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Laboratory model test and research of the reinforced-earth wall

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ABSTRACT: According to a number of model tests and data analyses this paper shows the working stress, deformation and stability property of wall mass for the reinforced-earth wall.

1. PURPOSE

Reinforced - earth wall has been widely applied in practical engineering, but its working stress, deformation are still not understood completely, the design and the calculation used for the structure are not consistent and perfect. The laboratory model tests upon the reinforced-earth wall have been made in order to make further the mechanism clearer, to find out the magnitude of tensile force at the reinforcing elements of soil mass, its deformation behaviour and stability, and to verify and improve the current design and calculation methods. The model test was divided into two parts: the actual working behaviour and the stability of reinforced-earth wall.

2. TEST EQUIPMENTS AND METHOD

2.1. The model test for the actual working behaviour of reinforced-earth wall

The test was carried out in the experimental tank with 1500x1700x1300, the wall areas were 1500x800mm. The front plates and the strips were made of the plexiglass, fill material was a machine-processed quartz sand, its mechanic overall index are $\phi = 38^\circ$, $\gamma = 15t/m^3$. Under the condition of supporting by the special angle steel, the model wall was built up alternatively by filling with sand, installing front plates, laying strips and placing instruments. When all the above work was finished, we demolished the supports and started to measure the bearing capacity of wall mass untill the measured values tend to be constent.

2.2. The model test for the stability of reinforced-earth wall

This test was similar to the above one. The area of model wall was 1500x800mm or 1500x600mm. The model wall was filled up after the measuring plate with 50x50mm grid graph drawn by toothpaste was sticked at the both sides of test tank. After the model wall was built up according to the design, loading units (loading beam, synchronous jack) were placed. Then, the supports were demolished and the loading was performing untill the wall was broken.

3. DATA PROCESSING AND ANALYSIS

3.1. The model test for the actual working behaviour of reinforced-earth wall

3.1.1. Lateral pressure applied to the front plates

The overall table of lateral pressure (average value) could be deduced from a number of actual measured data, and then the relative distribution curves were drawn out (Fig 1).

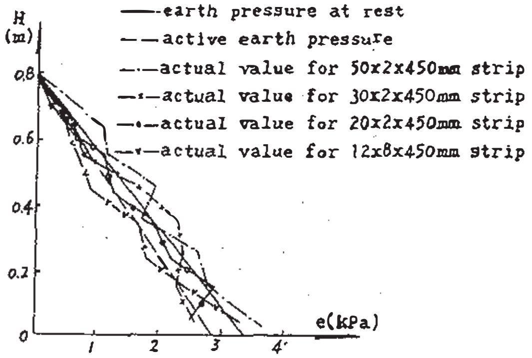


Fig 1. Lateral pressure distributed curves

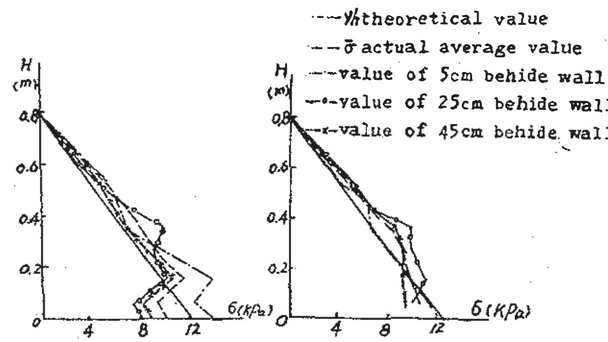
As shown in Fig 1,the lateral pressure applied on the wall face presented the curve distribution along the height of the wall. Because of a significant difference between the model wall and the in-situ reinforced-earth wall (mainly the front plates of model wall were built up by supports and the wall face was laid on rigid foundation), the wall produced the overall displacement after demolishing the supports. The lateral pressure was similar to that which happened before demolishing it, and the distribution pattern of lateral pressure of model wall was different from that of the full-scale reinforced-earth wall.

