CHEMICAL ENGINEERING TRANSACTIONS

VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216

DOI: 10.3303/CET1651178

Research on Feasibility of Rubber-face Rockfill Dams

Zelin Ding*, Shuhui Guo, Bowen Sun

School of Water Conservancy, North China University of Water Resources and Electric Power, 450045, Zhengzhou, China
dingzelin@126.com

As a new dam type, the rubber-face rockfill dam (RFRD) is composed of rockfill dams as the mainstay and impervious rubber slabs rather than concrete slabs. With such advantages of rubber as high plasticity, high flexibility, good impermeability, low cost, and simple construction, the RFRD has offset what is inclined to be problematic for concrete-face rockfill dams (CFRDs), that is, slab joints are easy to open due to temperature stress and ground settlement. For operational mechanism of the RFRD, the paper designed and optimized its structure. Also, for durability of rubber, the paper undertook a freeze-thaw test and a chemical resistance test aimed to analyze how durable the rubber is and to further analyze feasibility of RFRDs.

1. Introduction

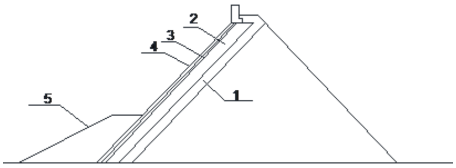
A CFRD is a rockfill dam with supporting rockfill and impervious concrete slabs on its upstream face (Xu and Guo, 2007; Xu and Deng, 2008). During normal operation of the dam, the rockfill doesn’t have direct contact with water of reservoir. Instead, water pressure is transferred to the rockfill through the slab, the bedding layer, and the transition layer (Liu, 2001; Yang et al., 2011). Therefore, the thin-wall seepage control structure may deform under direct pressure of both self-weight and water of reservoir. What’s more, influenced by temperature and material attributes of its own, the impervious concrete slab is easy to be cracked, which, if happened, will seriously harm its anti-seepage effects and service life (Zhou et al., 2015; Liu and Tang, 2007; Zhang et al., 2014; Wang and Dai, 2009). Thus, based on the stable structure of CFRDs, and in combination with high impermeability, the paper studied flexible-face rockfill dams. It is of great significant for such dams to meet the demands of structural stability against dam settlement and deformation, and to bear a good imperviousness at the same time.

Hence, with impervious materials of rubber rather than concrete, the RFRD is endowed with high plasticity, high flexibility, good impermeability, low cost, and simple construction, and is spared problems of open joints or cracked joints due to temperature stress and ground settlement as well. To address the above-mentioned problems, the paper carried research on structural design of the dam body and also conducted the durability test on the slab. The result that the rubber is perdurable proves the feasibility of the RFRD.

2. Structural design of the dam body

Given the structure of face rockfill dams, the paper replaced concrete slabs with rubber slabs. The mainstay of RFRDs on the upstream face from inside out was: transition layer, dry stone cushion, inner foam cushion, rubber face layer, and outer foam cushion wall (as shown in Figure 1). The rubber face layer was composed of adjacent multi-strip rubber slabs, whose apertures in the joint planes were connected with expansion joints (Figure 2). A concrete base was designed in the peripheral areas of the rubber face layer, which connected the rubber slab, the riverbed, and bed rock at both sides, and which fastened the bottom and side walls of the rubber face layer so as to form a waterproof closed system. Expansion joints were designed between the base and the contacted areas of the rubber face layer, with certain margins left (Figure 3). A blanket covered the rubber face layer either directly or between an outer foam cushion that was glued to the surface of the rubber face layer.

Please cite this article as: Ding Z.L., Guo S.H., Sun B.W., 2016, Research on feasibility of rubber-face rockfill dams, Chemical Engineering Transactions, 51, 1063-1068 DOI:10.3303/CET1651178



Note: 1 Transition layer, 2 Dry stone cushion, 3 Inner foam cushion, 4 Rubber face layer, 5 Outer foam cushion and the blanket

