Engineering Characteristics and Application of Geomembrane Composite

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Abstract In this paper, the properties comparison between the composite geomembrane and single geomembrane both having same thickness of impervious geomembrane has been elucidated. Finaally, two engineering cases of different embankments and dams with the composite geomembrane as impervious layer have been enumerated in order to expound those required engineering characteristics and effects of the composite geomembrane.

1. Introduction

Geosynthetic, a novel engineering material, is made from high polymers, and according to its hydraulic properties, it can be divided into two main kinds: permeable and relatively impermeable. The former is geotextile which is mainly used in drainage, filtration, separation, reinforce, while the latter is geomembrane which is mainly applied in water or vapor barrier.

There are many engineering cases in which geomembrane was applied, not only in earth and rock–fill dam engineerings, but also in crevasse filling for concrete dam. With the developments of membrane and construction technology, geomembrane is being used in wider fields, such as in the construction of high dams.

Single geomembrane may be punctured by supports or other sharp things, ruptured by gas pressure and water pressure, teared or rubbed due to the sliding of boundary surface when used to prevent seepage. In view of the above–mentioned facts, single geomembrane, when applied to prevent seepage, must be protected on one side or two sides according to various engineering conditions, and geotextile is the best protective material which acts as cushions to draining water (gas), and shock–absorbing. Formerly, single geomembrane and geotextile were laid separately and they have no internal relations. In order to imporve this structure system, simplify construction and enhance the geomembrane's ability against tension, tear, puncture or burst. In 1986, we combined geomembrane with geotextile to produce a new product——composite geomembrane which is a whole section member (Tang and Tao, 1989) and this new product has been applied in many projects in China. The main properties of the composite geomembrane are shown in Table 1.

2. Engineering Properties

The engineering properties of the composite geomembrane refers to the property indexes demanded in engineering design such as tensile strength, shear strength, puncture resistance and transmissibility.

2.1 Tensile Strength

Tensile strength resulted from the deformation of dam body.

The properties of the composite geomembrane depend mainly on membrane's impermeable property to water barrier in dykes and dams, but it is so soft itself that it needs the support of the dam. When the dam body suffers the water pressure, the geomembrane will obstruct seepage flow and the load on the geomembrane can be calculated according to the coupled equation (Zionkiwicz, 1985) of seepage field and stress field.

In the coupling calculation, if the friction between the geomembrane element and the dam body element is not considered, the maximum tensile deformation will occur in the dam body.

Table 1 Main Properties of Composite Geomembrane

Types	Tensile strength (kNm)		Hydraulic bursting (kPa)		CBR (kN)	
	GM	C_{GM}	GM	C_{GM}	GM	C_{GM}
PVC t_{GM} = 0.25 mm NP–NW 150 g / m²	4.36	9.24	150	900	0.70	1.54
PVC t_{GM} = 0.70 mm NP–NW 300 g / m²	13.81	28.0	660	2150	2.2	3.77
PVC t_{GM} = 0.50 mm NP–NW 200 g / cm² and 300 g / m²	8.92	28.30	280	2300	1.3	5.10
PVC t_{GM} = 0.86 mm NP–NW Double 300 g / m²	8.60	24.8	450	7100	2.4	6.50

The calculated results shows that the maximum horizontal and vertical displacements of the rock–fill–dam occur both at the upper part of the dam body, but the maximum relative displacement of the nodes at the two ends of the geomembrane element always occur at the lower part, about the $1/5H \sim 1/3H$, and the reason is that the bottom of the geomembrane has been fixed.

As for the composite geomembrane fixed in the bank slopes, in the period of water storage, the dam body will displace toward the lower reach under the water pressure, especially the dam body on the high and steep bank slope will displace toward the middle part of the dam, causing the composite geomembrane suffering tension.

Tensile strength resulted from the breaking of the hole of support materials

The composite geomembrane which is laid between the support materials, must suffer the extrusion from support materials especially in the period of water storage. At this time, the composite geomembrane may be broken in the hole of support material, and breaking degree depends on the normal pressure (soil pressure and water pressure), diameter of the hole of support material (grain diameter). The demanded tensile strength of the composite geomembrane in breaking can be calculated (Giroud, 1981).

