International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
 ISBN 90 6191 820 0

Experimental study of reinforced-earth wall

Zhonglun Shi & Mingde Cheng
Fourth Survey and Design Institute, Ministry of Railways, Wuhan, People's Republic of China

ABSTRACT: From a large number of model and full-scale testing data, this paper has analyzed the force acting on the reinforced-earth wall and deformation features and also has presented a design and analysis method of reinforced-earth wall.

reinforced-earth wall has several advantages : light weight, good appearance , flexible to deformation and wide application , also its construction is simple and efficient, taking less land and costs.So it develops rapidly and tends to replace gravity retaining wall . However, the functional mechanism, the load state of structure and design and analysis method etc.are still under study. For further understanding to this structure,based on the actual condition in china , full-scale tests and laboratorial model tests have been carried out A large number of actual data has been obtained. Through comprehensive analysis, a conclusion could be drawn as follows. (Owing to the limitation of the testing data , the conclusion is only appropriate to the retaining wall less than 10 m high.)

1 DETERMINATION OF SOIL COLUMN STRESS IN REINFORCED-EARTH WALL MASS

It could be seen from Fig 1, the actual soil column stress varies in direct proportion with the fill height, and it approaches the theoretical value rh, so rh is adopted.
The supplemental soil column stress due to the load could be seen in Fig 2. Comparatively the actual value approaches the elastic theoretical value. So supplemental influence of the load could be suggested to be considered with distributed angle method.
By the superpose theory,the soil column stress in the reinforced-earth wall mass is the sum of soil column stress caused by soil mass and supplemental stress caused by load.

2 LATERAL PRESSURE ACTING ON REINFORCED-EARTH WALL FRONT PLATES

Different testing conditions produce different results (Fig 3) . However , according to the actual data from the full-scale wall, the lateral pressure distribution pattern is approximately consistent: the distribution of the upper part of the retaining wall is approximately linear , and it approaches the static soil pressure; the distribution of the lower part is in broken line . Because of the loose backfill and the difference of construction conditions between the model wall and the full-scale wall , while the supports being demolished,the deformation occurs in the whole wall mass.the lateral pressure is approximately linear along the wall height , and it is higher than the active soil pressure. Besides, the wider the strips are,the heavier the front plates will undertake.
According to the above-mentioned data , to the full-scale wall, the lateral pressure acting on the front plates without loading could be simplified for calculation by Fig 4.
The composite force of the simplified lateral pressure is larger than that of the actual lateral pressure,only the actual stress of the local site in lower part is larger than the simplified value, and it is also larger than the Coulomb's active soil pressure (1.18 times).
The comparative curve of the load to the lateral pressure is illustrated in Fig 5.
The actual result approaches the theoretical value of the elastic subgrade,its distribution pattern is also similar.Considering the insuf-

