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Case history study on the application of reinforced earth technology in the loess area of China

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ABSTRACT: Since 1970 s, reinforced earth technology has been used in a large scale in highway engineering, railway engineering and other civil engineering fields in China. In this paper, the application conditions of this technology for highway engineering in the loess area of the North-west of China are introduced. Some special reinforced earth retaining walls and abutments are studied.

1 INTRODUCTION

Reinforced earth is a new civil technology developed in 1960's. The constructions of reinforced earth are novel, reliable and significantly economical. In early 1970's, the modern reinforced earth technology was introduced into China and than has been developed and applied rapidly. Up to now, several hundreds of reinfroced earth constructions have been builded. The highest reinforced earth retaining wall reached up to 50.13m in height and the longest one did up to 1000m in length. In the north west loess nodel platean of China, reinforced earth technology has been developed even more rapidly. Only in ShanXi Province, have 39 reinforced earth structures been constructed. The total area of wall face is up to 47000m². It is more commendable that clayey soil could be used as backfilling materials and polypropylene plastic strips be as reinforcements. In 1991, the design and construction codes of highway reinforced earth have been issued. The CAD procedures and general drawings of highway reinforced earth are being edited. The highway engineering problems where over ravins and through steep natural grades in the loess area have been overcome by using reinforced erarth technology. Where highwsys pass over ravins, the cost of the projects can be reduced by 50～100% using reinforced earth retaining walls compared with using overbridges. Where through steep natural grades, the highway cost can be reduced by 20～60% by using reinforced earth compared with using conventional retaning wall. Moreover, reinforced earth structures can be used in some places whee conventional rigid retaining wall can not be builded because of poor soil fondation and construction height. Therefore, the road alingment can be improved and shorted and more economical benift can be obtained

2 GENERAL APPLICATION CONDITIONS OF REINFORCED EARTH

2.1 Main construction materals

2.1.1 Backfilling materials

In the North West Loess area, excepting that flyash and slag are used as backfilling materials in a few of reinforced earth structures, the local loess (yellow clayey soil) is the main backfilling matearials of most reinforced earth structures. The loess is a very special clayey soil being distributed in a large area of about 640,000km². The main engineering properties are shown in Table 1. The optimum compaction water content ranges from 14% to 16%.

Table 1. The physical and mechanical properties of the loess

Grading		
>0.05	0.05～0.005	<0.005
11～29	52～74	8～26

Physical and mechanical properties							
Specific Gravity	Dry Density	Void Ratio	Water Content	Pastic Index	C	φ	PH
KN/m³	KN/m³	%	%	Ip	kPa	0	
2.5～2.84	1.43～1.69	0.7～1.24	3.3～25.30	7～14	30～60	20～30	7～9

2.1.2 Reinfrocements

The reinforcements used in most reinforced earth projects are polypropylene plastic strips with the thichness of about 1mm and the width of 18mm. The mechanical properties are shown in Table2.

Table 2. The mechanical properties of polypropylene plastic strips

Tensile modulus,	MPa	110~160
Fatigure strength(10⁷cycles),	MPa	11~22
Brittle temperature,	℃	0~35
Rupture strength,	MPa	127~276
Tensile elongation,	%	10~20
Design tensile strength,	MPa	30~50

For the used steel strip reinforcements, the specified minmum thickness and width are 4mm and 40mm respectively in the design code. In the North west area, steel strips only need being oil painted for preventing crossion because of the dry and less rain wether. The used steel material is normally A_3 steel with the elastical modulus of $2.5 * 10^5$ MPa and permissible tensile strength of 135MPa. Waisted steel strips also have been used in a few of projects.

In addition to using polyproplylene plastic strips and steel strips, reinforced cement concrete bars also have been used in a few of reinforced earth structures.

2.1.3 Wall face panels

Wall face panels used in Chian are normally pre-cast reinforced cement concrete slabs. The forms of wall face panels may be rectangle, cross or hexagon.

