IMPERVIOUS ASPHALT MEMBRANES FOR AGING CONCRETE DAMS

YUE ZHU SHAN FENG WEIBIAO WANG
Xi'an University of Technology, Xi'an, China

ABSTRACT

Concrete dams have a long history to be widely constructed as this type of dams possess adequate safety in good geological foundation conditions. However, aging of concrete dams with time has become one of serious engineering problems due to weathering, lowering and raising of the reservoir level, and freezing-thawing of cycles. The stability of concrete dams generally maintains, however, the imperviousness of the upstream faces of concrete dams are gradually deteriorated with time and some leakages occur. The rehabilitation of the upstream faces is usually to use spray coating materials and the coating is easily to be peeled off when the faces have become porous due to aging. The paper presents the advantages of asphalt membranes with prefabricated concrete slabs anchored on the concrete faces of concrete dams. The detailed design and a case study are also presented.

1. CONCRETE DAMS IN CHINA

Two-thirds of built large dams are concrete dams in China. Concrete dams have many advantages compared with other types of dams. However, aging has become one of serious problems for concrete dams with time. Concrete dams are continuously subjected to physical and chemical changes due to weathering. After years' aging the dam behaviors have been deteriorated with time. Especially, the upstream faces of the dams have gradually lost the imperviousness and some leakage may occur. In such cases, maintenance and repair have become necessary to keep the operation.

Most of concrete dams in China have been built after the 1949. According to the statistics for 109 large and medium-sized concrete dams, 67 of them had existed over 40 years till 2010, and the oldest was nearly 70 years. It is difficult to accurately give an aging period of each typical dam, however, the imperviousness of the upstream faces of concrete dams start to be gradually deteriorated with time and some leakages may occur after 30 years of operation. At present, the rehabilitation of the upstream faces is usually to use spray coating materials and the coating is easily to be peeled off when the faces have become porous due to aging.

2 . FACTORS AFFECTING THE IMPERVIOUSNESS OF CONCRETE DAMS

The factors affecting the imperviousness of the upstream faces of concrete dams are mainly the aging.

2.1 Freezing-thawing of Cycles and Frost Heave

Freezing-thawing of cycles and frost heave of the upstream faces of concrete dams are a kind of physical damage. In the process of temperature change from positive to negative, the water volume expands about 9%. When water stays in large voids and turns into ice, the frost heave stress is produced. The ice forces the unfrozen water in the deep voids to generate osmotic pressure. When the combined stress of the frost heave stress and osmotic pressure is larger than the allowable fatigue stress of concrete, damage will occur.

2.2 Surface Carbonization

The surface carbonization of concrete dams is a chemical damage. CO2 in the air penetrates pores of unsaturated water, reacts with Ca(OH)2 that is the cement hydration product, and produce CaCO3. The carbonization results in two detriments. On the one hand, the alkalinity of concrete is reduced from the surface to the center and cause the surface layer of concrete to fall off. On the other hand, the carbonization consumes a part of the cement binder and may cause cracks or small holes due to volume shrinkage.

2.3 Leakage Corrosion

$Ca(OH)_2$, a cement hydration product in concrete dams, is continuously lost along with pressure water leakage. When it starts to react with CO_2 at the leakage outlet to produce $CaCO_3$, a sign that indicates the concrete dams have been damaged by dissolution. The dissolution is a complex physical and chemical reaction process. The compressive and tensile strength of concrete will be reduced by 38.5% and 66.4%, respectively, when $Ca(OH)_2$ has been dissolved (by CaO content) up to 25%. Simultaneously, the void content increases, the imperviousness decreases, and the water absorption increases by 90%. When CaO in the concrete has been dissolved up to 33% the concrete becomes loose due to the significant strength decrease.

3. REHABILITATION OF UPSTREAM FACES OF CONCRETE DAMS

It is necessary to control the damages of the imperviousness of upstream faces of concrete dams to keep the dams in a good performance. The rehabilitation of upstream faces of concrete dams is usually to use spray coating materials and the coating is easily to be peeled off when the faces have become porous due to aging.

