Anchor Slab Structure Retains Earth Fill

Structure Soutènement avec Plaque d'Ancrage

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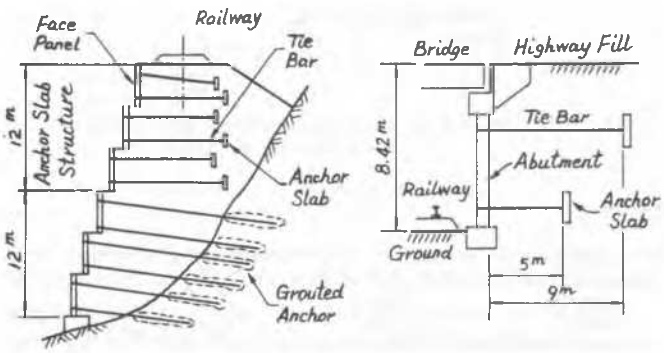
SYNOPSIS The anchor slab structure is a type of retaining wall which consists of prefabricated face panels, tie-bars and anchor slabs embedded in earth fill. The structure maintains itself in equilibrium through soil-structure interaction. In comparison with masonry retaining walls, the anchor slab structure is very light and comparatively flexible. It is especially suitable to be adopted in regions of low bearing capacity. The principles of the equilibrium and stability analysis of anchor slab structures are presented hereof. Finally, the results of monitor observations on some of these structures are mentioned briefly.

INTRODUCTION

The first anchor slab structure was built in 1974 on a railway in Shanxi, China, as shown in Fig.1(a). Several such structures have been built since then, and in 1978 some new type of bridge abutments with anchor slabs were designed and constructed, Fig.1(b). Monitor instruments were installed in five of these structures and periodic observations were continued for 2 to 6 years respectively. The results appear satisfactory and there is a tendency of growing interest in this kind of structure among engineers.



(a)Shanxi Retaining Wall (b)Wuchang Abutment
Fig.1 Anchor Slab Structures

The internal forces within the anchor slab structure consist of the internal earth pressure on the face panel, the tension in the tie-bar and the passive resisting force on the anchor slab. The equilibrium of the structure can be maintained only if the load carrying capacity of the anchor slab is adequate to balance the earth pressure exerted on the face panel. Meanwhile, there are also external forces acting on the boundaries of the structure. These include the external earth pressure and the shear resistance produced under the action of dead and live loads.

The structure will be stable as a whole only when the external forces are in equilibrum. Therefore, the design of an anchor slab structure involves the study and analysis of its equilibrium and stability. These are described separately as follows.

Fig.2 Photograph of the Shanxi Retaining Wall

CONDITION OF INTERNAL EQUILIBRIUM OF THE ANCHOR SLAB STRUCTURE

Suppose an anchor slab structure is represented by an elementary unit as shown in Fig.3 AB is the face panel of the unit, CD is the anchor slab. The internal forces within this structure are very complicate because it varies with the deformation of the structure. Generally speaking, the internal earth pressure on the face panel should lie between the active earth pressure and the earth pressure at rest, and the total earth pressure on the anchor slab should be equal to the total pressure on face panel. In order to get a rough estimation of the required area of anchor slabs, the conditions may be simplifed by making the following two assumptions:

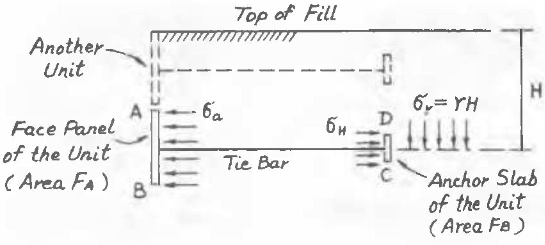


Fig.3 An Elementary Unit Structure

(1) The pressure on the face panel AB is assumed to be equal to the active earth pressure,
(2) The horizontal pressure in front of the anchor slab is assumed to be the major principle stress in the soil.

