Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Application of geotextile / geomembrane composite in the core wall of a rock-fill dam

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ABSTRACT: A geotextile/geomembrane composite liner is placed on the upstream slope of the clay core between the core and rock-fill shoulder to prevent seepage through a rock-fill dam at the Zhushou Reservoir. The composite characteristics are determined in the paper through analyses of coupled effects of stress–seepage, ball bursting and geotextile filter. These results show the composite can meet the demands of the engineering.

1 INTRODUCTION

The Zhushou Reservoir is located in the HuiLi County, SiChuan Province, China. The core wall type rock-fill dam is 60.22m in height and its normal cross section is shown in Fig.1.

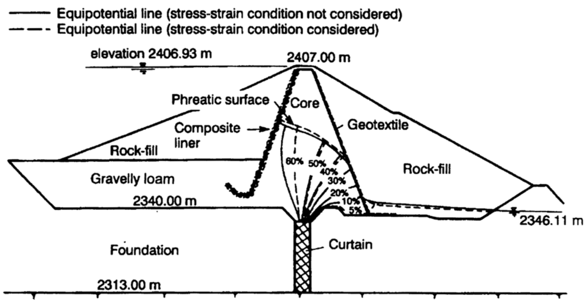

Fig.1 Sketch of Zhushou Reservoir rock-fill dam.

(Note: Equipotential lines expressed as perent of total pressure drop.)

Gravelly clay A (D_{50}=0.04 mm, k=2.2×10^{-5} cm/s) and gravelly clay B (D_{50}=8 mm, k=1.0×10^{-3} cm/s) are selected as core wall materials (shown in Fig.2). The dam of the Zhushou Reservoir,

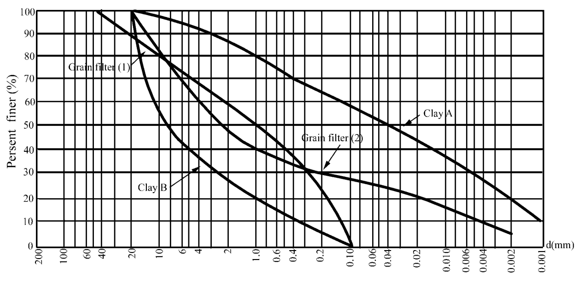

Fig. 2 Grain size distribution curve of gravelly loam of Zhushou Reservoir dam.

which was constructed from March 1975, had the elevation of 2355 m in 1980 after five years for land clearing, excavation, curtain grouting and clay blanket construction (dam height reached to 2407.0 m). Owing to the shortage of gravel clay A, the construction of the dam was suspended. Then, the geotextile/geomembrane composite was proposed to be installed between the upstream side of core wall materials and the rock-fill shoulder of the dam as impervious barrier. Moreover, besides the core wall, a large quantity of grain filter must be installed, which will cost enormous manpower and money. Therefore the geotextile was adopted as filter in this paper (see Fig. 1). The dam was then reconstructed in February 1993. Because geotextile/geomembrane composite liner can't be connected with the grouting curtain as possible as to cut the passage of filtration in the dam of the Zhushou Reservoir, the composite liner was installed as shown in Fig.1. The parameters of the geotextile/geomembrane composite and geotextile used as filter were determined through experiments.

2. ANTI-SEEPAGE PERFORMANCE

2. 1 *Performance of composite in a core wall type rock-fill dam*

Owing to the flexibility, low permeability and good tensile strength, geotextile/geomembrane composite installed at the upstream side of a dam core can deform with any relative movement between the core body and dam shoulder until stress equilibrium is achieved. Usually, the characteristics of the upstream and downstream filling materials on both sides of the composite are significantly different, then the vertical settlement and horizontal displacement of the upstream and downstream filling materials may also differ greatly. Because of the different interface friction angles between the composite and the upstream and downstream filling materials of dam shoulders, and the difference in deformation of the upstream and downstream filling materials, different magnitudes of deformation may develop on the opposite sides of the composite. For example: on the upstream side of the composite, the friction between the rock-fill and composite is relatively high, and thus, the composite will deform simultaneously with the dam body. On the other hand, on the downstream side the composite will act to restrain the deformation of the dam body so that the tensile forces mobilized in the composite will control the strain in the dam.