2.2 Shear Strength

The composite geomembrane must be contacted with the supports on the two sides. Its shear strength can be expressed as friction angle. Considering that the dyke and dam will displace in filling and operation, if the shear force is greater than the shear strength between the composite geomembrane and the adjacent materials, slide will occur. In impevious surface layer, the shear action between the composite geomembrane and the adjacent materials may be increased in somewhere because of the deformation of dam body, which can also result in sliding. In the coupling calculation the elements of the composite geomembrane are treated according to contact element.

As for a certain composite geomembrane and a certain dam body material, the relation of τ_s and relative slide Δu can be measured under the different action of σ. If an obvious non–linear relation curve is obtained, it can be fitted with hyperbola.

2.3 Puncture Resistance

When the composite geomembrane is applied in dyke and dam engineering, it suffers the water pressure and the extrusion of adjacent materials, and bears the concentrated force which is vertical to its plane. That the composite geomembrane will be broken in the holes of supports because of the normal stress has been expounded in 2.1. The fact that composite geomembrane will be punctured by the supports under the concentrated forces and loss its impermeability is called puncture.

2.4 Geogeotextile Transmissibility

The composite geomembrane can not only prevent seepage in normal but also perform the function of geotextiles horizontal drainage and substitute geomembrane and the cushions at the two sides. Thus, the back of the composite geomembrane to water side must be designed and manufactured according to the seepage capacity through the geomembrane.

3. Tests on Engineering Property

3.1 Tensile Test

Eight group of tensile tests with different widths of sample (50, 100, 200, 300, 400, 500, 600, 700 mm) have been conducted using the test sample shown in Fig. 1 (Lafleur, 1986) after consulting Gourc *et al.*(1986). The test results are shown in Fig. 2. From the results, it can be seen that: (1) tensile strength limit tends to be constant when the width b is greater than 500mm. (2) the ratio of the sample width to the tensile strength of composite geomembrane(Fig. 3) increases relatively, after the geotextile and the membrane with high temperature have been compounded (3) the tensile

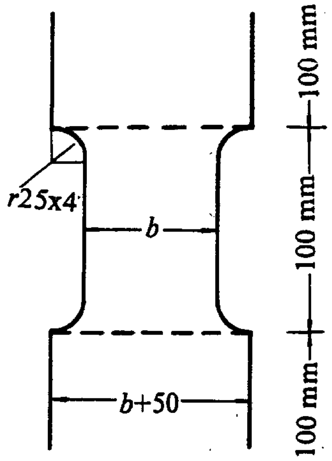

Fig. 1. Tensile Strength Specimen.

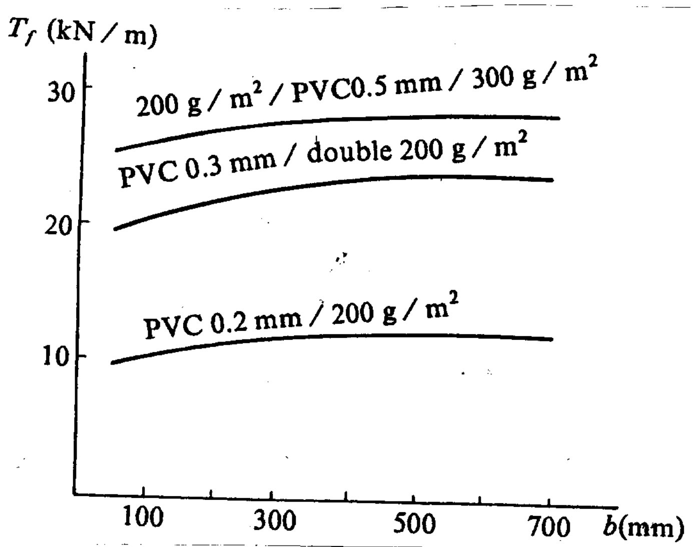

Fig. 2. Tensile Strength Variation with Sample Width.