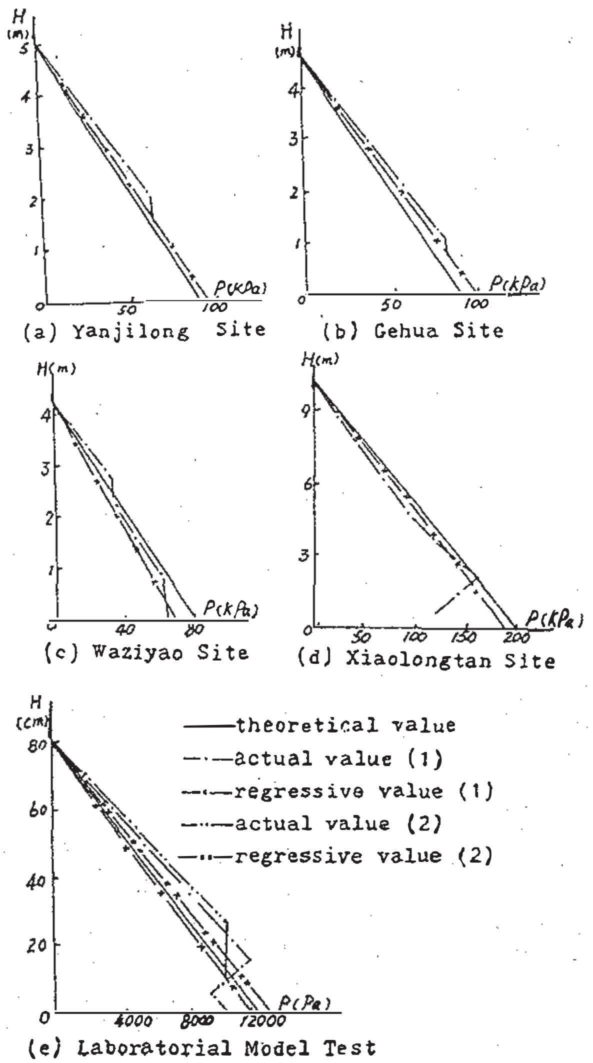


Figure 1. Distribution curves of soil column

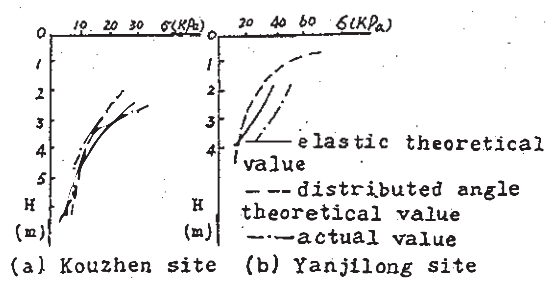


Fig. 2. Stress curves of soil column resulted from load.

ficient data of this respect, a suggestion would be to calculate the supplemental influence of loading to the lateral pressure acting on the front plates with the elastic subgrade theory. So the design load of the front plates on the reinforced-earth wall would

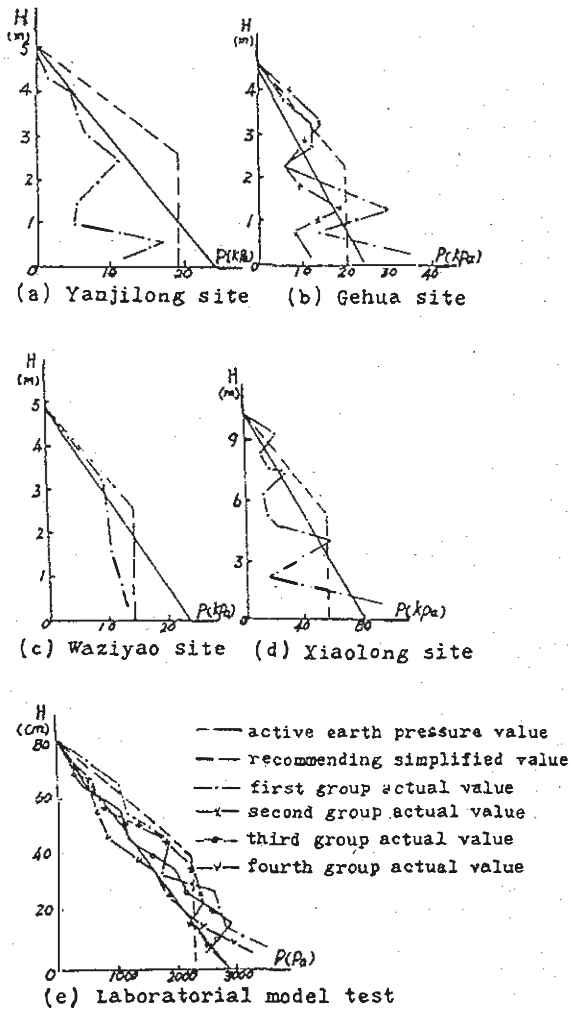


Fig. 3. Distribution curves of lateral pressure on the front plates.

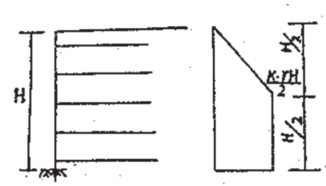


Fig. 4. Simplified distribution curve of lateral pressure due to backfill.

