INTERNATIONAL SCIENTIFIC CONFERENCE
CIBv 2010
12 – 13 November 2010, Braşov

DESIGN OF ANCHORED WALLS: THE INFLUENCE OF DESIGN APPROACHES AND DESIGN METHODS

Nicoleta Maria ILIEŞ[*], Trifan Alexandru HULPUŞ[*], Augustin POPA[*]

[*] Technical University of Cluj Napoca, Faculty of Civil Engineering

Corresponding author: Trifan HULPUŞ, E-mail: trifan.hulpus@cif.utcluj.ro

Abstract: Development of works of real estate in urban areas requires solutions for deep excavations retaining walls. Assuming correctly the embedment depth and all stresses acting on the wall is very important for the behaviour of the adjacent structures. The design of retaining walls may be performed with design methods, according to European norms (SR EN 1997-1:2006), considering design approaches. This paper presents a parametric study of different design approaches and calculation methods for anchored walls.

Key words: soil investigation, geotechnical parameters, in situ tests.

1. INTRODUCTION

"(For)... problems of soil-structure interaction, analyses should use stress-strain relationships for ground and structural materials and stress states in the ground that are sufficiently representative, for the limit state considered, to give a safe result" (Eurocode 7)

Design methods of deep excavation retaining walls are permanently improving. Classical methods using the limit state of equilibrium of the pressures acting on the retaining walls were developed by introducing numerical methods: subgrade reaction modulus (MCR), finite differences method (FDM) or finite elements method (FEM). For simple structures, stiff walls having one anchor or one prop, limit equilibrium method can provide good results, but for more complex structures it is mandatory to count on the soil-structure interaction.

2. LIMIT EQUILIBRIUM METHOD

The oldest design method for retaining walls improved its design approaches. The three design approaches consider values of partial safety factors which affect the actions, geotechnical parameters and the resistances according to Table 1.

Table 1. Design approaches for ULS design according to SR EN 1997-1:2006

Design approach	Actions		Soil parameters		Resistances	Equation
DA 1-1	A1	+	M1	+	R1	(1)
DA 1-2	A2	+	M2	+	R2	(2)
DA 2*	A1	+	M1	+	R2*	(3)
DA 3	A1[a] or A2[b]	+	M2	+	R3	(4)
a- structural action, action from a supported structure applied directly to the wall						
b- geotechnical action, action transmitted to the wall through the ground						

National code SR EN 1997-1/NB 2007 recommends for limit states STR and GEO design approaches (DA 1-1, DA 1-2) and the design approach 3 (DA 3).

Table 2. The values of the partial factors according to SR EN 1997-1:2006 for earth retaining systems

Actions			Soil parameters			Resistances			
	A1	A2		M1	M2			R1	R3
γ_G	1.35	1.0	$\gamma_{\varphi'}$	1.0	1.25	- bearing capacity	$\gamma_{R,v}$	1.0	1.0
						- sliding resistance	$\gamma_{R,h}$	1.0	1.0
γ_Q	1.50	1.30	$\gamma_{c'}$	1.0	1.25	- earth resistance	$\gamma_{R,e}$	1.0	1.0

** According to SR EN 1997-1:2006 the value of R2=1.4*

Decision on the design approaches and on the values of partial factors can be different, depending on national Annex of each European country. For example, DIN 1054:2005 recommends for deep excavations design EAB (2006) – design approach 2 (LC2) with partial factors shown in Table 3.

Table 3. The values of the partial factors according to DIN 1054:2005

Actions			Soil parameters			Resistances			
	A1	A2		M1	M2		R1	R2	R3
γ_G	1.2	1.0	$\gamma_{\varphi'}$	1.0	1.15				
						$\gamma_{R,e}$	1.0	1.3	1.0
γ_Q	1.3	1.2	$\gamma_{c'}$	1.0	1.15				

The design of propped retaining walls, using pressures scheme based on limit equilibrium method and taking into account the design approaches presented in Table 2 can be performed with geotechnical software GEO 5. In the limit equilibrium method the retaining wall is considered as an embedded wall (in the soil below the excavation level), the active and passive pressures acting on the wall are in the static equilibrium state, Fig. 1.