Asphalt concrete is impervious, corrosion-resistance, anti-aging material and presents viscoelastic behavior. It has been widely used as water barrier in dams and dikes [1, 2]. Asphalt membranes used for rehabilitating the watertightness of upstream faces of concrete dams can be traced back to 1966 for the Agger Dam in Germany. The 40 m high Agger dam was built in 1929 and the upstream face had been aged with time. The upstream face was rehabilitated by anchoring prefabricated reinforcement concrete slabs of 28 cm in thickness and filling asphalt concrete of 12 cm in thickness between the upstream face of concrete dam and the slabs.

Asphalt concrete (impervious membrane) between the prefabricated concrete slabs and upstream face of concrete dams is protected by the slabs from sunshine, air, reservoir water level fluctuations, and weathering. The aging is dramatically reduced and hence the durability of the asphalt membrane is ensured.

3.1 Thickness of Asphalt Membrane

Asphalt membrane has a high impervious gradient and a low permeability coefficient of below $10^{-9} \sim 10^{-10}$ cm/s. In order to ensure the workability and imperviousness of asphalt membrane, there should be more free bitumen in the asphalt membrane. The void content of the membrane is commonly less than 1%. Figure 1 shows the seepage versus the thickness of asphalt membrane. It can be seen that when the thickness of asphalt membrane is bigger than 3~4 cm, the seepage is dramatically reduced and can be neglected. When the thickness is bigger than 6 cm, there is no significant effect on the imperviousness of the asphalt membrane. The asphalt membrane with a thickness of 4 cm has been used for the upstream face of the Shangyoujiang concrete dam, Jiangxi Province, China, for more than 70 years and performed well. Test results indicate that the shear rheological rate of asphalt membrane increases with the increase of temperature and thickness of asphalt membrane. The thickness of asphalt membrane should be between 5~10 cm considering the factors such as the construction quality assurance, unevenness of the dam face, maximum aggregate size of asphalt membrane, convenience for construction.

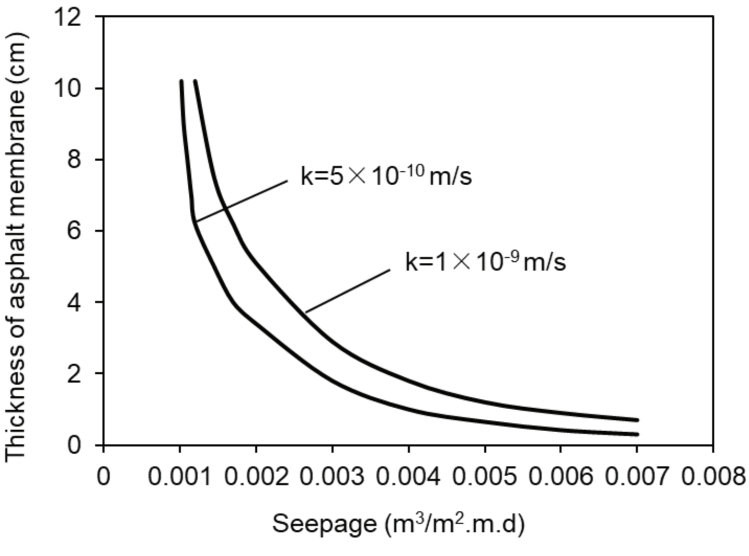


Fig. 1 : Thickness of asphalt membrane versus seepage with different coefficients of permeability.

3.2 Prefabricated Concrete Slabs

The functions of the prefabricated reinforcement concrete slabs for asphalt membrane are: (a) to be as formworks for asphalt mixture filling; (b) to prevent the asphalt membrane from losing stability due to rheology; (c) to prevent the asphalt membrane from being damaged by floating debris impacts.

The thickness of the prefabricated concrete slabs is in the range of 6-12 cm. The height and length of the slab depend on several factors such as construction equipment, technical level, convenience for installation, filling of asphalt mixture and minimization of joints of slabs. According to the practices in China, the height of slabs is in the range of 30~100 cm while the length is in the range of 100~200 cm. Figure 2 shows a typical structure of the slab.