In addition, when a composite is installed between two dissimilar kinds of soils, the stronger soil body will tend to be extruded into the weaker one, then fill, this can result in bursting and puncturing of the geomembrane component of the composite. The degree of bursting and puncturing will depend on the normal stress during dam operation, the properties of the adjacent filling materials and the characteristics of the composite. If the ultimate tensile strength of the composite is approached, or excessive strains are induced, the composite will be ruptured, or its resistance to puncture reduced, and thus, its ability to prevent seepage may be impaired.

2.2 C*oupling calculation model for Geomembrane/Geotextile compositee*

The effects of stresses in the dam body are often overlooked in the analysis of seepage flow. Conversely, in the analysis of the stresses and strain of dam body, seepage forces are often treated as an external load. In fact, the stresses and strain of the dam body will change the porosity of the filling, and then the permeability of the filling through the dam body and the distribution of seepage forces will be changed. In turn, the change of seepage flow will affect seepage forces and the state of stresses and strain in the dam. Therefore, when the geotextile/geomembrane composite is used in the dam body, the coupled action of stress field and seepage field should be considered.

Simultaneous partial differential equations are constructed to represent the coupled action of stress field and seepage field in dam body. The equations are based on the Biot consolidation theory, a hyperbolic constructive model for soil (Duncan and Chang, 1970). These equations can be expressed in the following matrix form:

$$[\mathbf{K}][\Delta\mathbf{u}] + \rho g[\mathbf{Q}][\mathbf{h}]^{n+1} = [\Delta\mathbf{F}_1] - [\mathbf{Q}][\mathbf{h}]^{n} \quad (1)$$

$$[\mathbf{Q}][\Delta\mathbf{u}] + ([\mathbf{S}] + [\mathbf{R}]\Delta\mathbf{T})[\mathbf{h}]^{n+1} = [\Delta\mathbf{F}_2]\Delta t - [\mathbf{S}][\mathbf{h}]^{n} \quad (2)$$

where: $[\mathbf{K}]$ = stiffness matrix; $[\Delta\mathbf{F_1}]$ = load increment matrix per unit volume; $[\Delta\mathbf{F_2}]$ =constant matrix solved using known value of hydraulic head; $[\mathbf{Q}]$ = coupled stress-seepage matrix; $[\mathbf{S}]$= compression coefficient matrix of fluid; $[\mathbf{h}]$ = hydraulic head matrix;$[\mathbf{R}]$ = permeability matrix; and $[\Delta\mathbf{u}]$= displacement increment matrix. In the case of no pressure, fluid compressibility may be ignored.

In this case, the coupled stress-seepage calculations were based on 748 four-noded isoparametric elements with 816 nodes. Tensile loads can be expected to develop in the composite as a result of deformations in the dam. One approach to modelling the relationship between load and strain is to assume a simple linear elastic model. If the composite is installed between two materials with different properties, for example, the clay core and the rock-fill shoulder, a relative displacement will occur. In this case, an alternative approach to modelling load-strain behavior of the composite liner is to use a contact element. The geotextile/geomembrane composite liner was installed between the upstream side of the gravelly clay core and the rock-fill shoulder as shown in Fig. 1. The material parameters used in this example are summarized in Tables 1 and 2.

Table 1. Seepage parameters used for example calculations.

Upstream water elevation (m)	Downstream water elevation (m)	Permeability (m/s)				
		Core	Rock-fill	Foundation	Curtain	Composite liner
2406.93	2346.11	1×10^{-5}	6.0×10^{-4}	4.05×10^{-4}	1×10^{-7}	1×10^{-13}

Table 2. Material parameters used for example calculations.