Using the design scheme shown in the Figure 1, Blum (1931) developed a simple design method, based on the determination of y using monographic chart. In Blum method, the simplification is in consideration of a uniform distribution diagram of active pressure (active domain) on the height of the wall (AC), who's reaction E_h is located at the depth „a" from the point A'.

In the classic method, pressures diagram has a linear distribution; the values of pressures (active/passive) are calculated with Caquot-Kerisel (1948) formula.

The values of active pressure are given by equation (1):

$$e_a = K_a \cdot \gamma \cdot z \tag{1}$$

and the passive pressures are given by equation (2):

$$e_p = K_p \cdot \gamma \cdot z \tag{2}$$

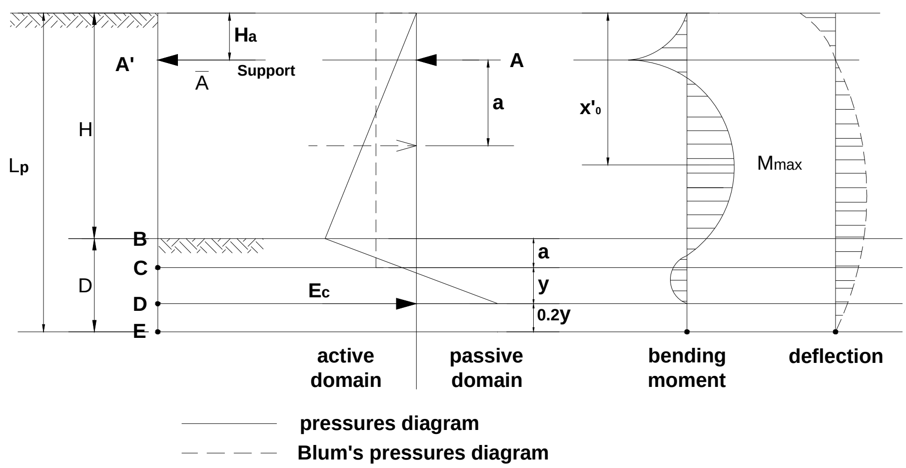

Fig. 1. Application of LEM for an anchored retaining wall

Distribution diagrams for active pressures (earth pressure) and passive pressures (earth reaction) are calculated for ultimate limit state (ULS) for three design approaches (DA) according to SR EN 1997-1 : 2004, Fig. 2.

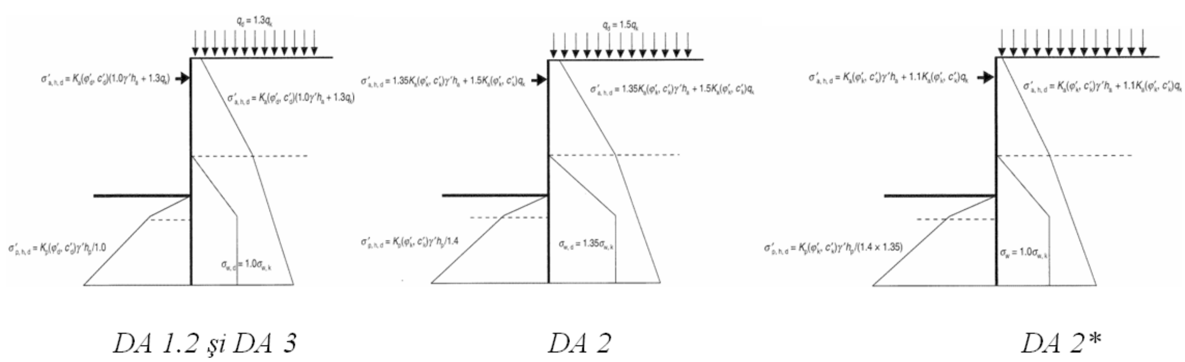

Fig. 2 Application of LEM methods for design approaches

3. EAB METHOD (2006)

This method is based on a design scheme like shown in the Fig. 3. The numerical method can give the embedment depth, considering limit equilibrium between active pressure and passive reaction of the earth acting on the inferior part of the wall, eq. 3:

$$B_{h,d} \leq E_{ph,d} \tag{3}$$

where,

$B_{h,d}$ is the horizontal design component of the reaction forces (passive + support reaction)

$E_{ph,d}$ - is the horizontal design component of the active pressures (permanent + variables actions)