2.2 Some cases of reinforced earth structures builded before

In the North-west loess area, reinforced earth technology has been used in highway, railway, water conservancy, mine engineering. Some highway projects cases are shown in Table 3

Table 3. Some cases of reinforced earth structures builded before in the loess area

Date	Location	height (M)	length (M)	wall face panel	R-type	memo
80	LingChuan	12		R40*80	RC	Mine
80	TianBa			C80*80	P	Mine
83	YanAn	11	180	C80*80	P	
83	LiuShuGou	25	90		P	
84	BaoJi	8.0	79	H60*60	P	
84	KuYi	35.5	75	R40*80	P	
87	TaiPintGou	28.7	230	H45*45	P	Double side
87	WuJiaYuan	13	68		P	
87	ChangZhi	18.2	80		P	Double side
88	BianQiao	17	840	C80*80	P	Double side
88	ChenJiaWa	23	126		P	
89	XiBaoXian	7.8	315	C	P	Double side
89	XiBaoXian	23.39	126	C	P	Double side
91	HuangLing	17.98	31.8	R	RS	
93	ShenRen	24.16	24	C80*100	P	Abutment
	Jian	28	31	C80*100	P	Abutment
94	Yulin	17	18.0	R	S	In Flood Land
	Yulin	17	208	R	S	Double side
95	LuoChuan	50.13	213	R75*75	RS	

Note: 1. The backfilling materials of the TianBa retaining wall are slag and that of others are the local loess.
2. R-type: the type of used reinforcements; P-propylene plastic strips; S-steelstrips; RS-ribbed steelstrips. RC-reinforced cement concrete bar.
3. Wall face panel: C-Cross, R-rectangle, H-hexagon. X*Y--the height of the panel is X and the length of that is Y.

3 INTRODUCTION OF SOME SPECIAL PROJECTS

3.1 Kou Zhen and Fu Xian test reinforced earth retaining walls

Since 1982, the application of reinforced earth technology has been extended by ShanXi Province. For good application extension of reinforced earth technology, the highway administration builded two special reinforced earth reatining walls as test walls in order to obtain design and costructuion experiences of reinforced earth structures. KouZhen test wall has the length of 180m and average height of 5.5m, maxiumum height of 9m. The local loess was used as backfilling materials and polypropylene plastic strips, reinforced cement concrete bars and wasted steel strips were used as reinforcements. The size of wall face panels is 32×100cm and the reinforcement horizontal and vertical spaces are 0.3 and 0.5m. The cross section of the polypropylene plastic strips is 16 * 0.7mm with the ultimate rupture force of 2500N per strip and the design permisible force of 500N per strip and the rupture elongation of 14%. The cross section of reinforced cement concrete reinforcements is 120 * 80mm with the permissble design strength of 135MPa. The cross section of the wasted steel strip is 30*60mm with the permissble strength of 135MPa. During the construction period of the reinforced earth retaining wall, the reinforcement tensile force, pullout resistant force were measured and loading test of the constructed wall was carried out.

For the lateral cross section of 9m in height, the length of the polypropylene plastic strips is 7, 6, 5, 4m; the length of the reinforced cement bars is 3, 4.5, 3m and that of wasted stell strip is 4m depanding on the depth of the reinforcement.

FuXian test wall is 138m in length and 12.91 in height in a river flood land. The backfilling materials are the local loess. The reinforcements are polypropylene plastic strips with the cross section of 18*1mm and tensile strentth of 50 kPa and the rupure elongation of 20%. The wall face panels are cross pre-cast cement concrete with the size of 90×100cm and the horizontal and vertical spaces are 0.6 and 0.44m. During and after the construction of the wall, soil pressure and reinforcement force were measured and loading test of the wall was carried out.

The length of reinforcements is 7m (from 0～4m in depth), 6m (from 4～6.6m) and 5m (from 7～12.91m).

The design and construction experiences and test data have been very helpfull and usefull for the extension of the application of reinforced earth technology in loess area. Up to now, these two walls has been working very well.

3.2 Shen Ren Jian reinforced earth abutments

In 1990, ShanXi province highway administration builded two reinforced earth bridge abutments at the Shen Ren Jian bridge. The reinforced earth abutment in one end of the bridge is 28m heigh and 31m long, one in the orther end is 24.66m heigh and 24m long. These two bridge abutments are comparatively high reinforced earth abutments using polypropylene plastic strips as reinfocements and loess as backfilling materials. A great deal of cost of the bridge project was reduced by using reinforced earth technology.