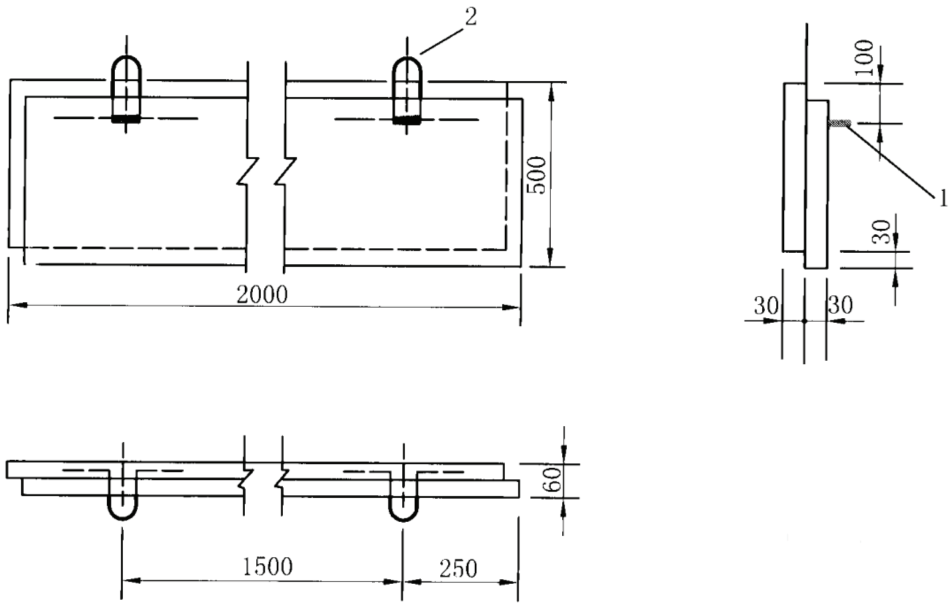


Fig. 2 : Typical structure of prefabricated reinforcement concrete slab.1: fixed ring; 2: hanging ring. Unit: mm

The slabs are fixed on the dam face by anchored reinforcement bars. The space between bars on the concrete face and diameter of the bars as well as the length of the bar in the concrete are determined according to the stability requirements of the slabs and the lateral rheological pressure of the asphalt membrane. The bar diameter is in the range of 16~20 mm and the anchoring length of the bars in the concrete is in the range of 40~150 cm.

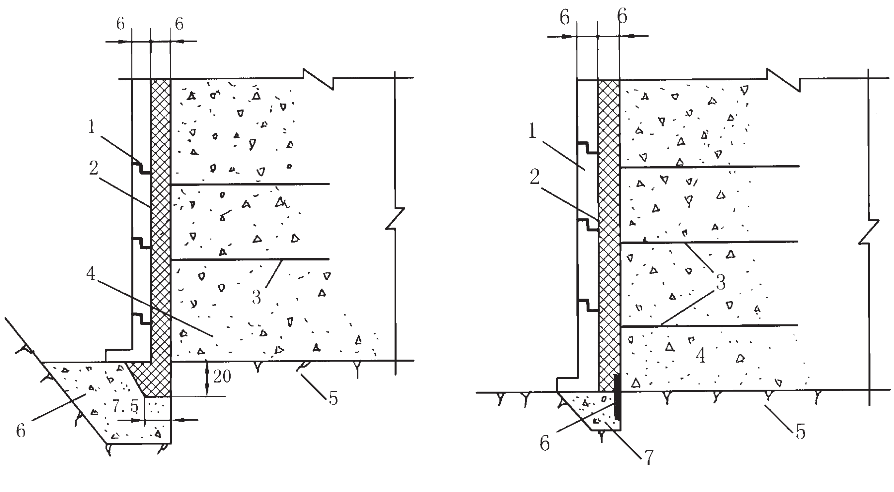
3.3 Connection of Asphalt Membrane and Perimeter Structure

There are two types of connection structures of asphalt membrane and foundation and abutment slope. One is to set cut-off groove. The width of the bottom of the groove should be larger than the thickness of the asphalt membrane, commonly 1.5 times of the thickness of the asphalt membrane. Asphalt mixture should be filled in the groove to extend the contact length. The groove bottom at the abutment slopes is designed in a slope but not steeper than 8V:1H. Other is to set water stop in the concrete base. Asphalt membrane is directly seated on the rock foundation or concrete base. One end of the water stop is embedded in the concrete base, the other end is embedded into the asphalt membrane. Figure 3 shows typical connections of asphalt membrane and rock foundation.