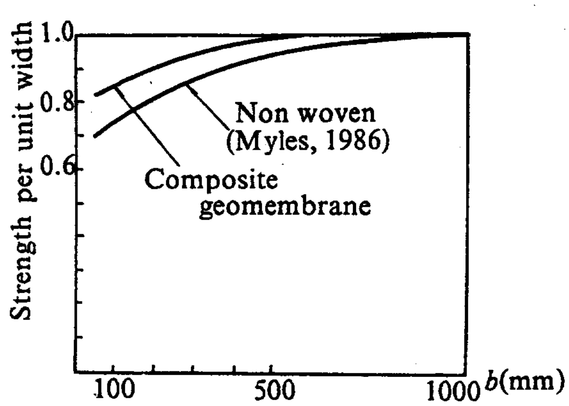

Fig. 3. Inflence of Sample Width on Strength.

strengths of single geomembrane and composite geomembrane is shown in Table 1, and which shows that: the tensile strength of geomembrane depends mainly on the strength of geomembrane itself and the geotextile selected. The strength of membrane depends on its prescription and its processing technology, while the strength of geotextile depends on its weight and the processing technology.

3.2 Bursting Test

The test method DIN 53861 is adopted in the burst test with hole area 10 cm^2 (innerdiameter is 35.68 mm). Fig. 4 shows the values of water pressure when the single geomembrane and composite geomembrane are burst, which indicate that the composite geomembrane can bear higher water pressure. With the increase of the thickness of geomembrane and the weight of geotextile, the bursting ability of the geomembrane is improved. The value is also related to one–side composite or two–side composite

3.3 Puncture Test

Three typical shapes (sphere, cylinder, circular cone) are considered in the puncture tests and the test procedure mainly consults the standards of DIN54307 and VTT. The test results are shown in Fig. 5.

The test result shows that : (1) the puncture resistance of the composite geomembrane is closely related to the weight of geotextile and composition at one side or two sides. (2) the puncture resistance is related to the shape of puncture material and it increases with the increase of area of the contact surface. (3) the puncture resistance of the single geomembrane is far less than that of the composite geomembrane.

3.4 Hydraulic Bursting Test

In order to simulate the state of stress when the composite geomembrane is applied in engineering and define the standard and size of the composite geomembrane, the test device similar to that of Fayoux and Loudiere(1984) was employes in the test. It is difficult to extrapolate the behaviours of a composite geomembrane subjected to stress in operation if only the conventional mechanical tests are used. The hydraulic bursting test results are shown in Table 2.

3.5 Friction Test

Friction test can determine the property on surface between geomembrane or composite geomembrane and adjacent materials by using horizontal shear instrument. In the test, 20 × 20 cm sample is adopted, the maximum normal pressure is 250 kPa, and the variance of the horizontal displacement velocity is 0.02~ 3 mm / min. The test results are shown in Table 3.

Table 3 shows that the composite geomembrane can improve the frictional property of single geomembrane.

3.6 Permeability Test

Table 2 Results of Hydraulic Bursting Test

Material		Transitional material	
	1～100 mm	50～150 mm and permeable concrete	permeable concrete 5～30 mm
Geomembrane A′	water pressure 0.5MPa $K=2\times10^{-9}$ cm / s	water pressure 0.4MPa $K=3\times10^{-9}$ cm / s	water pressure 0.3 MPa $K=9\times10^{12}$ cm / s
		water pressure 0.5 MPa $K=5\times10^{-11}$ cm / s	water pressure 0.5 MPa $K=2\times10^{-8}$ cm / s
			water pressure 0.49 MPa $K=5\times10^{-9}$ cm / s
Composite A	water pressure 1.5 MPa $K=3\times10^{-10}$ cm / s	water pressure 1.2 MPa $K=5.07\times10^{-11}$ cm / s	water pressure 1.5 MPa $K=9\times10^{-11}$ cm / s

Note:Composite A——250 g / m² / PVC 0.5 mm / 400 g / m²

Table 3 Frictional Property

Frictional surface	Friction coefficient
Sand / PVC 0.2 mm / GT 300 g / m²	0.432
Sand / PVC 0.8 mm / GT 300 g / m²	0.383
Sand / GT 300 g / m² / PVC 0.5 mm	0.496
Sand / GT 200 g / m² / PVC 0.3 mm	0.513
Clay / PVC 0.2 mm / GT 300 g / m²	0.396
Clay / PVC 0.8 mm / GT 300 g / m²	0.354
Clay / GT 300 g / m² / PVC 0.5 mm	0.412
Clay / GT 200 g / m² / PVC 0.3 mm	0.421
Concrete / PVC 0.2 mm / GT 200 g / m²	0.378
Concrete / GT 300 g / m² / PVC 0.5 mm	0.398
Concrete / GT 200 g / m² / PVC 0.3 mm	0.425