The used reinforcement has the cross section of 18 * 1mm and permissible strength of 50KPa. The horizontal and verical reinforcement space are 0.42m and 0.4m respectively. The wall face panel are cross pre-cast reinforced cement concrete slab with the size of 800 * 1000mm and the thickness of 250mm.

The length of the reinforcements is 16, 14, 12, 10m depanding on the depth of the reinforcements in the reinforced earth.

3.3 Double side reinforced earth retaining wall

During 1987-1989, a double side reinforced earth retaining wall has been constructed at the national highway line 210. The height of the wall is 23.39m and the length is 200m. Pre-cast cement concrete wall panels with the thickness of 140mm and polypropylene plastic strips were used. The backfilling materials was also the local loess soil.

The pavements are asphalt construction with the width of 9m. The double side reinforced earth retaining wall has been working very well up to now excepting that local settlement occered in the central part of pavements.

3.4 Luo Chuan reinforced earth retaining wall

The maximum height of Luo Chuan reinforced earth retaining wall is 50.13m and the length is 213m, which is the highest one in China now. The wall has been ust builded in last two years. A steped lateral cross section was used. The length of the step at the interface of each adjancent stages of wall mass is 1.5 m. At the interface, anchor plates were used to strengthen the monolithic stability of the wall and make good contact between the backfilling materials and the existing soil. The reinforcement lentgth in the first stage wall mass(top one) is 10m, 8m in the second stage wall mass and 6m in the third, forth and fifth stages of wall masses. The wall face panels are pre-cast cement concrete slab with the plane size of 750 * 1250mm and both horizontal and vertical reinforcement space is 750mm. In cooperating the design and construction of the wall, a great deal of research work has been carried out including model reinforced earth retaining wall test in the laboratory of the department of road and traffic engineering of TongJi University, performance survey of the wall during and after the construction. Vaulable design and construction experience and a great deal of test and analysis data about the application of very high reinforced earth retaining wall have been obtained from the contruction of the very high reinforced retaining wall.

4 CONCLUSIONS

1. In the North-west loess area, significant economical effects can be obtained by using reinforced earth technology. Compared with conventional retaining wall, 20%～60% of project investment can be reduced. Where highways pass over through ravins, 50～100% of project investmant can be reduced compared with overbridge. Since reinforced earth retaining wall face can be construcoted to be nearly vertical, highway construction land can be safed compared with embankment slope.

A lot of difficult engineering problems could be overcome by using reinforced earth technology. The use of reinforced earth technology in the North-west loess area of China indicated the adavantages of reinforced earth structures.

2. High and very high reinforced earth retaining wall and bridge abutments (>20m in height) can be builded using polypropylene plastic strips as reinforcements and the local loess as backfilling materials. The builded reinforced earth structures have very good stability and enough load bearing capacity. However, the wall face displacement of most reinforced earth retaining wall is comparetively big because of the creep deformation of polypropylene plastic strips. The existing wall face displacement shows a "Drum" type curve and wall face panel dislocation can be caused by the displacement.

3. Most of reinforced earth structures constructed before have been woking very well. Only a few of reinforced earth retaining walls are failue. If the height of reinforced earth structures is greater than 20m, the application experience indicated that steped lateral cross section should be used and anchor plates may be used too, which are very benificial to the monolithic stability of retaining structures.

4. From the application of reinforced earth technology, a great deal of experience of the design and construction of high or very high (20～50m) reinforced earth structures has been accumulated. However, the design theory and structure mechnical analysis method is still lacking for the design of high or very high reinforced earth structures. The performance survey and laboratory model test research results have shown that the design method developed in the existing design specification could no be used to design high or very high reinforced earth structures. The assumptions about the failure surface and stress, strain and displacement of reinforced wall

masses made in the specification design method can not duplicate the real state of high or very high reinforced earth.

5. Where the reinforced earth structures are builded in the loess nodel platen, attentions should be especially payed to the draiange system design for resinforced earth structures. During construction, backfiling soil compaction density should be cotrolled. Eventhough reinforced soil structures are considered to be flexible ones which can bear a certain displacement, a suitable foudation is also needed to be constructed for reinforced earth structure.