Also Fig 1. shows that the lateral pressure applied on the front plate bears a relationship to the cross section of strips.For the isopachous strips, the wider the strip was, the higher the lateral pressure would be. For the model wall built up with 12 x 8 x 450mm strips , the pressure applied on the front plates was the minimum. This was due to the fact that the interface of both the faces of strip and the fill material was small, and the vertical stiffness of strip was relatively high, it caused the partial bottom face of strip not to be close up to the fill material, which has influenced the monolithity of the reinforced-earth wall. This means that the better the monolithity of reinforced-earth wall is , the higher the lateral pressure applied to the front plate will be.

The above analysis indicated the optimal design of how to select the cross section of strip and its laying density in the design of the reinforced-earth wall is to be further explored.

3.1.2. Soil column stress in the reinforced-earth wall mass

The overall table of soil column stress (average value)was collected and its distribution curves were drawn out in Fig 2.



(a) 50x2x450mm strip (b) 12x8x450mm strip

Fig 2. Soil column stress distribution curves

As shown in Fig 2, the actual stress of soil column mainly presents a linear distribution along the heigh of wall and is about 20% higher than the theoretical value, but the actual value measured in the bottom layer of the front plates obviously decreased.During the built-up of the model wall, the above distribution pattern was observed when the height of wall was about 40cm. How to explain this kind of distribution has to be waited.

Fig 2. also shows that, for the wall built up with 50x2x450mm strips, the actual pressure of soil column near the front plate was higher,which was determined by the construction method; for the model wall filled with sand by the free-falling method, the area near the front plate needs to be tamped because of hollow hole due to the wider strips, and this leads the area to be denser, so after having demolished the supports the displacement of the front plates was small and it had no evident influence on the density. That determined the magnitude of stress distribution. In the model wall built up with 12x8x450mm strips,the stress of soil column near the centre of strip was high, this was due to the fact that a great displacement occured on the wall face after demolishing the supports, the density of the filling sand near the front plate decreased and led the strip to act as a dis-

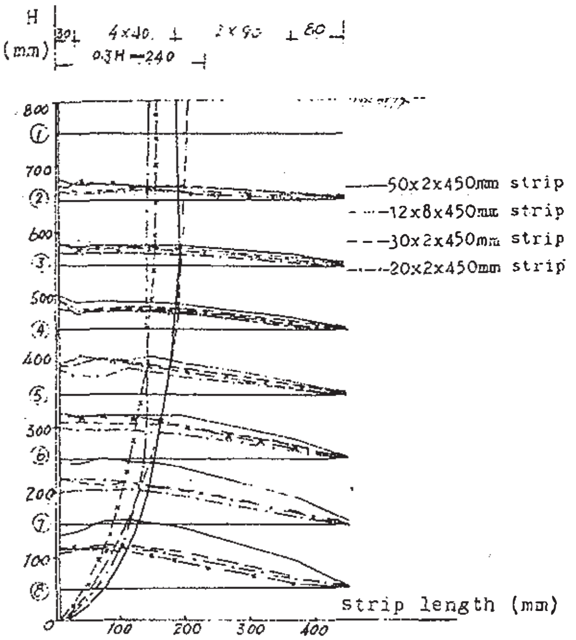


Fig 3. Strip tension distribution curves

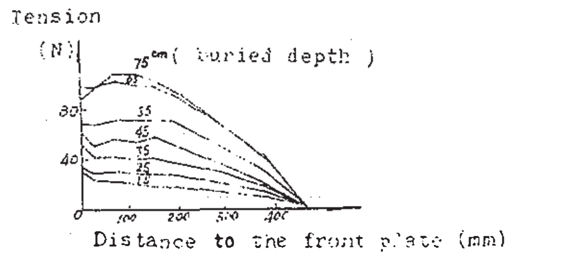


Fig 4. Comparison of the forces acting on the different layers of strip (50x2x450mm)

charging beam, it made the stress of soil column in this area reduced and that outside the centre of strip increased, so that the above mentioned distribution pattern was formed.