To fullfill the conditions of equilibrium, it is required that the state of stress of the soil in front of the anchor slab should not exceed the state of plastic equilibrium, which is represented by the equation:

$$\frac{\sigma_H-\sigma_v}{2} \leqslant \sin\phi \left[\frac{\sigma_H+\sigma_v}{2} + \frac{c}{tg\phi}\right] \quad (1)$$

Let F_s be the factor of safety of anchor slab, F_A be the area of face panel, F_B be the area of anchor slab, H be the depth of embeddment of anchor slab, $\sigma_v=\gamma H$, K_a be the coefficient of active earth pressure, γ be the unit weight of soil and C,ϕ be the cohesion and angle of internal friction of soil. It follows that:

$$F_A K_a \gamma H = F_B \sigma_H \quad (2)$$

From equations (1) and (2), the following formula were deduced:

$$F_B = F_s F_A K_a \left[\frac{1-\sin\phi}{1+\sin\phi + \frac{2c}{\gamma H}\cos\phi}\right] \quad (3)$$

With this fofmula, the F_s of some existing anchor slab structures were computed and listed as shown in Table 1.

STABILITY ANALYSIS OF ANCHOR SLAB STRUCTURE

In the stability analysis of anchor slab structures, two typical cases were considered separately, Model tests were carried out and formulae were deduced for each case. The results are as follows:

(1). Anchor Slab Structure with Vertical Boundary

If the length of upper tie-bar in an anchor slab structure is shorter than the lower tie-bar, as shown in Fig.4 the stability of anchor slabs C_1 and C_2 should be analyzed by considering the forces acting on soil masses $AB_1C_1D_1$ and $AB_2C_2D_2$ respectively. The point B_2 is taken to be the mid-point between upper and lower tie-bars, as shown in the figure.

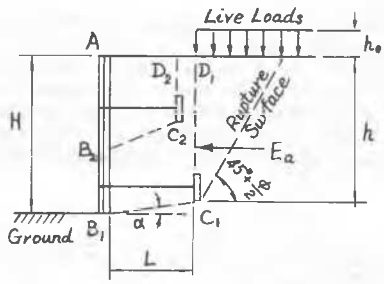


Fig.4 Anchor Slab Structure with vertical boundary

TABLE I Examples of the analysis of F_s

Site of structure	Date of completion	Soil parameters	Height of wall H(m)	Spacing c-c struts D(m)	Area of anchor slabs $F_B(m^2)$	F_B/F_A (F_A=HD)	F_s (Equ.3)
Shanxi retaining wall	Oct. 1974	C=0 $\phi=40°$	12	2	6x1.1x1.1	0.3	5.5
Tsinghai retaining wall	Aug. 1976	C=0 $\phi=35°$	9	1	9x1x0.16	0.16	2.16
Beijing retaining wall	Aug. 1977	C=0 $\phi=35°$	5	2	4x0.6x0.6	0.144	1.95
Chengchow abutment	Sept. 1978	C=0 $\phi=30°$	5.5	1.6	2x0.8x0.8	0.145	1.30
Taiyuan abutment	Nov. 1978	γ=17.4KN/m^3 C=20Kpa $\phi=26.5°$	8	1.6	4x0.8x0.8	0.20	1.60

Taking the stability analysis of $AB_1C_1D_1$ as an example, the structure $AB_1C_1D_1$ is pushed by an active earth pressure E_a acting on the vertical boundary C_1D_1, and it is resisted by the horizontal component R_h of the reaction on B_1C_1. The result of stability analysis led to the following formulae:

$$E_a = \frac{1}{2}\gamma h(h+2h_o)tg^2(45^o - \frac{\phi}{2}) \qquad (4)$$

$$R_h = \frac{1}{2}\gamma L(H+h)tg(\phi - \alpha) \qquad (5)$$

$$F_{s1} = \frac{R_h}{E_a} = \frac{tg(\phi-\alpha)}{tg^2(45^o-\phi/2)} \cdot \frac{L(H+h)}{h(h+2h_o)} \qquad (6)$$

In which F_{s1} is the factor of safety against sliding for the case of vertical boundary, ϕ is the angle of internal friction of the soil, and L, H, h, h_o, α are those dimensions as shown in Fig.4 respectively.