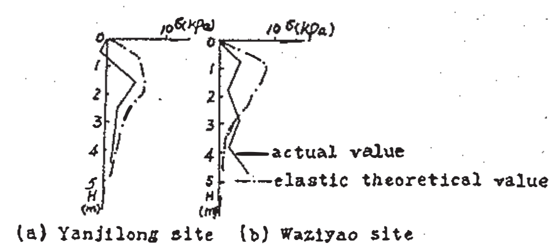
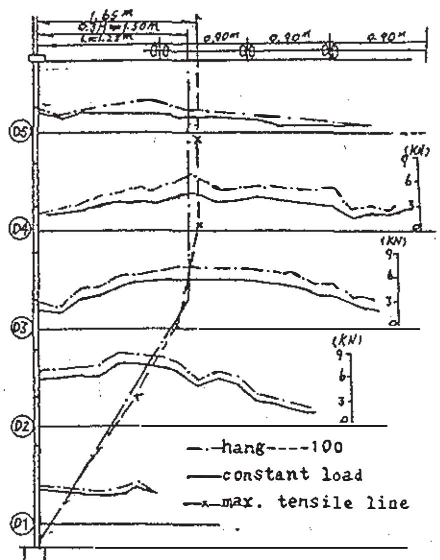


Fig. 5. Additional lateral pressure and stress curve due to load.

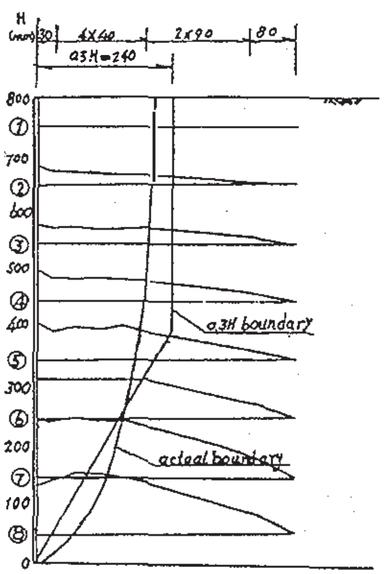
Table 1. A comparative table of the lateral pressure on the corresponding plates. (actual value)

order	Model test										Waziyao site					Yanjiliang site		
	20x2x450mm strip					50x2x450mm strip												
	E	T_o	T_{max}	T_o/E	T_{max}/E	E	T_o	T_{max}	T_o/E	T_{max}/E	E	T_o	T_{max}	T_o/E	T_{max}/E	E	T_{max}	T_{max}/E
1	7.8	15.0	22.9	1.92	2.94	20.6	20.0	24.1	0.97	1.17	5800	3500	3700	0.92	0.97	4290	16494	3.85
2	21.3	21.0	24.9	0.99	1.17	25.3	27.0	30.7	1.16	1.32	5500	2500	6200	0.42	1.13	5850	16260	2.78
3	24.4	21.0	32.3	0.86	1.32	38.5	40.0	42.2	1.04	1.10	7000	3000	7000	0.43	1.0	3430	21850	6.37
4	37.8	43.0	55.4	1.14	1.47	34.3	45.0	56.6	1.31	1.65	5500	6300	8300	1.15	1.51			
5	43.8	63.0	70.3	1.44	1.61	52.0	63.0	70.2	1.21	1.35	9000	4300	5000	0.48	0.56			
6	57.2	62.0	69.6	1.08	1.22	55.4	80.0	101.2	1.44	1.83								
7	50.4	59.0	64.9	1.17	1.29	69.3	85.0	106.1	1.23	1.53								
Σ	242.7	284.0	340.5	1.17	1.40	295.4	360.0	451.1	1.23	1.47	30800	19600	30200	0.65	0.98	13580	54600	6.04

Note: E is the lateral pressure (actual value) (N) applied to the plates.
T_o is the tension of the connecting place between plates and strips (actual value) (N)
T_{max} is the max. tension (actual value) (N)