3.1.3. Stress applied to strip

The tension distribution curves of strips could be drawn out according to the actual results measured (Fig 3).
As shown in Fig 3, when the strip was shallow-buried, the distribution of tension within a certain length near the front plate was horizontal, which indicates that the horizontal distribution force is not fully mobilized and the tension at the end of strip is reduced gradually to zero; when the strip is deeply-buried, the tension along the length of strip primarily was a parabolical distribution. Linking smoothly the sections of minimum tension, the so-called " potential failure surface " is obtained, which approaches the normally called "0.3H failure surface ".
It is also seen from the figure, the magnitude of the tensile stress of strips bears a relation to the section, The wider the section is, the higher the tensile stress will be. This means the value of stress horizontally distributed on the strip is referred to the interface between the strips and fill material,and its relationship is in direct proportion. In addition, as the height of fill material increased at the top of strip, the strip tension become relatively high. As shown in Fig 4,the magnitude of horizontal component applied on the strip bears a relation to the overburden pressure.
The above mentioned analyses show the horizontal component applied on the strip is approximately propertional to the height of fill material and the width of strip under the condition of the loose fill material. It indicates that the above situation is mainly caused by the friction between the soil and the strips.
Moreover, as the joint between the strip and the front plate is undesired, the partial strip near the front plate has a phenomenon of stress concentration, which results in the measured value being relatively high.

3.1.4. Wall mass displacement

The actual displacement curve of the wall face is shown in Fig 5. The model wall under this spacing of strips has primarily formed a composite massif. Its upper deformation is mainly the horizontal displacement, while the lower deformation is considered as a "rotation".
As shown in the Fig5,the displacement of the wall was affected by the number of strips,the more the number of strips are,the less the displacement will be. It also indicates the more the number of the strips are, the better the monolithity of the mall mass will be obtained.

3.1.5.Relationship between the strip tension and the lateral pressure acting on the front plate

Theoretically, the tension at the joint of strip and front plate is

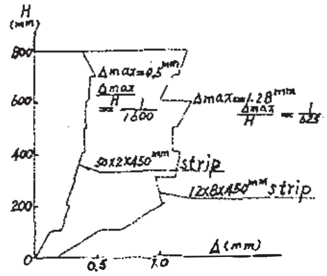


Fig 5. Actual displacement data of wall after demolishing the wall

Tab 1. Comparison of actual laterial pressure and tension on the model wall with different strips

Layers	12x8X450mm strip						20x2x450mm strip						30x2x450mm strip						50x2x450mm strip					
	E	T_0	T_0'	T_{max}	T_0'/E	T_{max}/E	E	T_0	T_0'	T_{max}	T_0'/E	T_{max}/E	E	T_0	T_0'	T_{max}	T_0'/E	T_{max}/E	E	T_0	T_0'	T_{max}	T_0'/E	T_{max}/E
2	10.1	15.0	12	15.4	1.19	1.52	7.8	18.9	15	22.9	1.92	2.94	11.2	22.4	12	15.6	1.07	1.39	20.6	32.4	20	24.1	0.97	1.17
3	14.7	23.7	18	20.9	1.22	1.42	21.3	31.0	21	24.9	0.99	1.17	15.5	32.6	28	32.6	1.81	2.10	23.3	33.9	27	30.7	1.16	1.32
4	17.7	36.5	25	29.5	1.41	1.67	24.4	42.7	21	32.3	0.86	1.32	34.2	49.4	31	36.4	0.91	1.06	38.5	52.9	40	42.2	1.04	1.10
5	37.0	39.6	32	43.6	1.00	1.36	37.8	47.5	43	55.4	1.14	1.47	45.8	46.5	43	55.3	0.94	1.21	34.3	61.4	45	56.6	1.31	1.65
6	36.8	50.5	45	47.5	1.22	1.29	43.8	71.8	63	70.3	1.44	1.61	47.4	57.8	51	57.4	1.08	1.21	52.0	68.0	63	70.2	1.21	1.35
7	47.4	50.5	48	54.2	1.01	1.14	57.2	72.7	62	69.6	1.08	1.22	45.1	73.8	55	69.5	1.22	1.54	55.4	95.6	80	101.2	1.44	1.83
8	65.8	61.7	61	63.0	0.93	0.97	50.4	61.9	59	64.9	1.17	1.29	51.5	61.5	60	69.3	1.17	1.35	69.3	86.4	85	106.1	1.25	1.53
Σ	224.9	277.3	241	274.9			242.7	346.5	284	348.3			250.7	344.0	280	336.1			293.4	430.6	360	431.1		
					1.07	1.22					1.17	1.40					1.12	1.34					1.23	1.47

Not. E-- Actual laterial pressure acting on the front plate(N)

T_{max}--Actual maximum tension of strip(N)

T_0 -- Actual tension at the joint of strip and front plate

T_0' -- T_0 Analyzing velue

equal to the relative lateral pressure acting on the front plate. In the test there was an influence of stress concentration was deducted according to the stress state , revising the actual results, and then the comparative table of the actual lateral pressure and the strip tension on the adopted strips could be obtained (Tab.1).