The values of these two resultants are calculated according to (SR EN 1997) for all the three design approaches, as shown in Fig. 1.

$$B_{h,d} = \gamma_G \cdot B_{Gh,k} + \gamma_Q \cdot B_{Qh,k} \tag{4}$$

and

$$E_{ph,d} = E_{ph,k} / \gamma_{R,e} \tag{5}$$

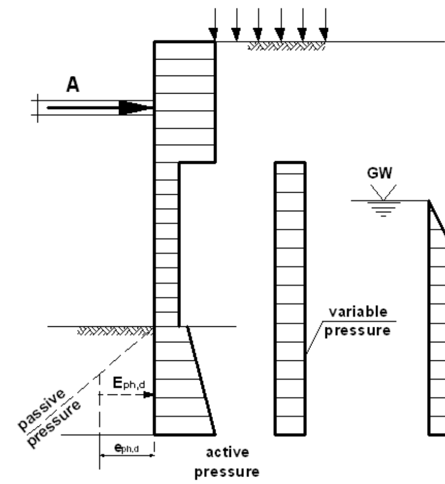

Fig. 3 Horizontal earth pressures in EAB Method

4. SUBGRADE REACTION MODULUS METHOD

The soil-structure interaction was one of the biggest challenges since the 19th century for geotechnical engineers. Because of the soil's complex behaviour, in design, soil structure interaction is replaced by a simpler method called „subgrade reaction modulus". As a soil model in subgrade reaction modulus method, it used a Winkler parameter. The contact between soil and wall is replaced by a system of independent elastic supports of stiffness k_h. The wall is modelled as one-dimensional elastic beam with 1 m width and the value of elastic reaction in one point is directly proportional with the horizontal displacement in the same point Fig. 4.

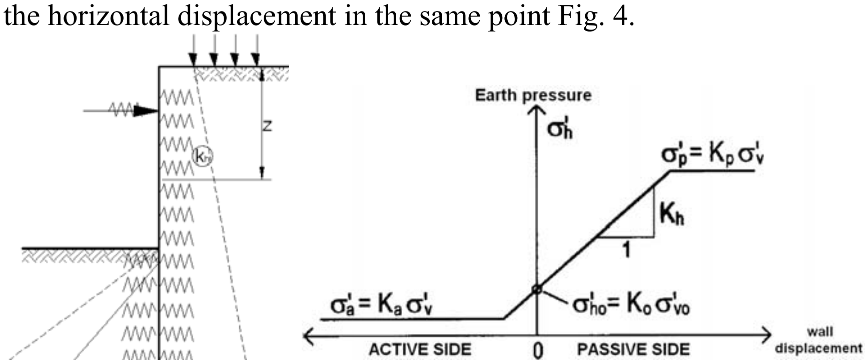

Fig. 4 Sugrade reaction modulus method

$$p_z = k_h y \text{ and } y = y(z) \tag{6}$$

The k_h parameter (subgrade reaction coefficient) is not a physical value that defines the soil, it is a design parameter depending on the wall stiffness (EI), geometry of the wall (ratio between the excavation depth and the length of the wall below the excavation level) and the ground conditions.

Many methods have been proposed for the calculation of k_h for the retaining walls (Terzaghi 1955, Menard 1964, Balay 1984, Becci and Nova 1987, Schmitt 1995, Simon 1995).

Lots of studies performed for a large number of foundations types indicated a smaller influence of the structure stiffness on the value of k. Vesic (1961) concluded that k_h is inversely proportional with $(\mathrm{EI})^{1/12}$

French researchers had an important contribution in determining k_h, their researches being based on original methods after "Menard et all" (1964) and presiometric methods (E_M).

Schmitt (1995) based on his research on observations of stiff and elastic walls different strains, adjusted Menard formula taking into account stiffness of the wall EI :

$$a \approx (EI / E_{oed})^{0.33} \tag{7}$$

and

$$\mathrm{E_{oed}} = \mathrm{E_M} / \alpha \tag{8}$$

Thus is obtaining:

$$\mathrm{k_h} = 2.1 \times \mathrm{E_{oed}}^{4/3} / \mathrm{EI}^{1/3} \tag{9}$$

According to relation for a given linear deformation modulus, a stiff wall would have a smaller k_h than an elastic one.

