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The design of a very high reinforced earth retaining wall

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ABSTRACT: A very high reinforced earth retaining wall (HRERW) has been constructed in Luo Chuan loess nodel platean. The design methodology used and the HRERW Construction are introduced in this paper.

1 INTRODUCTION

The very high reinforced earth retaining wall (HRERW) introduced in this paper has been constructed during 1994 and 1995. The HRERW is located in the cetral area of Luo Chuan loess nodel platean in the northen part of Shan Xi Province of China.

The HRERW has maximum lateral cross section height of 50.13m and the whole length is 213m inside a plane curve section of the highway. The whole wall is divided into 7 sections in longitudinal profile. The length of each section and the crossponding maximum lateral cross section height are shown in Table 1.

Table 1. Longitudinal profile section length and height

Section NO.	1	2	3	4	5	6	7
Section length(m)	25	20	60	60	10.53	19.48	70
Max. height(m)	19.33	28.66	35.62	50.13	34.42	30.01	10.41

Stepped lateral cross section was arranged for the HRERW; Each stage of the wall mass is ten meters in height. So that the highest lateral cross section has five stages. A step with the length of 1.5m at the interface of each adjacent stages of wall mass was applied. The wall face has a slope of 1/10. The top stage of the wall are shoulder retaining wall.

In addition to arrange steps, anchor plates with the space of 2.5~3.5m center to center were applied to ensure that the wall had good monolithic stability and the backfilling materials had aviable contact with the soil behind the wall.

2 DESIGN INPUTS

2.1 Reinforcement

The reinforcements used in the HRERW are A_3 oil painted ribbed steel strips. The permissible stress is 135MPa and ultimate strength is 437MPa. The permitted corossion thickness is 1 mm. Weld method was used to make the reinforements being contacted with the pre-embeded elements inside the wall panels.

2.2 Backfilling materials

The backfilling materials is the local loess soil (clayey soil). The physical and mechanical properties are shown in Table 2.

Table 2. The physical and mechanical properties of the backfilling soil

Grading			Physical and Mechanical Properties							PH
> 0.074	0.074~0.002	< 0.002	Specific Gravity KN/m³	Dry Density KN/m³	Void Ratio %	Water Content %	Pastic Index Ip	C kPa	ϕ	7.6
21	67	12	2.690	1.516	0.774	17.55	10.3	50	20°	

2.3 Load concerned in the structural design

The load process concerned about in the structural design of the HRERW is Qi-super 20 and earthguake 8°.

2.4 Wall face panels

The HRERW face panels are rectangular reinforcement cement concrete slab with the plane size of 75 cmx125cm and the thickness of 20cm. Four pre--embcded elements were made which were connected with reinforcements using weld method.

The horizontal and vertical space of reinforcements arc 0.75m.

3 THE STRUCTURAL DESIGN OF THE HRERW

3.1 Concern about structural desing method and the application of the existing design specification.

For the design of the HRERW with such height of 50m, the design procedure in existing specification only can be refered but not be directly used. Design specifications of so high reinforced earth retaining wall have not been developed in China or abroad. Therefore, the structural design of the HRERW was carried out based on the general design methodology and some research results.

Three aspects of controll have been considered about the internal stability.

1. As a monolithic retaining structure, the HRERW shall satisfy monolithic equilibrium requirements.

2. Considering each stage of wall mass has a indentation of 2.5m from bottom to top and each interface between two stages of wall mass is enhenced by anchor plates, each stage of wall mass could be supposed to be a single independant retaining wall, below which the wall mass be the base and above which be supercharge, Each stage of wall mass as single one should statisfy the requirements of pullout and rupture resistance for reinforcements.

3. As for the external stability, sliding on the base is the main controlled failure mode.

The thought of monolithic equilibrium analysis replys that there is a potential failure surface at any reinforcement layer, consquently, the reinforcements crossed by the potential failure suface should provide enough resistance to prevent the soil mass in active zone from leaving away from the wall mass. Generally, the thought of monlithic equilibrium method of reinforced earth could reflect the mechanism of reinfored earth.

Based on the specification of the monolithic equilibrium method, the internal stability shall satisfy the following equation.

$$K_j = \frac{1}{P_j} \sum_{i=m}^{1} S_i \geqslant 1.25$$

where: P_j=the horizontal sliding force produced by the soil weight in active zone and horizontal force at the top surface of the wall; S_i=the horinzontal reisitant force of the ith reinforcements crossed by the potential failure surface; K_j=safty factor.