Location	γ_d (kN/m^3)	R_f	K	n	K_b	m	Φ (°)	C (kPa)	K_s (MPa)	K_n (MPa)
Core	16.5	0.87	114	0.29	100	0.40	26	50	-	-
Rock-fill	20.0	0.70	400	0.45	500	0.10	40	0	-	-
Composite	-	-	-	-	-	-	20	0	4.66	4660

Notes: γ_d=dry unit weight; R_f=failure ratio(dimensionless); K=modulus number(dimensionless); n=modulus exponent(dimensionless); K_b=bulk modulus number(dimensionless); m=bulk modulus number(dimensionless); Φ=internal friction angle; C=soil cohesion; K_s=interface shear stiffness; K_n=interface normal stiffness.

2. 2. 1 *Effect of Stress on Seepage*

During construction and subsequent impoundment, increases in loads and seepage flow will change the state of stress. This leads to a compression of the soil, a change in soil porosity, and therefore a stress dependent change in soil permeability. One approach to quantify the relationship between soil permeability and minor principal stress is preferred in the following expression:

$$k = k_0\left(\frac{0.1p_a}{\sigma_3}\right)^b \quad (3)$$

where: k= soil permeability coefficient; k_0=permeability at σ_3=0.1Pa; b=empirical parameter determined from labor-atory test.

Fig.1 shows the seepage field of the Zhushou Reservoir with the composite. The results show: (1) the phreatic surface in the core-wall is higher when coupled stress-seepage condition considered than that when no coupled stress-seepage considered. But it will be opposite in the downstream dam shell; (2) the distribution of the seepage fields for the above two conditions are similar expect the 60% equipotential line; (3) the variety of permeability coefficient for every element in the dam is different because of the difference of stress variety. The permeability coefficient is about one-fourth of original in core-wall, making the seepage discharge per unit width decreased from 0.345m^3/day/m to 0.249 m^3/day/m; (4) based on the phreatic surface (the top flow line), the composite liner reduces the total head in the core by approximately 35%. With the composite in place, the elevation at which the phreatic surface intersects the downstream slope of the core is reduced from 2400 m to 2369 m, and the exit grade is about 1/2 of the original.

2. 2. 2 *Effect of Composite Liner on Stress*

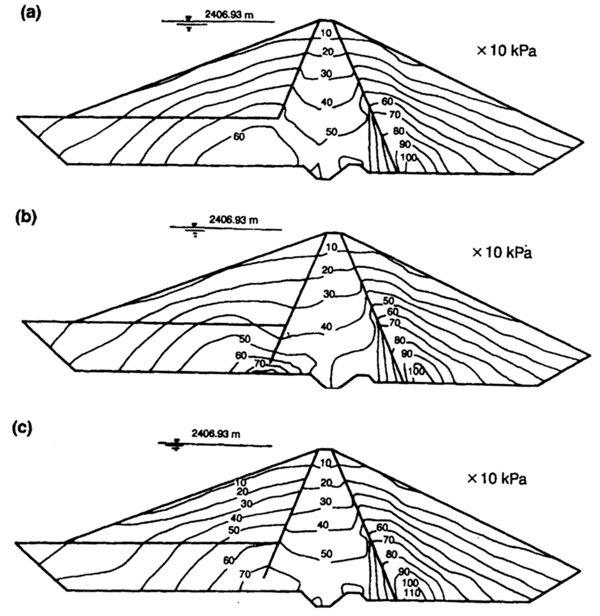

Fig.3 Contours of equal major principal stress under maximum water level. (a) without composite liner; (b) composite liner analyzed by use of linear elastic elements; (c) composite liner analyzed using contact elements

Since the composite liner is flexible, it deforms with the dam. When tensile stresses are developed in the dam, they will be partially transmitted to the composite that in turn will mobilize tensile forces. These tensile forces can then be expected to modify the distribution of stress and strain in the body of the dam. Fig.3 shows the distribution of major prin -cipal stresses, and Fig.4 shows the distribution of vertical displacements.

