Laboratory Testing of Geomembranes Used as a Blanket in a Reservoir

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ABSTRACT: Huangbizhuang Reservoir has operated for more than 30 years. On the horizontal blanket and the foundation of the auxiliary dam cracks often occurred. Laboratory test has been performed to verify the effect of the cracks on the safety of the reservoir and compare different types of geomembranes to strengthen the blanket and prevent piping caused by the cracks in the soil foundation.

1 INTRODUCTION

Huangbizhuang Reservoir is situated on the middle reach of Hutou River, Hebei Province, China, with a capacity of 1.21 billion cu. m. Two dams were built for the reservoir—one major dam and one auxiliary dam. The auxiliary dam is a hydraulic fill dam with a length of 7,000 m and a maximum height of 19.2m. The foundation of the dam is composed of cohesive soil (3～10m thick), medium sand (3～15m thick), sand and gravel (3～6m thick), gravel and cobble (7～20m thick) and bedrock. The natural cohesive soil layer was used as horizontal impervious blanket. Ditches, relief wells and banquettes were built up on the downstream side of the dam.

The reservoir was constructed from 1958 to 1960. In the early years of storage of water, a lot of cracks occurred on the blanket. In 1961, an additional artificial blanket was made on the natural soil layer. But cracks still occurred. Some cracks were found under the dam and might extend in the foundation as far as downstream side of the dam. The cracks were traditionally treated by digging ditches back filled with cohesive soil or by grouting with mud or cement. All these measures had very little effect. It was generally acknowleged that the cracks were caused principally by the non-uniform settlement of the foundation under high water pressure and the dam weight. Most of the cracks on the blanket had silted up , but cracks under the dam were mostly kept empty. It was generally considered that the cracks on the blanket would do no harm to the reservoir but those under the dam might cause seepage failure in the foundation. In order to refrain the water in the reservoir from flowing directly into the empty cracks under the dam it is proposed that a layer of geomembrane should be put on the upstream blanket to prolong the seepage path.

The purposes of the laboratory test are: (1) Confirming the filling of the cracks naturally with in-situ cohesive soil. (2) Comparing the effectiveness of different kinds of geomembranes used to strengthen the blanket for seepage control. (3) The function of non-woven geotextiles put under the geomembranes. (4) The necessity of the drainage system and non-return valves under the geomembranes. (5) Comparing different types of anchor measures adopted along the edges of the geomembranes.

The test started from the spring of 1993. At the end of 1993 items (1), (2) and (3) were partly completed and some results were obtained. Other items are still underway. This paper presents the preliminary analyses of the test results already obtained.

2 TEST EQUIPMENTS

(1) Test box. A box with size of 2.5m × 0.5m × 2.0m is made of steel and divided into four stories. The height of each story is 0.5m. Flange plates and rubber water-tight seal were used to prevent the leakage of water between stories. 32 small glass windows (8cm × 20cm) were provided on the front and back sides of the box for observation. Pressure gauge, inlet and outlet were installed as shown in Fig. 1. (2) 20 pore water pressure cells. (3) Water

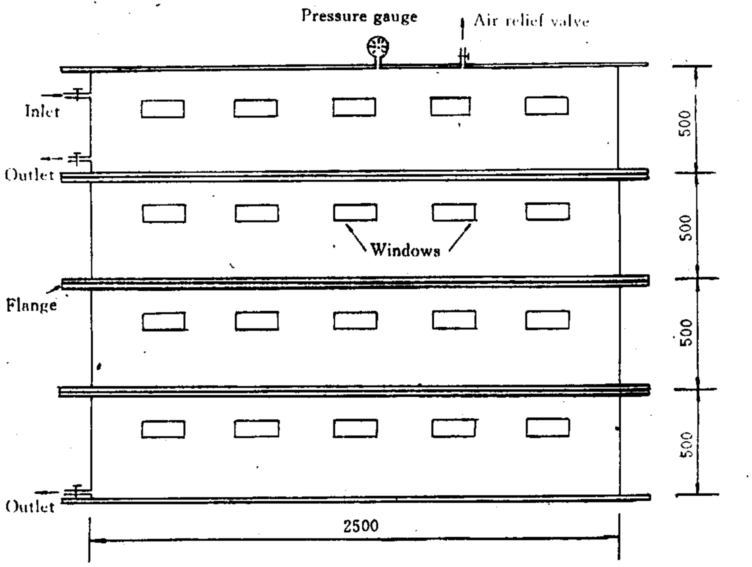

Fig. 1 Test box

supply system controlled by water tap with maximum pressure head of 12m (4) Auxiliary equipments.