Simon (1995) extends the Menard formulation adapted by Balay (1984) introducing the differentiation of k_h for zones with „free" deflections (free embedment heights and lengths) and „fixed" deflections (the area between two props/anchorages and a pre-stressed anchorage behind the wall). For the area between two props, having the distance L in between, and considering that a foundation, with B width, can produce deflections for a domain $\mathrm{L} \approx 1.5\mathrm{B}$, Simon proposes:

$$\mathrm{k_h} = \mathrm{E_M} / [0.13(4.4\mathrm{B})^{\alpha} + \alpha \times \mathrm{B}/6] \tag{10}$$

The relationship from above was put into practice by Chaideisson and later simplified by Monnet (1994), to determine horizontal subgrade reaction coefficient is:

$$\mathrm{k_h} = \left[20\mathrm{EI} \left(\frac{\mathrm{k_p}\gamma \left(1 - \frac{\mathrm{k_0}}{\mathrm{k_p}}\right)^4}{\mathrm{dr_0}} \right) \right]^{\frac{1}{5}} + \mathrm{A_p c'} \frac{\mathrm{tgh}\left(\frac{\mathrm{c'}}{\mathrm{c_0}}\right)}{\mathrm{dr_0}} \tag{11}$$

Where, EI - the stiffness of the structure;

γ - Unit weight;

k_p - Passive earth pressure coefficient;

k_0 - Coefficient of earth pressure at the rest;

dr_0 - Characteristic displacement (0.015m);

c' - Effective cohesion; c_0 - 30 kPa;

A_p - Coefficient depending on cohesion

Multi-propped walls behaviour is more complex and estimating the width B is uncertain, as a result of the fact that earth pressure distribution and the model of wall deformation are a priori known things. For example, for a multi-propped concrete diaphragm wall, with a large width, propped on several levels, realized through „top-down" construction method, having like supports the slabs of the underground structure, it will behave like a stiff box. The earth pressure can remain at its rest value k_0 and the various constrains will allow only small displacements of the wall. Therefore k_h (the ratio pressure - displacement) it is expected to be larger.

5. NUMERICAL ANALISYS

For the construction of a building with two underground levels and five floors, a conference rooms buildings in Oradea city it was imposed to calculate a retaining wall for an excavation, uphill the specific building.

The retaining wall was designed in secant pile wall solution; 400 mm diameter piles, at 500 mm inter axes (class of concrete - C 25/30). Secant pile wall is anchored at the superior part by a row of 21 anchorages spotted 2 m distance between their axes.

From the geotechnical study we have the following soil parameters:

Table 4. Values of soil parameters in Mohr-Coulomb model.

Layer	h(m)	φ'_k [0]	c'_k [kN/m²]	ψ [0]	E [kN/m²]	ν	γ/γ_{sat} [kN/m³]
(1)	2.00	17	14	-	9000	0.30	18.5/8.5
(2)	4.60	33	0.1	-	25000	0.50	20/10
(3)	1.00	24	0.1	-	11000	0.40	18.5/8.5
(4)	10.40	12	46		12000	0.30	17.7/8.5

Ground water table is at 3.50 m depth from ground level.

For the design, the friction between the wall and the soil was adopted considering internal friction angle, with the relationships:

$$\delta_a = 1/2\varphi'_k \text{ and } \delta_p = 2/3\varphi'_k \tag{12}$$

For the exterior surcharge the value considered is $q = 10kN/m^2$. Static scheme for design is presented in Fig. 5.