Table 3. Internal staiblity analysis resuluts of 50m high lateral cross section

Reinforcement layer number	Calculated depth (m)	Reinforcement thickness(mm)* length(m)	Critical slip wedge angle (°)	Slip wedge stability safety factor	Local stability safety factor	10m single wall * safety factor	
						rupture	pullout
2	1.5	4*12	29.5	2.85	4.55	3.24	1.79
6	4.5	4*12	31.0	2.25	2.18	1.59	2.21
10	7.5	6*10	31.5	1.71	2.25	1.68	2.67
14	10.5	6*10	41.0	1.58	1.64	0.79	1.33
18	13.5	8*10	39.5	1.20	1.20	0.78	1.72
22	16.5	8*8	35.0	0.95	1.40	0.99	1.84
26	19.5	8*8	34.5	0.84	1.19	0.43	0.99
30	22.5	8*8	34.5	0.69	1.29	0.78	1.23
34	25.5	8*8	31.5	0.67	1.14	0.79	1.84
38	28.5	10*8	42.0	0.60	1.02	1.02	0.75
42	31.5	10*6	29.0	0.52	0.93	1.03	0.74
46	34.5	10*6	50.0	0.49	0.93	1.03	0.74
50	37.5	12*6	50.0	0.41	0.85	1.12	1.28
54	40.5	12*6	57.5	0.40	0.94	12.35	1.51
58	43.5	12*6	52.0	0.32	0.94	4.15	0.66
62	46.5	12*6	54.0	0.27	0.76	2.83	1.27
66	49.5	12*6	35.5	0.23	0.71	1.79	1.57

Note*: Each stage of wall mass is supposed being a single retaining wall.

3.2 Design

The analysis results of the HRERW stability and designed reinforcements are shown in Table 3.

4. ANALYSIS OF ULTIMATE RESISTANT FORCES OF ANCHOR PLATES

4.1 The calculation of ultimate resistant force produced by the anthor plate.

The anchor plates used at the interface of each two stages of wall mass is very beneficial to the monolithic stability of the HRERW. That is one of the special design aspects of the HRERW.

Two assumptions were made where the ultimate horinzontal resistant forces of the anchor plates were calculated as follows:

The earth pressure acting at the wall panels is active earth pressure.

The earth pressure in front of anchor plate is active earth pressure.

From the equilibrium condition of this structure, the stress at any point inside the backfilling materials shold not be greater than that at plastic equilibrium state. The relation can be indicated by the following equation:

$$\frac{\sigma_h - \sigma_v}{2} \leqslant \sin\phi\left(\frac{\sigma_h + \sigma_v}{2} + \frac{C}{\mathrm{tg}\phi}\right)$$

where: σ_h=horizontal earth pressure, kPa; σ_v=Vertical earth pressure, kPa C=Cohesive force, kPa ; ϕ =friction angle (°).

The cohesive force of the backfilling soil is 50kPa, internal friction angle is 25°; The size of the anchor plate is 0.8×0.8m.

For the first layer anchor plate (the top one):

$Z=10m$, $\sigma_v = \gamma \cdot Z = 213.4$kPa.

$(\sigma_h - 213.4)/2 \leqslant 0.426[(\sigma_h - 213.4)/2 + 107.225]$

So, $\sigma_h \leqslant 682.7$kPa.

The ultimate horizontal resistant force of the anchor plate is:

$$T_{max} \leqslant \sigma_h \cdot 0.8^2 = 439.0\text{KN}$$

As calculated above, the ultimate horizontal resistant forces of the second、third、forth and the fifth layer ones are: 773. 4 , 1109. 9, 1546. 8, 1782.3KN respectively.

4.2 The founction of the anchor plates

Through the detailed calculation of two layers of reinforcements in the 50m heigh general lateral cross section, the benift of anchor plates to the monolithic internal stability of the HRERW could be indicated.

1. 22nd Reinforcement under load process I

The potenial failure surface angle at this layer is α=39.5°; The calculated safty factor of monolithic equilibrium is K_s=0.95(see table 3).

The potential failure surface crosses the first layer anchor plates. The calculated thickness is 16. 5m. The soil mass weight in active zone equals 1395. 8KN and the equivalent traffic load thickness equals 87.4KN. . The sum of the horizontal resistant force provided by crossed reinforcements can be computed from the above data and using equation (1)

$\Sigma S_i = (G + h_e)\cdot K_s/\mathrm{tg}(\alpha + \varphi) = 471.5$KN

where: G = soil mass weight in active zone; he=equivalent soil hight of traffic load; K_s = safty factor; α = angle of the potential failure surface; φ = internal friction angle of the soil.

The ultimate horizontal resistant force of each first layer anchor plate equal to 436.9KN. So considering the function of the anchor plate, the safty factor is:

K_{st}=(471.5+436.9×0.75/3.5).tg(39.5+32)/(1395.8+87.4)=1.138

2. 50th layer reinforcement under load process I

The pontential failure surface angle equals 50.0° and the calculated safty factor is 0.41. The failure surface crosses the first, second and third layers of anchor plates. The soil mass weight in active zone and the equivalent traffic load soil height equal 79494.6KN and 594.5KN respectively. Calculating as above, the safty factor equals 0.8495 if considering the function of the anchor plates.

From the calculated results above, it can be seen that the application of anchor plates can significantly improve the internal stability of the monolithic equilibrium of the HRERW. The safty factor is 1.2 to 2.0 times of that without considering the function of the anchor plates.