3 TEST FOR THE FILLING OF CRACKS

3.1 Test aim and properties of the soil sample

The aim of the test is to confirm the filling of the cracks on the blanket with in — situ cohesive soil during the storage of water. Three kinds of soil from different positions of the blanket were collected. Their physical properties are listed in Table 1.

Table 1

Soil Samples	γ_d (kN/m^3)	Distribution of Grain Size(%)				Coefficient of Pereab — ility (cm/sec)
		0.25~0.1mm	0.1~0.05mm	0.05~0.005mm	<0.005 mm	
No. 2	15.2	10.5	39.5	44.9	5.1	7.09×10^{-5}
No. 3	15.0		6.5	63.0	30.5	2.63×10^{-6}
No. 4	14.4	1.0	34.0	61.9	3.1	9.23×10^{-5}

The sand sample underlaid the cohesive soil was also gathered from the field. Its properties is listed in Table 2.

3.2 Test procedure

Table 2

Classification	Distribution of Grain Size(%)				
	20~ 2mm	2~ 0.5mm	0.5~ 0.25mm	0.25~ 0.10mm	< 0.1mm
Medium Sand	1.4	36.6	49.0	11.2	1.8

Three layers of soil and one layer of sand were laid in the test box. The thickness and dry unit weight of each layer from top to bottom are No. 3 soil, $t=38$cm, $\gamma_d=13.35$kN/m^3; No. 4 soil, $t=44$cm, $\gamma_d=14.8$kN/m^3; No. 2 soil, $t=56$cm, $\gamma_d=15.2$kN/m^3; sand $t=12$cm. Four artificial cracks were made in the soil body with widths of 1~2cm. Two of them passed through the three soil layers and reached to the underlaid sand and the other two ended up at the middle layer of the soil as shown in Fig. 2. 16 pore pressure cells were buried in the soil sample. The change of attitude of cracks could be observed through the glass windows. After the top cover was fixed, water was supplied with pressure head of 4m for 24hours, 8m for 40 hours and 12m for 30 hours. And then the head was gradually decreased.

3.3 Test results and interpretation

At the beginning of water supply, through the glass windows it was observed that the walls in the upper parts of the cracks were scoured and the lower parts of the cracks were filled with in — situ soil. As the pressure increased this tendency was developed and finally those cracks passing through the soil layers

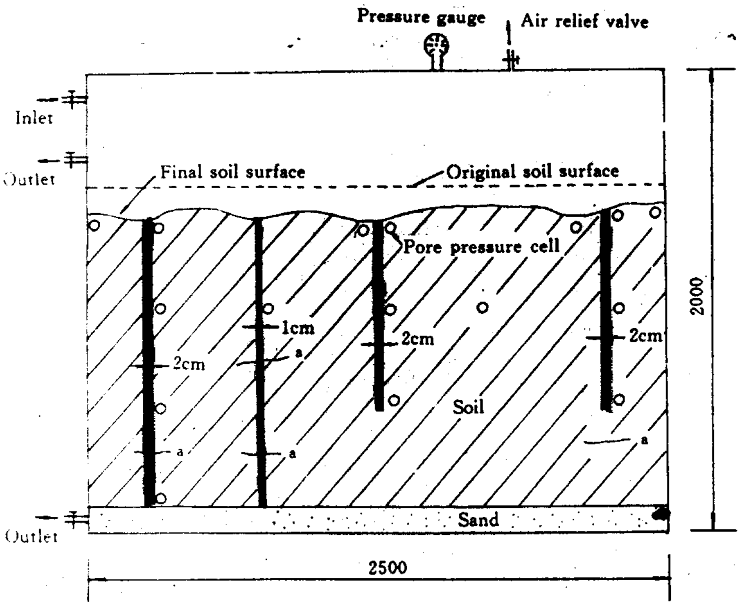

Fig. 2 Layout of test for filling of cracks(Horizontal cracks observed through windows after unloading the water pressure)

were entirely silted up and those ending at the middle layer of the soil were partly filled. Eventually different sizes of traps with funnel shape were formed at the top of all the cracks. At the lower ends of those cracks passing through the soil layers, it was found that very little fine soil particles intrude into the underlaid sand (with depth of 1～2mm). It is obvious that the sand layer has played a very good role of a filter. No piping of soil was caused by the cracks. At the max. head of 12m the total amount of settlement of the sample was 15～18cm. During unloading the water head, the soil body expanded and lifed 3 ～ 8cm. Some horizontal cracks were found in the soil sample due to the local tensile stress produced in time of expansion. The final longitudinal section of the soil sample is shown in Fig. 2.