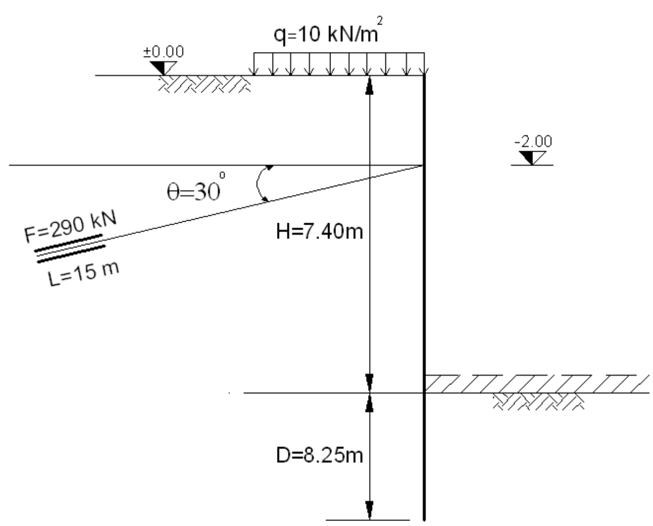

Fig. 5 The design static scheme of the anchored wall

For the wall were taking into design following characteristics: E_p=30500 MPa ; ν_p=0.18 ; γ=25 kN/m^3 ; d=0.40m ; I=7.952$\cdot 10^{-4} \cdot$m^4/m ; A=0.1414 m^2/m and for the anchorage were considered: d =15 mm ; E_s=21000 MPa

Calculation of active earth pressure was made after Coulomb method and the calculation of the reactions after Caquot-Kerisel method (1941)

Number of mesh elements for the wall in the subgrade reaction modulus method is 20. In the design was taking into consideration the pressures produced by earthquake, corresponding to Oradea city: a_g=0.1g

The stages of construction for the anchored wall are presented in Table 5

Table 5. Execution stages for the anchored wall.

Stage	Activity description
1	Execution secant pile wall(beam guidance + piles)
2	Excavation until -2.65 m level
3	Execution of anchor beam and the anchorages
4	Excavation until the bottom of the raft foundation, -7.40 m
5	Execution of the raft foundation, having 1 m thickness
6	Execution of injection of concrete in front of the wall and the canopy beam

After the calculation through limit equilibrium method (LEM) and subgrade reaction modulus method (MCR), resulted the values of bending moments, embedded depths, anchorage forces and the displacements presented in Table 6.

Table 6. Compared results through limit equilibrium method (LEM) and subgrade reaction modulus (MCR)

Limit equilibrum method (GEO 5) (LEM) Design approaches (SR EN 1997-1:2004)						Subgrade reaction coefficient (MCR) '			
	DA 1.1	DA 1.2	DA 2	DA 2*	DA 3	DA 1.1	DA 1.2	DA 2	DA 3
M_{max} [kNm/m]	214,24	201,71	214.24	147.98	251.89	231.12	189.55	231.12	221.95
D[m]	8.91	9.40	8.91	8.44	10.19				
N_A [kN/m]	268.04	255.60	268.04	196.91	292.23				
u_{max} [mm]						11	9.5	11	15.3

6. CONCLUSIONS

After numerical calculation performed and based on the resulted values, there are some conclusions to present:

1. Limit equilibrium method (LEM) does not allow the determination of horizontal displacement of the wall (U_h);
2. Subgrade reaction coefficient method allows the determination of horizontal displacement of the wall (U_h), without determination the vertical displacement of the adjacent ground. After some field measurements on the structure made, it can be considered that for anchored wall the maximum settlement of the ground is:

$$U_{v,max} = U_{h,max} \qquad (\leq 0.2\% \cdot H) \tag{13}$$

3. The value of the maximum horizontal displacement of the wall is 15, 3 this value do not exceed the maximum imposed (0.02 …0.04) H.

REFERENCES

1. CHADEISSON, R., *Parois continues moulees dans les sols*, Proceedings of 5th European Conference SMFE, PARIS, **Volume 2**, pg 563-568, 1961
2. FRANK, R., *Designers' guide to EN 1997-1 EUROCODE 7: Geotechnical design- General rules* Ed. Thomas Teldford, 2004
3. GEO 5, *User's guide vers 5*
4. GERMAN SOCIETY FOR GEOTECHNICS, *Recommendations on Excavations*, Ed. Ernst & Sohn, 2003
5. SADREKARIMI J., *Comparative study of methods of determination ofcoefficient of subgrade reaction*, Electronic Journal Of Geotechnical Engineering, **Vol. 21,** N01 1388
6. SMOLTCZYK, U., *Geotechnical engineering handbook,***Vol 3 Structures**, Ed. Ernst & Sohn, 2002
7. SR EN 1997 –1/NB, *Eurocod 7. Proiectarea geotehnică. Partea 1. Reguli generale. Anexa natională,* 2007.

Received September 20, 2010