4. CASE STUDY

There are ten concrete dams using asphalt membrane on the upstream face of the dams in the literature [3] (Table 1). This paper is to introduce the Luowan Dam using the asphalt membrane for rehabilitating the upstream face of the dam as a case study.

Luowan concrete gravity dam is located in the northwest of Nanchang City, Jiangxi



(a) Cut-off groove (b) Water-stop

Fig. 3 : Connection of asphalt membrane and rock foundation. 1: Prefabricated reinforcement slabs; 2: asphalt membrane; 3: reinforcement bar; 4: concrete dam; 5: rock foundation; 6: concrete base or water-stop; 7: concrete base. Unit: cm.

Table 1 : Asphalt membrane used on the upstream faces of concrete dams in China.

No	Name	Year	Dam type	Dam height (m)	Impervious area (m²)	Thickness of membrane (cm)	Thickness of Slab (cm)
1	Shangyoujiang	1957	Gravity	68.5	2100	4	7.5[b]
2	Agger[a]	1966	Gravity	40	6000	12	28
3	Fengtan	1977	Hollow, arch	112.5		5	
4	Hunanzhen	1978	Trapezoid buttress	128	6343	7	4
5	Biliuhe	1981	Gravity	53.5	2140	10	10
6	Baishan	1981	Hollow, arch	149.5	800	10	6
7	Fengshuba	1973	Wide joint	95.3	3196	6	
8	Kengkou	1986	RCC	56.8	3100	6	6
9	Huanren	1989	Buttress	78.5	6700	10	6
10	Fengman	1990	Gravity	90.5	16000	10	6
a Germany. b Wood was used for the slabs.							

Province, China. It was built in the 1970s with a height of 47m. The upstream face was obviously uneven with voids and pits due to the poor construction quality at that time. There were many vertical and horizontal cracks on the upstream face of the dam after 30 years' operation. The upstream face had to be rehabilitated and asphalt membrane was selected. The thickness of the asphalt membrane is 10 cm considering the uneven upstream face. Prefabricated reinforcement concrete slabs with a size of 60 cm × 200 cm and a thickness of 6 cm were fixed on the upstream face by anchored bars. The asphalt membrane was 3300 m^2.

4.1 Materials of Asphalt membrane

The mixed bitumen was initially used with two types of B100 and B10. The ratio of the two types of bitumen was determined by tests and was 60(B00):40(B10). The property of the mixed bitumen is shown in Table 2.

Table 2 : Property of mixed bitumen.

Ratio (B100:B10)	Penetration(25°C (100g,5s) (0.1 mm)	Softening point (°C)	Ductility (25°C) (cm)
60:40	30	60	60

Crushed limestone aggregates were used for the coarse aggregates and the maximum aggregate size was 15 mm. River sand was used for fine aggregates. Limestone powder was used for the filler. Different mixes were tested on workability, density, void content, permeability, compression behavior, long-term shear rheology and other behaviors. Suitable mix was suggested for construction and is shown in Table 3.

Table 3 : Suggested asphalt mix for impervious membrane on the Luowan Dam.

	Coarse aggregate (<15mm)	River sand (<5mm)	Filler (<0.075 mm)	Mixed bitumen
Mix proportion (%)	31	31	21	17

A high bitumen quality of B70 was available during constructing the asphalt membrane on the Luowan Dam and the bitumen was used to replace the mix bitumen of B100 and B10. Accordingly, the mix proportion was adjusted by testing for the asphalt membrane and is shown in Table 4.

Table 4 : Mix proportion of asphalt membrane using B70.

	Coarse aggregate (<15mm)	River sand (<5mm)	Filler (<0.075 mm)	Bitumen (B70)
Mix proportion (%)	34	34	18	14

4.2 Construction

The thickness of the asphalt membrane is 10 cm. The size of the prefabricated slabs is 60 cm × 200 cm, with a thickness of 6 cm. The bitumen was dehydrated and heated by a thermal insulation pot with double layers. The dehydration temperature of B10 was 200°C and 140°C for B100 and B70. The dehydration time for the three types of bitumen was about 4 hours. The heating was controlled after the bitumen had been dehydrated totally so that the temperature for B10 would be controlled at 180±5°C, and at 160±5°C for B100 and B70. The bitumen was weighed and put into other thermal insulation pot at the designed ratio of B100:B10=60:40 by weight. The temperature of the mixed bitumen was controlled at 170±5°C.