(2).Anchor Slab Structure with Stooping Boundary

An anchor slab structure with stooping boundary is defined as a structure in which the line CE joining the upper and lower anchor slabs forms an angle of inclination $45^o + \frac{\phi}{2}$ with the horizontal, as shown in Fig.5

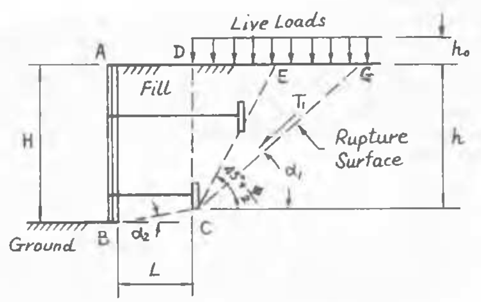


Fig.5 Anchor Slab Structure with Stooping Boundary

In the stability analysis, a critical condition occurs when a sliding force T_1 acts along the rupture surface CG. It is transformed into a sliding force T' along the surface CB, and is resisted by the shearing resistance R on the surface BC. The result of stability analysis led to the following formulae:

$$T_1 = \frac{1}{2}\gamma h(h+2h_o)\cot\alpha_1(\sin\alpha_1 - f\cos\alpha_1) \qquad (7)$$

$$T' = T_1[\cos(\alpha_1-\alpha_2) - f\sin(\alpha_1-\alpha_2)] \qquad (8)$$

$$R = \frac{1}{2}\gamma L(H+h)(f\cos\alpha_2 - \sin\alpha_2) \qquad (9)$$

$$F_{s2} = \frac{R}{T'} = \frac{L(H+h)}{h(h+2h_o)} \cdot \frac{(f\cos\alpha_2-\sin\alpha_2)}{\cot\alpha_1(\sin\alpha_1-f\cos\alpha_1)} \cdot \frac{1}{\cos(\alpha_1-\alpha_2)-f\sin(\alpha_1-\alpha_2)} \qquad (10)$$

in which F_{s2} is the factor of safety against sliding for the case of stooping boundary, ϕ is the angle of internal friction of the soil, $f = tg\phi$, and $L, H, h, h_o, \alpha_1, \alpha_2$, are those dimensions as shown in Fig.5 respectively.
In order to obtain F_{s2}, a number of trial values of α_1 should be assumed, and the corresponding values of F_{s2} should be calculated. The minimum F_{s2} value obtained from these calculations represent the critical condition, and it often happens when α_1 is some where arround 40°-45°.

(3).The Simplified Method of Stability Analysis

The afore-mentioned stability formulae can be reduced to the following simplified forms:
For the case of vertical boundary:

$$F_{s1} = A_1 \frac{L(H+h)}{h(h+2h_o)} \qquad (11)$$

For the case of stooping boundary:

$$F_{s2} = \frac{A_2}{BC} \frac{L(H+h)}{h(h+2h_o)} \qquad (12)$$

in which

$$A_1 = \frac{tg(\phi-\alpha)}{tg^2(45^o-\phi/2)}$$

$$A_2 = f\cos\alpha_2 - \sin\alpha_2$$

$$B = \cot\alpha_1(\sin\alpha_1 - f\cos\alpha_1)$$

$$C = \cos(\alpha_1-\alpha_2) - f\sin(\alpha_1-\alpha_2)$$

A_1, A_2, B, C are dimensionless constants. They were computed and plotted as nomographs in Fig6 and Fig.7 The procedure of stability analysis can be much simplified by using these nomographs.

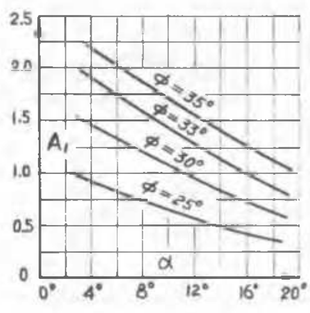


Fig.6 Stability Coef. A_1 for vertical Boundary

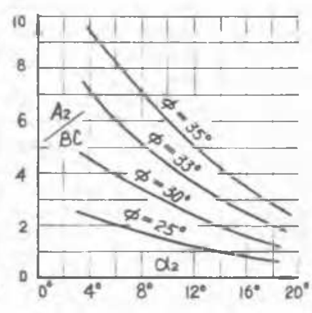


Fig.7 Stability Coef. A_2/BC for Stooping Boundary

ULTIMATE CARRYING CAPACITY OF ANCHOR SLABS

In order to obtain reliable data regarding the ultimate carrying capacity of anchor slabs, three groups of full scale field tests were carried out at different sites. The typical load-deformation curves and test arrangements are shown in Fig.8 The anchor slabs were made of reinforced concrete with bearing areas ranging from 0.5x0.5 to 1.4x1.4 square meters, and the depth of embeddment ranged from 3 to 6.7 meters. Tensile loads were applied to the tie-bar in increments, and every increment of load was held constant until the displacement reached its final value.