Figure 1: Structure of the RFRD

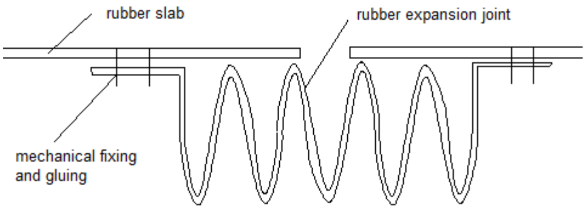


Figure 2: Diagrammatic cross section of the expansion joints

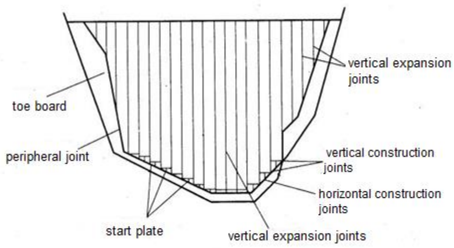


Figure 3: Front view of the RFRD

The middle section of the middle expansion joint is arranged in the transverse cavity which is to be jointed with the joint at the two ends of the joint of the adjacent rubber plate. Setting the capacity chamber at the intersection position. In the joint, the transverse cavity and the volume chamber are respectively perfused with the impervious adhesive. In the adjacent panel of rubber joints, with transverse cavity and capacity of cavity surface, which is covered with a layer of felt.

The edge expansion joint is at the end face of the joint of the rubber panel and the base connected with transverse sealing plate. Set of PVC waterstop sealing in the gap on the seams in the lateral sealing plate. The rubber panel includes a rubber layer on the inner side of the frame and the outer surface of the frame. The rubber panel, first of all, should be made of a panel frame, and then coated with a rubber layer on the outer panel.

The blanket layer with certain thickness and strength to cover the whole surface of dam. In order to reduce the damage of the rubber panel, such as wave brush, sediment erosion, heavy load impact, and so on, the dam face is covered with mud stone. The role of blanket gravity, can avoid danger under water pressure in the rubber panel is set off. The transition layer is arranged between the cover layer and the panel, which is using foam board. The masonry of stone material is solid, no weathering layer or crack, no dirt stone surface, rust and other impurities. For the surface of the stone, the color should be uniform.

3. The durability test of rubber slabs

The aging of rubber is a very important problem in the design of the RFRD. The aging of rubber which is mainly related to sunlight, temperature, oxygen, mechanical, radiation, chemical medium and the ozone in the air (Wang et al., 2009; Xiao and Wei, 2006). The rubber panel is almost not affected by the illumination, oxygen and radiation (Liu et al., 2014; Zhang et al., 2004; Zhang et al., 2009; Li and Yang, 2005; Ren and Jin, 2003). Because the bedding layer covers the entire surface of the dam (Gao, 2002). But the temperature, mechanical and chemical medium can lead to deterioration of rubber properties. Influence the durability of the rubber panel. The durability of the rubber panel directly affects the safety and life of the project. Rubber durableness affects directly construction safety and the service life of the product, hence it is of great necessary to conduct durability tests on rubber slabs. In this connection, the paper mainly considered the properties of freeze-thaw durableness, chemical resistance and mechanical test. The following were the tests and result analysis.

3.1 The freeze-thaw test

The vertical difference of reservoir water temperature is very large in summer, there was no significant difference between the upper and lower water temperatures in winter. The freeze-thaw test methods are as follows: First, the anti-frost treatment was done on the sample surface. n=0times,50times,100times, 200times,300 times of freeze-thaw cycles were done in the specified refrigerating equipment in accordance with corresponding specified technical parameters (An et al., 2010; Wang, 2009; Duan and Fang, 2013; Cheng et al., 2015).

The specified technical parameters for one freeze-thaw cycle were: cycling 2.5-4.0h; cooling 1.5-2.5h, heating up 1.0-1.5h (the thawing time shall be no less than 25% of the total time for a freeze-thaw cycle); when the cooling stage and the heating up stage ended, the corresponding central temperature for the sample shall be within (-18±2) ℃ and (5±2) ℃, respectively. Hand the temperature of the freeze-thaw fluids shall be controlled within -25-20℃.

Table 1: Results of freeze-thaw test

freeze-thaw cycles	0	50	100	200	300
Weight(g)	425	425	425	425	424
permeability	no	no	no	no	no

After 300 times of freeze-thaw cycles, no damage was found on the rubber sample, demonstrating a good freeze-thaw durability.

3.2 The chemical resistance test

By calculating the mass loss rate of the rubber sample after it was soaked in certain fluids for a time, the paper inspected its chemical resistance and water resistance (“certain fluids” were designed to be mainly a combination of saturated $Ca(OH)_2$ solution, 10% HCl solution, and 10% NaCl solution) (Ren et al., 2012; Wang et al., 2002; Liang and Yuan, 2007; Yang, 2007).