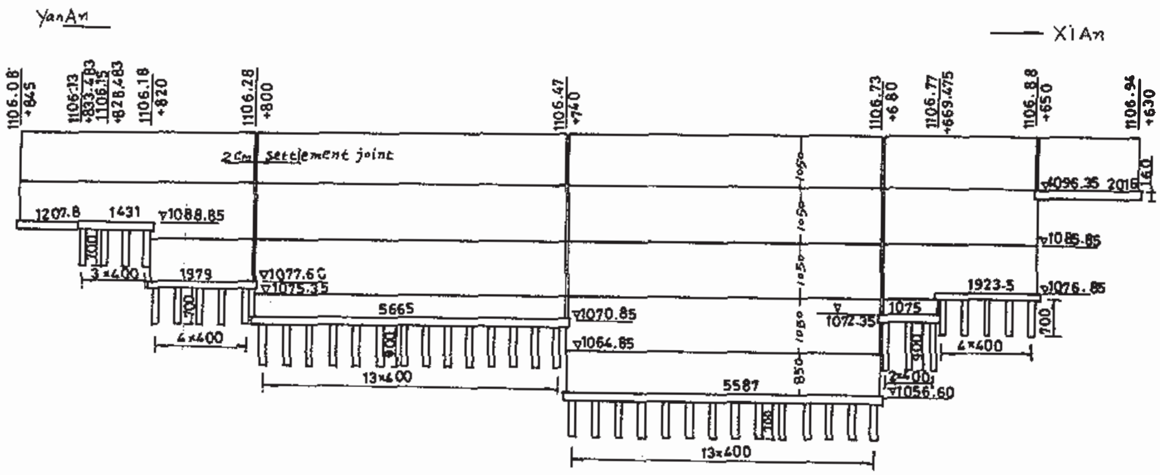
5 CONCLUSIONS

1. Where highways have to pass over ravines in the loess nodel plateau of China, sucessfull contruction of the HRERW indicates that reinforced earth retaining wall is more economical than overbridge and also more feasible. 50~100% of cost can be reduced comparing with overbridge.

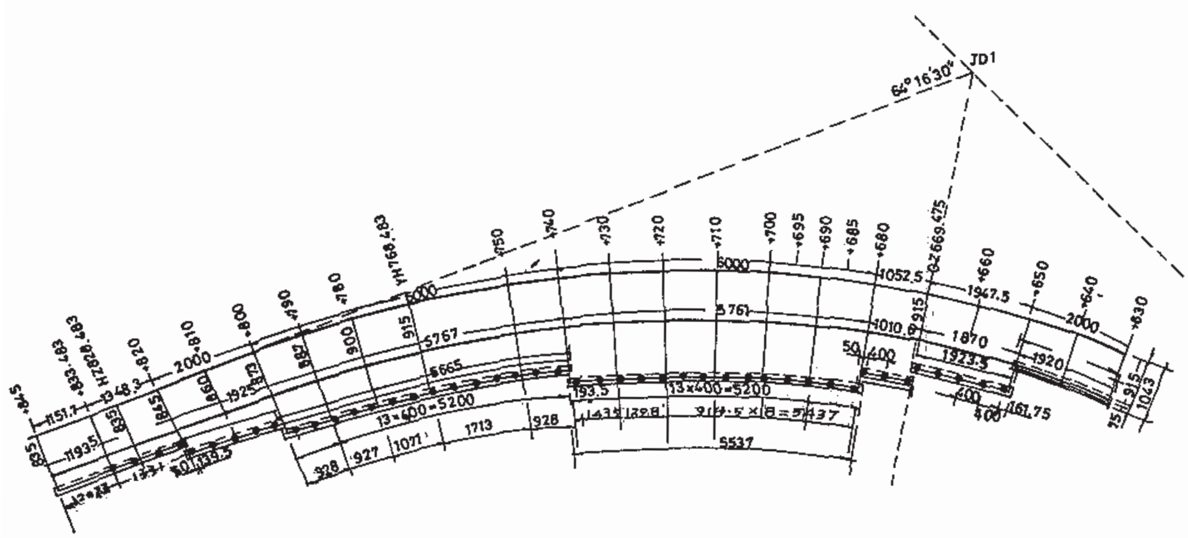
2. Monolithic equilibrium method can be used to do structural design of a very high reinforced retaining wall.

3. The special design aspects for the HRERW include ① reinforced cement concrete pile foundations, ② stepped lateral cross section; ③ the application of anchor plates at the interface between each two stages of wall mass.

4. The analysis results shows that the anchor



(b) unit: cm scale: 1:500



(a) unit: cm scale: 1:600

Fig.1(a) (b) The plane and longitudinal profiles of the HRERW

plates have significant benefit to the monlithic internal stability of the HRERW. The safty factor about the monlithic equilibrium can be increased about 20~100% by the applicationof the anchor plates.

5. The designed HRERW has been successfully builded in the last two years. The real construction period is about 14 monthes. The plane and longitudinal profiles are shown in Fig.1(a) (b).

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