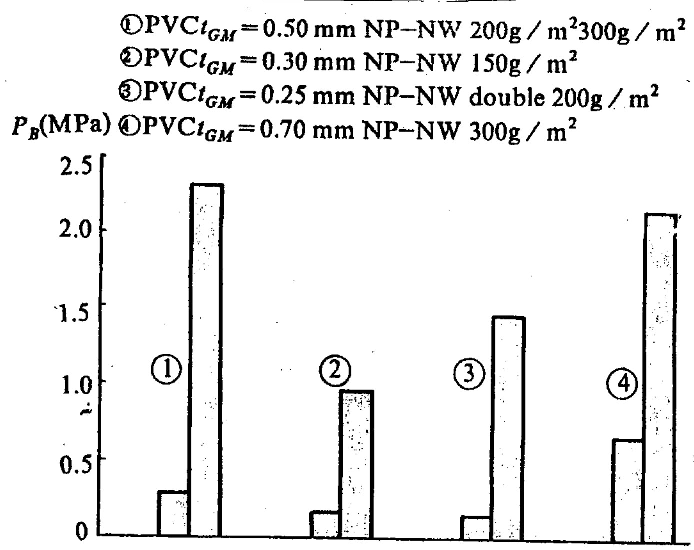

Fig. 4. Hydraulic Bursting Tests(Geomembrane, Composite Geomembrane).

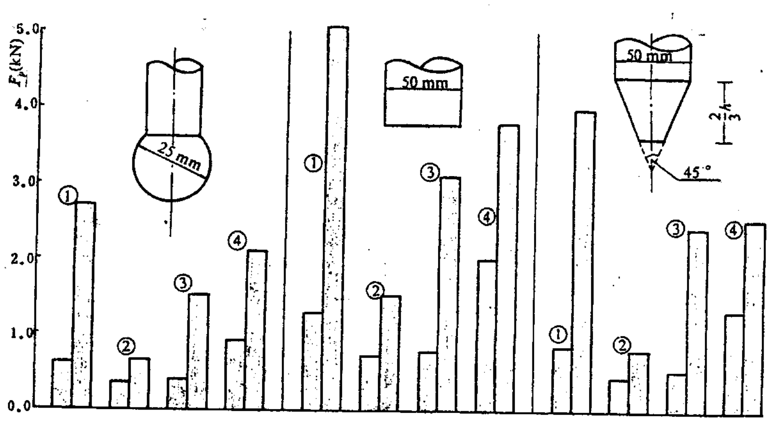

Fig. 5. Puncture Tests

3.6.1 Normal Permeability of the Geomembrane

The permeameter is used in the permeability test of geomembrane. In order to lessen the effect of edge , the test area is taken as 200 cm² and the maximum pressure is 1000 kPa. The test results of PVC geomembrane shows that if the water pressure is relatively small, the permeability coefficient is also unusually small, thus, there exists a starting water pressure for the permeability of the geomembrane. When the water pressure is smaller than the starting water pressure, the geomembrane is regarded as impermeable, and when the water pressure is greater than the starting water pressure, the permeability coefficient increases with the increase of pressure, and finally arrives the maximum (about 100~200 kPa). At this time, the value of the water pressure is called critical water pressure. But when the water pressure exceeds this critical value, the permeability coefficient decreases gradually.

3.6.2 Textile transmissibility

The geotextile transmissibility of the composite geomembrane is measured with 10× 200 cm plane permeameter. In view of the fact that needle–punched geotextile possesses obvious compression property and that its thickness and permeability coefficient will decrease with the increase of the pressure, the measuring installation is fitted with a microscope which can measure the thickness of geotextile under a certain pressure. The results can be shown in Fig. 6, which shows that the geotextile transmissibility decreases with the increase of pressure stress, when $\sigma < 500$ kPa, the change of geotextile transmissibility is obviously and when $\sigma > 500$ kPa, the transmissibility tends to be a constant. Different geotextile has different relation curve of $\theta - \sigma$.

