieback Supported Cuts in Overconsolidated Soils. *J. Geot. Eng. ASCE*, No. 4, April, 521-545.
- Xanthakos, P.P. (1979). *Slurry Walls*. McGraw-Hill. New York.