Steps: weigh the rubber sample in the air and record the value as m1. Soak the weighed sample with certain fluids in a lidded glass dish. Full contact between the sample and the fluid shall be guaranteed. No bubbles were allowed on the sample surface. No contact was allowed between each piece of samples or between the sample and the side walls of the glass dish. The sample shall be completely submerged in the fluids. During the process of immersion, the glass dish shall be placed in a cool place. The test lasted for 3600h (or 5 months).

After the test was finished, take the sample out of the glass dish. Rinse the sample with distilled water repeatedly with no liquid residual. Wipe the sample dry with filter paper. Set the sample under the temperature of (60±2)℃ for 24h. Weigh the sample again and record the value as m^2.

Calculate the mass loss rate according to the following expression:

$$\triangle m= (m1-m2)/ m1\times 100\%$$

Where △m denoted the mass loss rate, %; m1 denoted the sample quality before the soaking, g; m2 denoted the sample quality after the soaking, g.

Five parallel tests were done on chemical resistance. The average mass loss ratewas calculated as shown in Table 2.

Table 2: Results of mass loss rate

Item		result	specification
Mass loss rate /% (room temperature)	water	0.036	≤2
	Saturated $Ca(OH)_2$ solution	0.128	≤2
	10% NaCl solution	0.4	≤2

Note: The referenced specification is DLT949—2005 Standard for Joint Plastic Sealant of Hydraulic Structure.

As seen from the test results, the mass loss rate of the rubber after it was soaked for 3600h was lower than the specified value. This proved a good fluid-proof stability for the rubber and that the rubber had satisfied the specification.

3.3 mechanical test

Rubber panels are acted by water load on the RFRD, is under the bending stress, tensile stress and compressive stress (Luo et al., 2015). In the test, get 10 group of acrylonitrile-butadiene rubber, which subjected to stress free, bending stress and tensile bending stress. Bending stress is bending the sample to the bending and fixing both ends. Tensile bending stress is bending of the sample after tension (tensile strain of about 2%). Test results see table3.

Table 3: acrylonitrile-butadiene rubber under different stress

stress	stress free	bending stress	tensile bending stress
Storage life	19a	9.7a	2a

Rubber material will accelerate aging by stress in table 3. Especially by tensile bending stress. The joint planes are connected with expansion joints is very necessary. It can avoid the rubber panel by over stretching.

3.4 Properties of rubbe in natural aging

Table 4: Properties of cross-linked rubber in natural aging

Rubber specimen	Year(t)	Shore hardness	elongation at break	tensile strength(Mpa)	modulus at100% (Mpa)	Stress relaxation coefficient	Compression deformation coefficient (%)
1 acrylonitrile-butadiene rubber (1#)	0	75	242	11.5	6.8	1	0
	8	81	153	12.9	9.7	0.73	47
	18	83	148	13.3	12.4	0.59	67
	28	85	131	12.8	-	0.51	77
2 acrylonitrile-butadiene rubber (2#)	0	81	152	18.4	12.5	1	0
	8	83	173	19.3	12.3	0.81	16
	18	83	153	18.1	-	0.8	19
	23	81	157	17	10.3	0.8	21
3 silicon rubber (1#)	0	45	329	6.2	1.2	1	0
	8	53	265	4.4	1.5	0.78	27
	17	52	260	6.4	-	0.81	38
	27	55	271	3.8	1	0.81	41
4 silicon rubber (2#)	0	45	275	4.3	1.4	1	0
	8	52	240	3.9	1.6	0.53	73
	17	56	224	3.9	-	0.44	81
	27	59	203	3.6	-	0.4	84
5 chloroprene rubber	0	77	301	13	5.4	1	0
	8	86	197	13.3	10	0.45	79
	18	89	132	13.5	11.6	0.38	88
	28	90	133	11.9	-	0.32	91
6 fluorine rubber	0	78	297	17.9	5.5	1	0
	8	80	310	18.2	5.8	0.72	43
	18	78	321	17.9	-	0.67	51
	23	78	329	17.6	-	0.68	52

The tensile strength, elongation at break, modulus at 100%, Stress relaxation coefficient and compression deformation coefficient of rubber is very important in the RFRD, it represents the normal work of the rubber panel. Table 4 is the properties of rubber materials in natural aging, it shows the physical properties of rubber seals changing with aging time. Such as acrylonitrile-butadiene rubber (1#), from 0 to 28 years, the hardness of the material is almost unchanged, it ensures that the rubber will not be damaged by floating matter in river. The tensile strength of test pieces changed little, it prevent the rubber panel crack failure by the dam settlement deformation. The elongation at break and compression deformation coefficient Indicates that the material remains plastic.