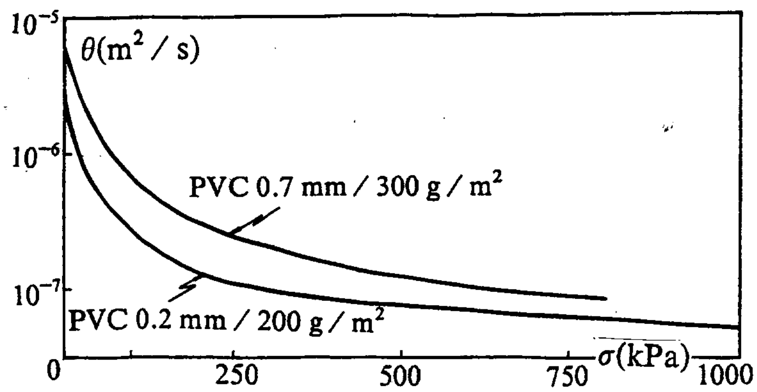

Fig. 6. Transmissity Tests of Geogeotextiles.

4. The Impervious Effect of Composite Geomembrane

For a dyke or dam on permeable foundation, dam surface (core) blanket is commonly used to prevent seepage. The reason that the composite geomembrane is extensively used for this purpose is that: (1) The normal permeability coefficient of composite geomembrane is far smaller than that of clay or concrete. (2) The composite geomembrane is soft and wholly structured, and can endure some elastic–plastic deformations resulted from the subsidence, expansion–contraction or accidental overload, landslide, and seepage of soil, and all these advantages make composite geomembrane superior to clay and concrete. (3) The composite geomembrane possesses certain mechanical strength, this is favourable for the selection of dam–filling materials and lowering the cost of construction.

4.1 The Blanket Impervious Effect

The impervious blanket on dam surface can counteract about 50–70% of the total water head and its infiltration capacity will change with the relative length of blanket L/T, when $L/T > 6$, the effect is less obvious than that when $L/T < 6$.

4.2 Vertical Impervious Effect

From the calculation flownet of vertical impervious curtain we know that: (1) The impervious effect of counteracting water head is relatively obvious. (2) When the composite geomembrane waterproof curtain cuts off the strong permeable layer, more than 80% of the total head can be counteracted and its infiltration capacity will change with the relative depth of vertical waterproof curtain S/T, if $S/T > 0.8$, the infiltration capacity decreases obviously.

4.3 Comparison of Impervious Effects

The comparison of effects of impervious blanket and curtain under the same seepage capacity is shown in Fig.7, which indicates that, when the relative depth of vertical curtain $S/T < 0.5$, the effect of blanket is superior to that of vertical curtain, but when $S/T = 0.5 \sim 0.8$, the effect of vertical curtain is superior to that of blanket and when $S/T > 0.8$, the effect of vertical curtain arrives the best.

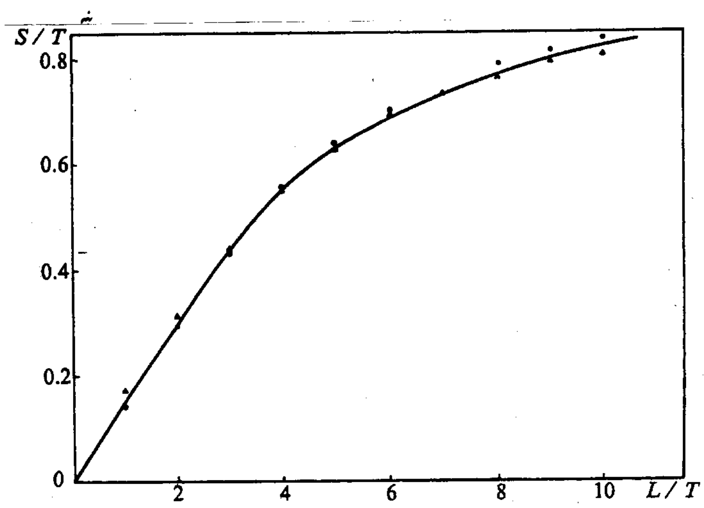

Fig. 7. Comparison of Effects Between Blanket and Curtain.

5. Engineering Cases

There are more and more engineering cases in China in which the composite geomembrane is applied. In this paper, five cases with different engineering projects(earth dam, rock–filled dam, core–earth dam, cofferdam and dyke) are presented.