As shown in Tab.1, the sum of actual tension of the strips near the front plates was about that of the actual lateral pressure of the relative front plate, and the difference was only 10-20%. The sum of actual max tension measured on various strips was about 1.2-1.5 times greater than that of actual lateral pressure of the relative front plate. To a single strip and its corresponding front plate, there was a certain difference between the tensile force T and the lateral pressure E, some even a great difference. This was probably caused by the interference among the front plates. It should point out that the model wall on some tests was calculated according to the current design method and its stability factor was less than 1. This shows that the current design theory is rather conservative.

3.2. Model test of stability for the reinforced-earth wall

According to the test results, the failure of the model wall was divided into three types.

3.2.1. Failure formed due to the large displacement of wall mass

This type of failure mainly appeares in the case of the model wall with the narrow strips or with loading at the end of wider strip, or with a loose fill material. The characteristics of failure were that, under the condition of load, the wall face was in convex, the high settlement of fill material occured at the loading beam, which obviously displaced with the fill material. There was a obvious slickenside on the measuring plate but no apparent boundary line there, the overall slip surface was primarily a logarithmic spiral which crossed over the rear edge of the load beam and the spring of retaining wall. The failure was similar to that of subbase, there was only a difference that the side of wall face was an open-to-space and there were some strips in the reinforced-earth wall mass.

3.2.2. Failure due to the collapse of wall mass

It occured in the range of length of strip subjected to load and in the model wall with the great density of fill material. Under the condition of the load, the retaining wall was suddenly collapsed, but the overall wall only had a little deformation before the collapse. The characteristics of failure was extremely similar to that of the wall with the brittle material. To simulate a reinforced-earth wall in 9m high, the loading test was performed on the model wall built up with the strip which was equal to point six five times of the height of the wall. When the actual distributed spacing of strips was 1/8 defined by the design, and the fill is sand of medium compactness (Dr=57.6%), the limit bearing capacity of retaining wall was three times greater than the relative design load. If the wall was built up according to the current design theory and the construction requirments, its bearing capacity will increase by ten times. This means that the current design theory is conservative.

3.2.3. Failure due to the lack of the strength of elements

It appeared in the case that the section of strip was rather wide, the fill material loose and the load was applied on the top of retaining wall. The failure characteristics were that, under the condition of the load, the settlement of loading beam was relatively large, and the displacement of wall face was small. The front plates at the top were broken out. The front plate have come out where the fill material ran off seriously, and the bearing capacity of wall was relatively high, which normally was monitored by the strength of elements For the reinforced-earth retaining wall which produces this failure, its pull strength is greater than the strength of elements, so that the elements broken first.

4. CONCLUSION

4.1. The soil column stress in the wall mass is approximate to the γh value, it could be calculated by the current calculation method.

4.2. The linking line of the maximum stress acting on the strip, which is the so-called " failure surface ", presents a logarithmic spiral , the recommendation is given for using " 0.3H method " to calculate the effective length of strip.

4.3. As the actual maximum tension of strip is about one or two times greater than the lateral pressure applied to the relative front plate, the strip section and the joint elements should be designed according to two times larger than the lateral pressure acting on the relative front plate.

4.4. The wall stability is considerably affected by the density of the fill material, it should attach a great importance to the quality of tamping for the fill material.

4.5. The more perfect the monolithity of reinforced-earth wall is formed, the better the overall stability will be, and the higher the stress acting on the element materials are used, therefore, the design of reinforced-earth retaining wall still needs to be optimized.

4.6. The current design method tends to be conservative and needs to be improved.