4. Conclusion

RFRD has a good effect on hydraulic engineering. It has good plasticity, flexibility and anti permeability, and the construction is simple and the cost is low. Compared with the concrete face rockfill dam, the RFRD does not need to consider the temperature stress, the foundation settlement and other factors caused the joint opening, fracture and so on. Compared with the rubber dam (Closed bag, which is filling water or air to form a water retaining bag is only for water crest water resistance. The largest rubber dam is only 6 meters). Rubber dam with high strength and high stability characteristics, more suitable for high dam construction.
Through the structure design in the aging problem of bedding layer covering dam surface to solve the rubber panel. Through the durability test on rubber, it can be found that the use of perdurable and chemical-resistant rubber guarantees both quality and service life of RFRDs. With rubber slabs, the RFRD is endowed with high plasticity, high flexibility, good impermeability, low cost, and simple construction. Also, compared to the CFRD, the RFRD is spared problems of open joints or cracked joints due to temperature stress and ground settlement as well. The effect of stress on the storage life of rubber is great. The stress accelerated the aging process of rubber. The expansion joints avoid the rubber panel by over stretching which is set between adjacent panels. The design of RFRDs is proved to be feasible.

Acknowledgments

This work is financially supported by NSFC-Henan Provincial People's Government Joint Fund of Personnel Training (No. U1304511), Henan Provincial Natural Science Foundation (No. 132300410020, No. 112300410035), Collaborative Innovation Center of Water Resources Efficient Utilization and Protection Engineering, Henan Province, Program for Science & Technology Innovation Talents in Universities of Henan Province (No. 15HASTIT049), and Program for Innovative Research Team (in Science and Technology) in University of Henan Province (No. 14IRTSTHN028). Our gratitude is also extended to reviewers for their efforts in reviewing the manuscript and their very encouraging, insightful and constructive comments.

References

An X.Z., Yi C., Liu Y., et al, 2010, Study on Concrete Damage Experiment under Sulfate Attack and Freeze-thaw Cycles, China Concerete And Cement Products, (2): 1-3. Doi: 10.3969/j.issn.1000-4637.2010.02.001.

Cheng Z.K., Chen X.H., Huang Y.Y., et al, 2015, Impacts of temperature loads on working behavior of arch dam during changing water level. Hydro-Science and Engineering, (5): 75-81, Doi: 10.16198/j.cnki.1009-640X.2015.05.010.

Duan G.Z., Fang C.Q., 2013, Research progress and new thinking of destruction of concrete due to freeze-thaw cycles. Concrete, 0(5):16-20. Doi: 10.3969/j.issn.1002-3550.2013.05.005.

Gao B.H., 2002, development and prospect of rubber dams at home and abroad. Water Resources and Hydropower Engineering, 33(10):5-8. Doi: 10.3969/j.issn.1000-0860.2002.10.002.

Liu X.D., Xie J.J., Feng Z.X., et al, 2014, Research Progress on Accelerated Aging and Life Prediction Method for Rubber Material. Synthetic Materials Aging and Application, 43(1):69-73. 10.3969/j.issn.1671-5381.2014.01.018.

Liu X.L., Tang G.G., 2007, Research on prediction method of concrete freeze-thaw durability under field environments. Chinese Journal of Rock Mechanics and Engineering, 26(12): 2412-2419. Doi: 10.3321/j.issn:1000-6915.2007.12.005.

Liu X.L., 2001, Fundamental Research On Safety and Durability of Major Structures In Civil And Hydraulic Engineering. China Civil Engineering Journal, 34(6): 1-7, Doi: 10.15951/j.tmgcxb.2001.06.001.

Li X.F., Yang X.X., 2005, A review of elastic constitutive model for rubber materials. China Elastomerics, 15(1):50-58. Doi: 10.3969/j.issn.1005-3174.2005.01.013.