5.1 Cofferdam in Shuikou Hydroelectric Power Station

The Shuikou hydroelectric power station is situated on Minjiang river in Fujian province, and its cofferedams on upstream and downstream are located on sand gravel course. The cofferdam on upper and lower reaches were constructed through stone riprap under water, filling sand–gravel in the middle above water. The upper part in the centre of cofferdam body is composite geomembrane and the lower part is plastic concrete seepage prevention wall. Its sectional structure can be shown in Fig.8. In May, 5, 1990, the rock–filled cofferdams were completed, and 31000 m^2 composite geomembrane was laid on the upstream and downstream cofferdams.

After test and calculation, we suggest to use the composite geomembrane of which PVC is 0.8～1.0 mm in thickness, geotextile is double 300 g/m^2 as the seepage prevention material. The main property can be shown in Table 1.

The construction of Shuikou cofferdam shows that plastic concrete and composite geomembrane both possess fine properties of seepage prevention and can adapt the deformations of cofferdam body and foundation. After measuring, the unit seepage capacity is 1.5 $m^3/day \cdot m$, and the demand in seepage prevention design is satisfied.

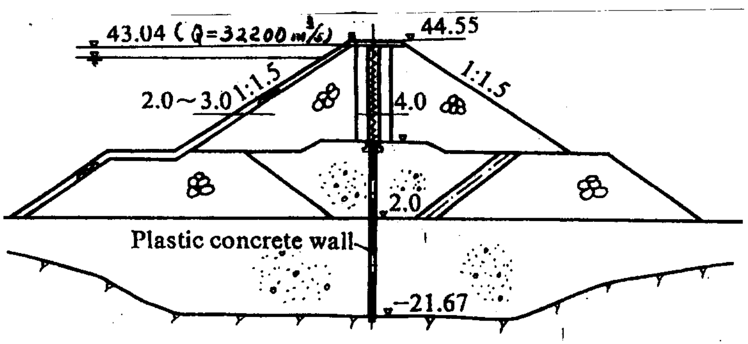

Fig. 8. Sectional Drawing of Shuikou Cofferdam.

5.2 Core–Earth Dam of Zhushou Reservoir

Zhushou reservoir is situated in Sichuan Province, the original design is clay core stone ballast dam with the height of 60.22 m. Because there are much gravels in the core soil and the permeability coefficient is great(1×10^5 m/s), it is suggested to lay a layer of the composite geomembrane at the upper side of the gravelly clay core wall, combining the composite geomembrane with the gravelly clay core wall to prevent seepage. Because the foundation has been grouted and some parts of the dam have been filled, it is unable to link the composite geomembrane with the foundation concrete impervious wall. The sectional drawing is shown in Fig.9.

The test and calculatiton show that: (1) Because the composite geomembrane has been combined with gravelly clay core wall to prevent seepage, the phreatic line lowers obviously; the seepage capacity decreases greatly, and meanwhile, if the stress–strain is considered, the permeability coefficient at the core wall geneally decreases about 2.5 times and the maximum arrives at 3.2 compared with the original permeability coefficient. (2) The distribution of pore water pressure is of parabolic because the composite geomembrane has been laid at the upper stream side of the core wall, and the pore water can only drain toward the lower stream side. After 40 days storage, the water level gets 2406.93 m, at this time, the distribution pore water pressure is stable. (3) If considering that the composite geomembrane suffers tensile stress and relative slide, obvious difference exists in the distribution curve of the stress and that of the displacement, and the isopath of the former is relatively lower than that of the latter; if considering relative slide, the isopath is not continuous at the point of the composite geomembrane. (4) according to the analysis and calculation, the standards of composite geomembrane is taken as 300 g/m^2/PVC t_m 0.5 mm/200 g/m^2. The main properties can be seen in Table 1.

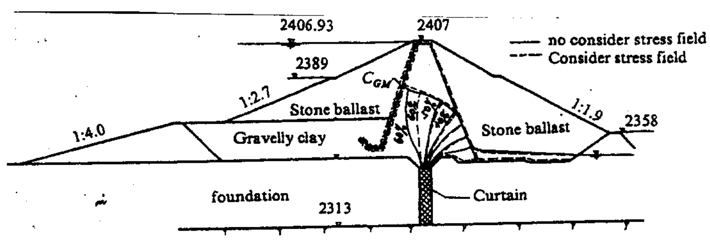

Fig. 9. Sectional Drawing of Zhushou Dam.

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