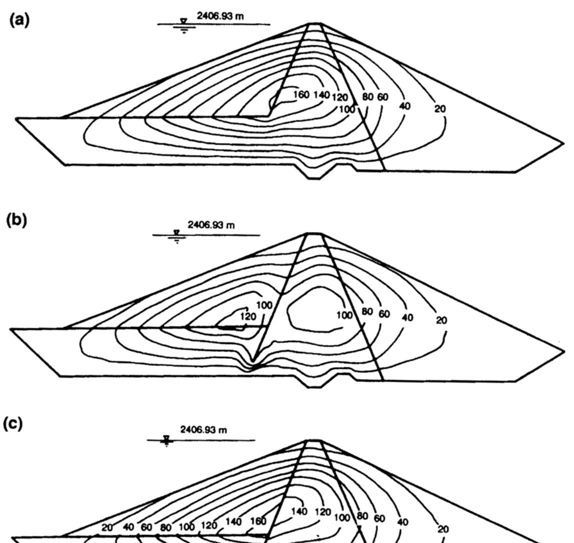

Fig.4 Contours of vertical displacement (in centimeters) under maximum water level: (a) without composite liner; (b) composite liner analyzed by use of linear elastic elements; (c) composite liner analyzed by use of contact elements

These calculated results show: (1) The magnitudes of major principal stress for the conditions without the liner and with the installed liner analyzed by use of contact element are very similar expect that the liner case leads to a more even distribution of stress. These analyses clearly demonstrate that the composite liner can modify the distribution and magnitude of principal stresses in the body of the dam. (2) Displacement: the maximum settlements occur at the half height of the dam body during construction and impoundment. The distributions of vertical displacements are similar when no composite liner or a composite liner is modeled by use of contact elements. When the composite is analyzed by use of linear elastic elements, the maximum settlements occur at the center of the core and in the upstream shoulder adjacent to the core. (3) The maximum tensile strength is 1.38 kN/m during impoundment.

2.3 *Determination of geotextile/geomembrane composite tensile strength*

When geotextile/geomembrane composite is laid between transition materials and core-wall clay, the most disadvantage is to be burst under the pressure of water and soil. Here, the tensile stress can be calculated by the following equation:

$$T = 0.293 d_{85}\left(P_1 - P_2\right) \qquad (4)$$

where: T =the tensile stress (kN/m); d_{85}= size of transition materials;P_1 and P_2 =pressures on opposite sides of the geotextile/geomembrane .

In this case, P_2=0, P_1=321.75 kPa, d_{85}=0.05 m, and T=4.71 kN/m.

2..4 *Determination of geotextile/geomembrane composite*

According to the analytical results of coupled stress-seepage and bursting, the tensile strength of geotextile/geomembrane composite used to the Zhushou Reservoir is 4.71kN/m. Simultaneously, a safety factor FS=3 is recommended for the consideration of the variability in composite properties and seams, variability in void size of the support material, difference between the laboratory test and practice, and other uncertainty. According to the tensile strength of the geotextile/geomem-brane composite used for the Zhushou Reservoir is 4.71 × 3=14.13kN/m, the geotextile/ geomembrane composite GT(300g/m^2)/GM(PVC 0.5 mm)/ GT(200 g/m^2)is selected as an anti-seepage material in the Zhushou Reservoir. Moreover, the composite properties are tested in laboratory (in Table 3). These test results show: (1) The pressure stress of hydraulic bursting of the composite is 1.3 MPa. For the transition material with a size of d_{85}=0.05m, $P_{1\max}$=1.175 MPa, which is far more than P_1=0.32 MPa. (2) The maximum load is 27.6 kN/m and larger than T=14.13 kN/m, meeting the demands of the engineering.