Liang Y.N., Yuan Y.S., 2007, Mechanism of concrete destruction under sodium sulfate and magnesium sulfate solution. Journal of the Chinese Ceramic Society, 35(4):504-508. Doi: 10.3321/j.issn:0454-5648.2007.04.022.

Luo S.R., Chen W.M., Wang X.F., 2015, Fracture properties of rubberized self-compacting concrete. Journal of Hydraulic Engineering, 46(2): 217-222. Doi: 10.13243/j.cnki.slxb.2015.02.011.

Ren S.W., Jin Z., 2003, Present status and analysis of determination standards for standard rubber properties. China Rubber Industry, 50(9):569-573. Doi: 10.3969/j.issn.1000-890X.2003.09.014.

Ren X.C., Wan X.M., Zhao T.J., 2012, Review of mechanism and mathematical model for salt scaling and freezing-thawing damage of concrete. Concrete, 0(9):15-18. Doi: 10.3969/j.issn.1002-3550.2012.09.006.

Wang F.S., Sun R.L., Qin X.J., 2002, The Investigation of Concrete Durability under Natural Condition of Ca Er Han Salt Lake. Bulletin of the Chinese ceramic society, 21(4): 16-21.10.3969/j.issn.1001-1625.2002.04.004.

Wang L.J., 2009, Predicting numerical model for the for the freeze proof durability of concrete. Concrete (4):1-4. Doi: 10.3969/j.issn.1002-3550.2009.04.001.

Wang S.J., Xiong J.P., Zuo Y., 2009, Study on Aging Mechanism of Rubbers, Analyzing Thermo-oxidation Aging of NR Vulcanizate by Using Thermal Analysis and PGC-MS. Synthetic Materials Aging and Application, 38(2): 23-33, Doi: 10.3969/j.issn.1671-5381.2009.02.006.

Wang Y., Dai H.C., 2009, Effects of Water Temperature Delamination in Large-scale Reserviors and Protection Methods. Journal of China Three Gorges University (Natural Sciences), 31(6):11-14. Doi: 10.3969/j.issn.1672-948X.2009.06.003.

Xiao Y., Wei B.R., 2006, Analyzing Thermo-oxidation Aging of NR Vulcanizate by Using Thermal Analysis and PGC-MS. Synthetic Materials Aging and Application, (2): 21-23, 10.3969/j.issn.1671-5381.2006.02.007.

Xu Z.P., Deng G., 2008, Development of high CFRD and key technologies for building super-high CFRD.39 (10):1226-1234. Journal of Hydraulic Engineering, Doi: 10.13243/j.cnki.slxb.2008.10.011.

Xu Z.P., Guo C., 2007, Research on the Concrete Face Slab Rupture of High CFRD, Water Power, 33(9): 80-84. Doi: 10.3969/j.issn.0559-9342.2007.09.029.

Yang J., Hu D.X., Wu X.L., 2011, The Safety Monitoring on 200-Meter High CFRDs. Advanced Materials Research, 204-210: 2123-2127. 10.4028/www.scientific.net/amr.204-210.2123.

Yang Q.B., 2007, Effects of sodium chloride concentration on saturation degree in concrete under freezing-thawing cycles. Journal of the Chinese Ceramic Society, 35(1): 96-100. Doi: 10.3321/j.issn:0454-5648.2007.01.021.

Zhang G.X., Chen P.P., Zhou Q.J., 2014, Real temperature load and the influence on the working performance of super-high arch dam. Engineering 45(2):127-134. Doi: 10.13243/j.cnki.slxb.2014.02.001.

Zhang K., Huang Y.H., Ma Y., et al, 2004, Methods for Accelerated Aging Tests and Shelf-life Predictions of Rubber Materials . Chemical Propellants & Polymeric Materials, 2(6):44-48. 10.3969/j.issn.1672-2191.2004.06.013.

Zhang L.P., Li H., Liu Y.P., et al, 2009, Research status and development trend on aging test of rubber materials. China Elastomerics, 19(4):60-63, Doi: 10.3969/j.issn.1005-3174.2009.04.016.

Zhou M.Z., Zhang B.Y., Zhang Z.J., et al, 2015, Mechanisms and simulation methods for extrusion damage of concrete faces of high concrete-faced rockfill dams. Chinese Journal of Geotechnical Engineering, 37(8): 1426-1432. Doi: 10.11779/CJGE201508010.