4 TEST FOR GEOMEMBRANES

4. 1 Test aim

The aim of the test is to compare different kinds of geomembranes used to strengthen the blanket and retard the interface flow in the space between the geomembrane and the soil.

4. 2 Types of geomembranes

Three types of geomembranes were used in the study. They are:

Type Ⅰ 0. 45mm PVC geomembrane
Type Ⅱ 0. 45mm PVC geomembrane +Non—woven geotextile
Type Ⅲ 0. 18mm PVC geomembrane

The physical properties of geomembranes and geotextile are listed in Tables 3 and 4.

The soil sample used in this test was a mixture of No. 2, No. 3 and No. 4 soil described before.

Table 3

Kind of Geomem—brane	Thickness (mm)	Weight (g/m²)	Strip Tensile Strength (kN/m)	Elongation at Break (%)
0. 45mm PVC	0. 45	563	5. 16	275
0. 18mm PVC	0. 18	217	1. 19	100

Table 4

Kind of Geotextile	Thickness (mm) Under 2kP.	Weight (g/m²)	Strip Tensile Strength (kN/m)	Elongation at Break (%)	Pore Size (mm)		Coefficient of Permeability (cm/s)	
					O_{90}	O_{50}	k_V	k_H
Non Woven Needle Punched	2. 78	294	12	81. 3	. 147	. 120	. 125	. 107

4. 3 Test procedure

Two stories of the box were used with total height of 1. 0m. The thickness of the soil sample was 0. 5m and $\gamma_d = 15kN/m^3$. A sand drain with a length of 30cm was placed at the outlet end of the box. Geomembranes were put on the soil surface with a 30cm gap to allow the water flow into the geomembrane — soil interface. Glue was used to prevent leakage along the inner surface of the box. 14 pore pressure cells were buried in the soil and 4 of them were laid just under the geomembrane. The detailed layout is shown in Fig. 3.

The soil sample was saturated in advance. Water was supplied with varied heads of 1m, 2m, 4m, 6m, 8m and 10m. Each head was kept for 12～24 hours until the amount of seepage water becoming stable. From the records of the pore pressure cells, the space between the geomembrane and the soil interface might be considered as the principal path of flow and the seepage water through the soil body was quite small and could be neglected.

4. 4 Test results and interpretation

Fig. 4 gives the relation between the rate of seepage flow, Q, and the pressure head, H, where H was recorded from the pressure gauge which was 0. 7m smaller than actual head. Real line represents the