For the convienence of analysis, the point on the load-deformation curve which corresponds to a displacement of 10cm is taken as the ultimate carrying capacity, and one third of this value is taken as the allowable load. The average value of these results are given in table 2.

It can be seen that under these circumstances, the allowable load may be taken as 100-150kN per square meter of the area of anchor slab.

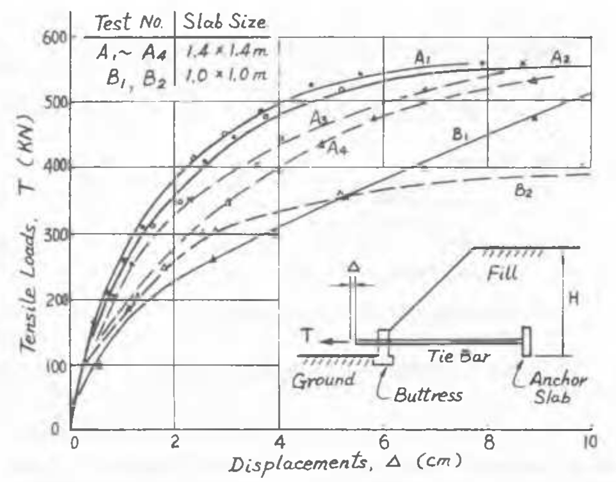


Fig.8 Test Arrangement and Typical Results

TABLE 2 Carrying Capacity of Anchor Slabs

Location of the test	Depth of Embeddment H(m)	Size of slab (m²)	Results of Field Tests: Ultimate load(kN)	Results of Field Tests: Allowable load(kN)
Taiyuan γ=17.4 kN/m³ C=20kPa Ø=26.5°	3.0	0.5x0.5	160	53
		0.75x0.75	210	70
		1.0x1.0	400	133
	6.0	0.5x0.5	120	40
		0.75x0.75	185	62
		1.0x1.0	277	92
Wuchang γ=19.4 kN/m³ C=27 kPa Ø=22.5°	5.0	1.0x1.0	500	167
		1.4x1.4	550	184
	6.7	1.0x1.0	380	127
		1.4x1.4	550	184
Changchow γ=19.1 kN/m³ C=23 kPa Ø=29.0°	3.0	1.0x1.0	280	93
		1.2x1.2	340	113

However, there is an unexpected phenomena that the deeper burried slabs give lower carrying capacities than the shallow ones. This may be due to the influence of greater moisture content in the deeper zone. But it is also suspected that other complicate factors such as arching action in the deeper zone may influence the stress state of the soil, and therefore no conclusion can be made on this point prior to further research work.

RESULTS OF MONITOR OBSERVATIONS

In order to monitor the performance of anchor slab structures, field instruments were installed in five of these structures to measure their stresses and deformations. Tension in the tie-bars, settlements of the fill and horizontal displacements of the wall were measured and recorded twice a year after the completion of the structure. It is worthwhile to point out two particular phenomena exposed by these observations:

(1) The earth pressure on the face panel continued to increase gradually for 2-3 years after the completion of work. It reached a maximum value which is higher than the active earth pressure, but not exceeding the earth pressure at rest.

(2) During the summer of 1977, a heavily loaded train with two locomotives was brought to stop for two hours on top of the Shanxi retaining wall, and meanwhile the stresses of the anchor slab structure were measured. It was found that the influence of this temporary load was negligibly small as compared with the result of calculations on the assumption of dead loads.

It is evident that the actual earth pressure and the influence of live loads on retaining walls is a complicated problem which deserves much more research works to be done. In the meantime, the above mentioned facts should be kept in mind and due considerations should be taken during the designing work.

CONCLUDING REMARKS

The anchor slab structure has proved to be effective and economical as used for retaining walls and bridge abutments in China. The basic conceptions and formulae of its equilibrium and stability analysis have been established herewith. Further research works on this type of structure are still going on and will be reported afterwards.