According to the mix proportion, the coarse aggregate and river sand were weighed. The weight of the coarse aggregate and river sand was about 0.2 m3, heated to 200°C in the dryer, while the filler was heated to 50°C on a steel plate. The mixed aggregates and the filler were put in the mixer and mixed for 20s. The mixed bitumen or B70 bitumen was put into the mixer and mixed for 60s. The hot asphalt mixture was controlled at 160±5°C.

The upstream face of the dam face had been cleaned and dried and the prefabricated slabs had been fixed before the asphalt mixture was filled between the both. The longitudinal and transverse cracks on the dam face were manually chiseled and filled with bituminous mastic, and then pasted with polyester membrane. The positions of the anchored bars were marked on the dam face according to the arrangement of the prefabricated slabs. The holes for the fixed bars were drilled with the depth of 60~80 cm from the dam face. Cement mortar was filled in the holes and the anchored bars with diameter 16 mm were inserted to ensure the cement mortar full of the holes.

The hot asphalt mixture was unloaded into the thermal insulation tank on the four-wheel vehicle and transported to the dam top. The tank was hoisted by a truck crane on the dam top to vertically transport to the spot on the dam upstream face. When the tank was at the right place, the bottom door of the thermal insulation tank was opened and the asphalt mixture flowed into the cavity between the dam face and the prefabricating slabs. Figure 4 shows the filling of asphalt mixture into the cavity between the slab and dam face. The asphalt mixture was tamped by iron rod manually with a depth 30 cm of layer and the temperature of the asphalt mixture was controlled over 140°C.

4.3 Performance

The construction of the asphalt membrane for the Luowan Dam was started in the middle of January 2002 and completed at the end of March. The height of the dam face was covered by the asphalt membrane was 24 m and the area was 3300 m2. No leakage has been detected through the asphalt membrane in the observation gallery and the dam has performed well up till now.

5. CONCLUSIONS

Aging of concrete dams is an irreversible process. Especially, the upstream face is subjected to freezing-thawing of cycles, frost heave, and carbonation in operation. Dam performance may be seriously affected when the imperviousness of the upstream face is deteriorated with time.

There are many ways to rehabilitate the upstream face of concrete dams. However, the asphalt membrane presents the most reliable and cost-efficient alternative. All the concrete dams with the asphalt membrane have performed well. There are many concrete dams in China faced aging and imperviousness deteriorating of upstream faces. The asphalt membrane alternative is competitive technically and reliably and one of good solutions.

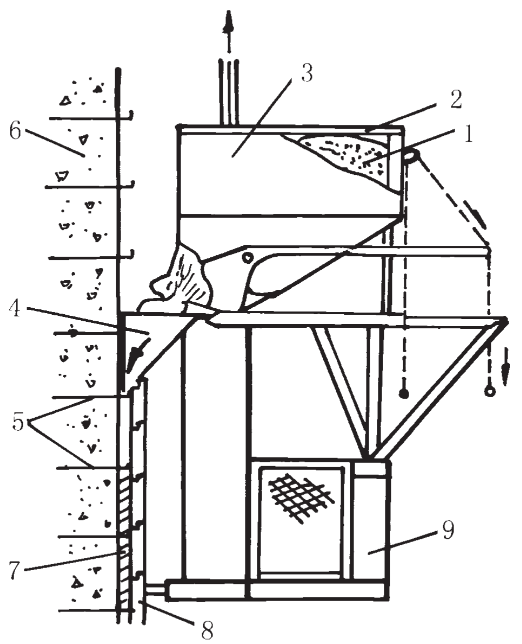


Fig. 4 : Asphalt mixture filling into the cavity between the slab and dam face. 1: asphalt mixture; 2: isolated layer; 3: tank; 4: funnel; 5; reinforcement bars; 6: dam; 7: asphalt membrane; 8: mobile hanging basket.

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