Table 3. Properties of Composite (300g/m^2/0.5mm/200g/m^2) from laboratory test

Test		Specimen size	Measured value	Test method
Mass/unit area		100×100 mm	998 g/m^2	GB 4669-84 (China)
Thickness(measured under load of 2 kPa)		100×100 mm	3.01mm	GB 3820-83 (China)
Strip tensile	Maximum load	50×200 mm	27.6 kN/m	GB 3923-83

E	longation		55.4%	(China)
Wide-width tensile	Maximum load	500×100 mm	28.47 kN/m	NFG 38014 (France)
	Elongation		49.1%	
Trapezoidal tear (maximum load)	Machine direction	/	0.781 kN	GB 3918-83 (China)
	Cross-machine direction		0.758 kN	
Ball bursting(maximum load)		25 mm	>2.0 kN	ASTM D 3787 (USA)
CBR puncture		150 mm	5.096 kN	DIN 54307E (Germany)
Impermeability		160 mm	2.0 MPa	NHRI-89 (China)
Hydraulic burst test		160 mm	1.3 MPa	DIN 53861 (Germany)
Interface friction angle	GC/clay	200×200 mm	15.6°	NHRI-89 (China)
	GC/TM		28.9°	

Note: GC - geotextile/geomembrane composite; TM – transition materials

3 GEOTEXTILE FILTER

A filter must meet the demands of permeability and sand holding capacity. According to the above demands and materials of Zhushou core wall type rock-fill dam, materials with grain size distribution curve shown in Fig.2 may be used as particle filter. In calculation, the particle filter materials is as a dry unit weight of 1.85 g/cm^3, a mean pore diameter of 0.063-0.078 mm for filter 1 and 0.281-0.312 mm for filter 2. Owing to the granular structure characteristics of clay soils (the granular diameter

$d_a \quad \sqrt{\frac{0.214}{1 \quad J}}$ [4]), d_a = 0.33 mm is adopted for the clay soil under the most disadvantage condition (J=1). Downward direction of the seepage flow, the mean pore diameters of materials of particle filters 1 and 2 are far smaller than d_a of the clay granular, and the permeability coefficients of the filters, k_1= 5.4×10^{-3} cm/s and k_2=4.5×10^{-2} cm/s, are larger than that of clay core. Thus, the particle filter materials can meet the demands of permeability and impermeability.

The geotextile filter is selected with filter size O_f<0.1mm and permeability coefficient k_g>10^{-2} cm/s, and the characteristic parameters of the geotextile are summarized in Table 4.

Table 4. Test results of geotextile blinding tests

GT 400 g/m^2		A/ GT	B/GT	PF1/GT	A/PF1/GT	A/PF2/GT	B/PF1/GT	B/PF1/GT
k_g=5.6×10^{-1} cm/s	k'_g (cm/s)	2.8×10^{-1}	3.6×10^{-1}	3.9×10^{-1}	2.4×10^{-1}	3.2×10^{-1}	4.2×10^{-1}	4.8×10^{-1}
	k'_g / k_g	0.50	0.64	0.70	0.43	0.57	0.75	0.86

Notes: G= geomembrane; GT=geotextile; k_g =original permeability; k'_g =permeability after blinding; A= clay A; B= clay B; PF1 and PF2= particle filters 1 and 2 .

It can be seen from the test results that the particle filter materials and geotextiles used in Zhushou clay core wall rock-fill dam can meet engineering demands.

4 ENGINEERING EXAMPLE

The dam of the Zhushou Reservoir, a clay-core rock-fill dam, was reconstructed on 28 Dec.1992 and completed in Dec.1995. There are 5 733 m^2 GM/GT composite and 2 748 m^2 geotextile totally installed in the dam of Zhushou Reservoir. Now, the dam has been safely operated for 6 years, and the vertical settlement is only 0.223 m and horizontal displacement is 0.027 m.

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