(a) Waziyao site



(b) 50x2x450mm in model test

Fig. 6. Tension distribution

Table 2. A comparative table of actual max. tension in model test to the designing lateral pressure on the corresponding layer of the plates.

order	12x8x450mm strip			20x2x450mm strip			30x2x450mm strip			50x2x450mm strip		
	E_d	T_{max}	T_{max}/E_d	E_d	T_{max}	T_{max}/E_d	E_d	T_{max}	T_{max}/E_d	E_d	T_{max}	T_{max}/E_d
1	17.3	15.4	0.89	17.3	22.9	1.32	17.3	15.6	0.90	17.3	24.1	1.39
2	28.8	20.9	0.73	28.8	24.9	0.87	28.8	32.6	1.13	28.8	30.7	1.07
3	40.4	29.5	0.73	40.4	32.3	0.80	40.4	36.4	0.90	40.4	42.2	1.05
4	46.1	43.6	0.95	46.1	55.4	1.20	46.1	55.3	1.20	46.1	56.6	1.23
5	46.1	47.5	1.03	46.1	70.3	1.53	46.1	57.4	1.25	46.1	70.2	1.53
6	46.1	54.2	1.18	46.1	69.6	1.51	46.1	69.5	1.51	46.1	101.2	2.20
7	46.1	63.8	1.38	46.1	64.9	1.41	46.1	69.3	1.50	46.1	106.1	2.30
Σ	270.9	274.9	1.02	270.9	340.3	1.26	270.9	336.1	1.24	270.9	431.1	1.59

Note: 1. E_d is the simplified value.
2. Unit: N.

be considered as the sum of the lateral pressure caused by the backfill itself (simplified value) and supplemental lateral pressure caused by load(an elastic subgrade theoretical value).

3 DISTRIBUTION AND MAGNITUDE OF STRIP TENSION

The distribution of the strip tension is in curves along the length direction. The distribution curve of the tension of the full-scale wall presents waved due to the order of compaction by rolling and the soil nature. In the model wall, because of the even backfill , its distribution curve is parabolical. To the same strip, the increase scale varies in inverse proportion with the fill height.while with the backfill on the top, the tension increases accordingly. The tension varies in inverse proportion with the baried depth, in direct proportion with the load.

4 BOUNDARY DETERMINATION OF STRIPS IN ACTIVE AND PASSIVE AREA

According to the actual data , smoothly connecting sections with the maximum tension on each layers,then "a potential failure surface" could be obtained as shown in Fig 6.Inside the failure surface is defined as a passive area, and outside as an active area . Its shape is similar to the common " 0.3H method ".

5 DETERMINATION OF DESIGN EXTERNAL TENSION OF STRIPS

By the current design method , the tension T_o of strips at the joint of the front plates should be equal to the lateral pressure E acting on the corresponding wall plates.maximum tension T_{max} should be greater than E . The actual results are shown in Tab 1. In the full-

Table 3.

order	Yanjilong site			Gehua site		
	E_d	T_{max}	T_{max}/E_d	E_d	T_{max}	T_{max}/E_d
1	6.7	12.5	1.87	5.4	4.8	0.89
2	10.5	14.3	1.36	9.5	4.5	0.47
3	10.5	18.9	1.80	9.7	10.2	1.05
Σ	27.7	45.7	1.65	24.6	19.5	0.79

Note: Unit is KN

Table 4. Actual displacement at plates on the retaining wall

Site name	H	Δmax	Δmax/H
Gehua	4.5	1.57	0.35 ‰
Yanjilong	5.0	1.1	0.22 ‰
Kouzhen	7.0	4.0	0.57 ‰
Waziyao	5.0	5.66	1.13 ‰
Daqin bridge	3.5	0.42	0.12 ‰
Model test	0.8	0.5 (50x2x450)	0.63 ‰
		1.28 (20x2x450)	1.6 ‰

scale wall, owing to the errors of the measurements and the insufficiency of the actual data, its behavior is not very obvious, additional data are required. In the model wall, its behavior is clear. Although the corresponding E and T. have differences due to the interactions between the plates, comparatively speaking, they are almost equal. To the whole wall, the ΣT. / ΣE is approximately 1.1 to 1.2, from the viewpoint of the entire wall the T_{max} is larger than the corresponding E, $\Sigma T_{max} / \Sigma E$ of the whole wall is approximately 1.2 to 1.5. Therefore, a conclution could be drawn that the current design method has been verified by the model.