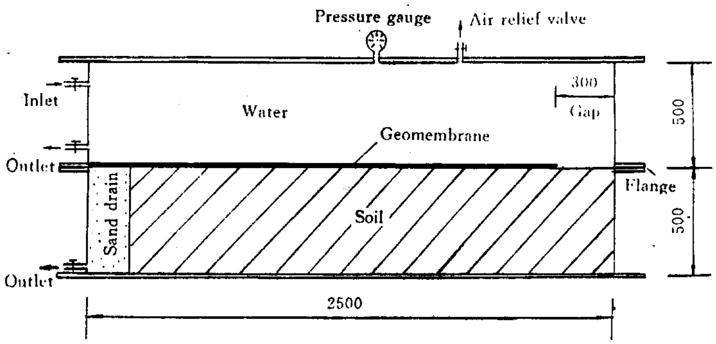

Fig. 3 Layout of test for geomembrane

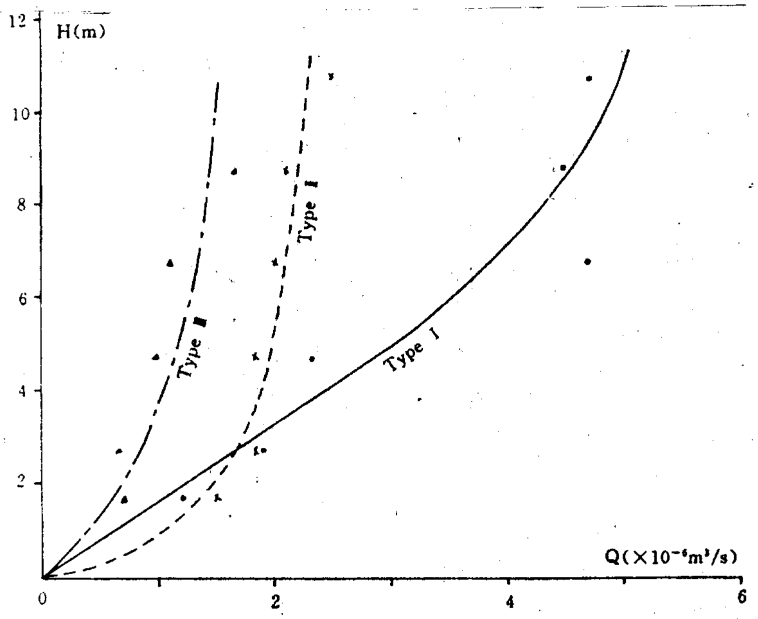

Fig. 4 Relation between rate of seepage flow, Q, and water pressure head, H

geomembrane of Type Ⅰ, dotted line of Type Ⅱ and intermittent line of Type Ⅲ.

From Fig. 4 it is discovered that the seepage rate of Type Ⅲ (0.18mm PVC geomembrane) is the smallest one among those of the three types. So it is most efficient to retard the interface flow in the space between the geomembrane and the soil. The seepage rate of Type Ⅰ (0.45mm PVC geomembrane) is the largest and it is the least efficient one. The efficient of Type Ⅱ (0.45mm PVC geomembrane + Non-woven geotextile) is much more than that of Type Ⅰ but less than that of Type Ⅲ.

For further comparison hydraulic transmissivity of the space between the geomembrane and soil was calculated by the following equation.

$$\theta = \frac{Q}{B}\frac{1}{I} \tag{1}$$

where θ is hydraulic transmissivity of the space; Q is flow rate through the space; B is width of the box; I is hydraulic gradient, $I = \triangle H/L$; $\triangle H$ is difference of readings between two pore pressure cells; L is distance between two cells.

Because of the low precision of the pore pressure cells and insufficient data obtained only qualitative analysis could be concluded as follows.

For Type Ⅰ (0.45mm PVC geomembrane): when the water head $H < 6$m θ increases with the head and when $H > 6$m θ decreases with the head. The reason may be that: this kind of geomembrane is comparatively rigid and surface of the soil is uneven and rugged. Under low head, when the water pressure above the geomembrane increases, less part of the geomembrane is pressed down to the soil surface and larger part of it lifted up from the soil surface. Therefore the average width of the space between the geomembrane and the soil increases. On the contrary, under high water head, when water pressure increases, larger part of the geomembrane is pressed down and less part lifted up so as to make the width of the interface space decreasing.

For Type Ⅱ (0.45mm PVC geomembrane + 300g/m² needle-punched geotextile): From beginning of the test θ decreases consistently with the water head and the rate of decreasing becomes smaller and smaller as the water head increases. When $H <$ 3m, θ of this Type is larger than that of Type Ⅰ and when $H >$ 3m it becomes smaller than that of Type Ⅰ. The reason is obviously that: at the beginning, the needle-punched geotextile is rather loose. When the water pressure above the geomembrane increases, it becomes denser and denser and makes good contact with geomembrane and soil surface.

For Type Ⅲ (0.18mm PVC geomembrane): At the beginning θ decreases rapidly with the water head up to $H = 3$m and afterwards the rate of decreasing becomes slower and slower. When $H <$ 2m θ of this type is larger than that of Type Ⅰ and when $H >$ 2m it becomes quickly much smaller than that of Type Ⅰ. Since this geomembrane is thinner and more flexible, when the water pressure increases, the geomembrane sticks more and more tightly on the soil surface and the width of the interface space becomes very small.

5 CONCLUSIONS

In Huangbizhuang Reservoir the soil blanket is underlaid with a layer of medium sand which can play a good role of a filter. The cracks on the blanket can be filled naturely with in-situ cohesive soil and causes no harm to the safety of the reservoir.

Geomembranes put on the blanket can prevent water from flowing directly into the empty cracks under the dam and prolong the seepage path so as to protect the soil foundation against piping.

PVC geomembrane with thickness of 0.18mm is the most efficient one among the three types in study. But it is too thin and could be easily damaged at the time of construction.

PVC geomembrane with thickness of 0.45mm is the least effective one among the three types. This type is not an ideal one.

0.45mm PVC geomembrane + 300g/m²needle-punched non-woven geotextile is the best choise among the three types. It is not only the one much more effective than type Ⅰ, but also the one for which the geotextile could protect the geomembrane from damage during construction and operation. Though the cost of this type is comparatively higher, it is still appropriate for a larger project like Huangbizhuang Reservoir.