A comparative value about the actual maximum tension and the corresponding design lateral pressure of the plates in the model test and in site is listed in Tab 2 and 3.

In the model test, almost all their rates are larger than 1.0, only some values are between 1.02 to 1.59. But in the full-scale test, there are great differences. Considering the limited number of the full-scale test sites and the inconsistency of conditions on each site, further information is to be obtained.

According to a comprehensive analysis to the above-mentioned data for safty, two times of the lateral pressure of the plates would be suggested to be the design load of strips in the calculation.

6 DISPLACEMENT OF WALL MASS

The displacement of the wall mass in site and model test is shown in Tab 4.

The horizontal displacement of plates is very small after the completion of the reinforced-earth wall with backfill. Besides the filling soil nature and the density of compaction by rolling, factors influencing the displacement of the reinforced-earth wall have direct relation with the number of strips.

According to the distribution of plate displacement scale on each layer along the wall height, the upper displacement scale is usually larger than the lower, and the upper is mainly a horizontal displacement . The lower is very small, and could be considered as a rotation.

7 DETERMINATION OF TENSILE STRENGTH OF STRIPS

The tensile strength is determined by the tensile testing. As strips are undertaking an upright pressure from the filling around . the tensile strength has a relation with the friction between the strips and the filling. Besides that , owing to tbe tamping and compaction by rolling to the filling around , a meshing force is added to strips under the horizontal tension condition. So the tensile strength T is a combination of friction and the meshing force. The frictional resistance only varies with the fill height h, the meshing force is a constant. Then

$$T = ah + b$$

In this formula, T could be expressed as the linear function of h. So by means of the linear regression and the testing data, the tensile strength of strips could be determined.

8 DAMAGES OF REINFORCED-EARTH WALL

Through a large amount of loading stability tests in model wall, the damages of the model wall could be classified in three catagories as follows.

8.1 Damages due to the excess deformation

This kind of damage mainly appears in narrow strips or in the loose filling model wall or when the backfill is on the end of the wide strips. The damage features are: the displacement of the wall surface is convex. The place with loading has a considerable settlement. The boundary of the damage area is not clear . The sliding surface is approximately determined by the displacement trace of the filling: it is a logarithmic spiral passing through the rear edge of loading and the wall bottom.

8.2 The landsliding damage of the wall mass

This damage only appears in the model wall

with loading acting within the strip length and the filling at high density.Under the condition of loading , a sudden landslide will occur in the wall . The whole wall only has a little deformation and could bear much backfill before the damage.
It could be known from the tests that the wall's bearing capacity is in direct proportion to the filling density as well as the dimension of strips, and it is in inverse proportion to the wall height.Simulating tests have verified that the ultimate bearing capacity of the reinforced-earth wall designed by the current design method is several times greater than the design load.

8.3 Damages due to the insufficient strength of units

The damage appears when the section of a strip is wide, the filling is loose and the backfill is acting on the top of the wall . The tensile strength of the strips of the reinforced-earth wall is larger than the bearing capacity of the unit itself.When the unit breaks,the plate falls off, as a result of that, plenty of filling runs off from the place with plates fallen off, hence damages the wall. these damage types are, of course, obtained from the model tests.Being confined by conditions, there probably exist some differences from the full-scale wall damages. However, these tests present such a regular pattern:
when other conditions are invariable, the more compact the filling is,the greater the bearing capacity of the wall will be, and the less the deformation will be . So suggest that: in the construction of the reinforced-earth wall, strictly control the quality of compaction by rolling and ramming for the filling, so as to meet the design requirements with a desired density.