CENTRIFUGE MODEL TESTS ON THE CONNECTING FORM BETWEEN CUTOFF WALL AND COMPOSITE GEOMEMBRANE OF COFFERDAM

B. Li [1], Y. H. Cheng[2], and Z. L. Cheng[3]
[1] Changjiang River Scientific Research Institute; Tel: +86-27 82820427; Fax: +86-27 82820428; Email: libo_auliso@126.com
[2] Changjiang River Scientific Research Institute; Tel: +86-27 82927236; Fax: +86-27 82820428; Email: chengyh@mail.crsri.cn
[3] Changjiang River Scientific Research Institute; Tel: +86-27 82926043; Fax: +86-27 82820428; Email: chengzl@mail.crsri.cn

ABSTRACT

The connection effectiveness between cutoff wall and composite geomembrane of cofferdam, which are both usually applied in the cofferdam engineering, plays an important decisive role in seepage control. Based on the site invitation of stage II cofferdam of TGP (Three Gorges Project), three centrifuge tests are performed in order to reveal the mechanism of the connecting form of cutoff wall and composite geomembrane through measuring the displacements of the cofferdam the fillings and cutoff wall and the strain of the composite membrane. The friction between the composite geomembrane and the cofferdam fillings is so large that the deformation expansion joint can't work. Two main influencing factors include the settlement of the weathered sand foundation and the lateral displacement of cutoff wall, which both play a decisive function on the fracture of the composite geomembrane. Furthermore, an improved method of the connecting form of the cutoff wall and composite geomembrane is proposed and validated by centrifuge testing. The improved method provides a reliable evidence for cofferdam engineering designing and construction.

Keywords: Cofferdam, composite geomembrane, cutoff wall, connecting form, centrifuge tests

INTRODUCTION

As an impervious system, the combination of cutoff wall and composite geomembrane is usually applied in the hydraulic engineering[Taeyoon & Craig 2000, Gu 2002, Cen et al 2009, Zhang et al 2011], in which the connection effectiveness plays a decisive role in seepage control. The impervious system is known as the lifeline of the cofferdam[Zheng et al. 1999]. Assuming that the deformation of the cutoff wall were inconsistent with that of the composite geomembrane, the composite geomembrane would be tension crack or tensile failure, which would brought hidden danger to the whole cofferdam. Take one cofferdam for example observed in site, as shown in Fig. 1 and Fig. 2, there are some damages near the connection between cutoff wall and composite geo-membrane of cofferdam, and the cutoff wall separated significantly from the cofferdam where the geomembrane is lay. Whether the water level were higher than the embankment, the water would flow through the cofferdam, which would cause the whole cofferdam instability or failure. Therefore, it is necessary to better understand the mechanism of the interaction of cutoff wall and composite geomembrane of cofferdam.

The site investigation was carried out during the period for the removal of the stage, and some key factors were analyzed and discussed based on these results (Li et al. 2005). First of all, there are large disagreement of settlements between the cutoff wall and the fillings of the cofferdam, which is about thirty centimeters long. The main reason is that settlement of the membrane is larger because it was lay on the weathered sands, which could be compressed easily under the weight of the overlying weathered sands, while the cutoff wall is made of the concrete and has little settlement. So the disagreement of the two parts could cause tensile stress near the connection, and the disagreement increases to be so large that the membrane could be damaged. Secondly, the horizontal deformation of the cutoff wall could cause the disagreement between the fillings and the cutoff wall, which is about five to fifteen centimeters width got from the field investigation. The relative displacement could make the membrane to tensile, when the tension is larger than the tensile strength of the membrane, the membrane could be torn.

The two main reasons are inferred from the excavation of the cofferdam from, which hardly shows the real failure process of the geomembrane. Therefore, the interaction between the geomembrane and the fillings of the cofferdam should be deeply studied through laboratory tests. Three centrifuge tests on the research of the connection form between geomembrane and the cutoff wall are carried out in order to reveal the failure process of the geomembrane under the settlements of the fillings and disagreement between the cutoff wall and the fillings. Furthermore, an improved method of the connecting form of the cutoff wall and composite geomembrane is proposed and validated by centrifuge testing.

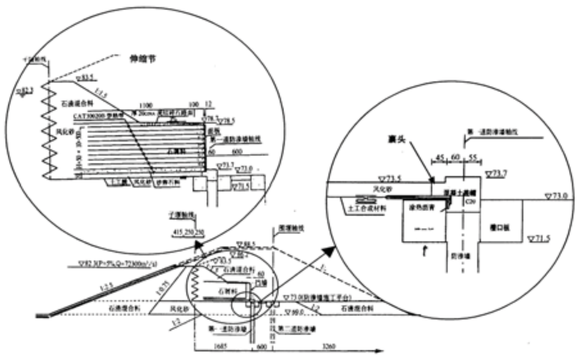
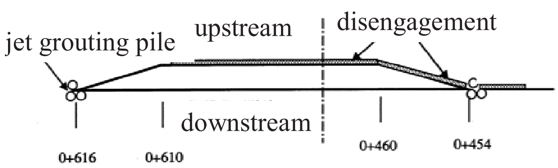
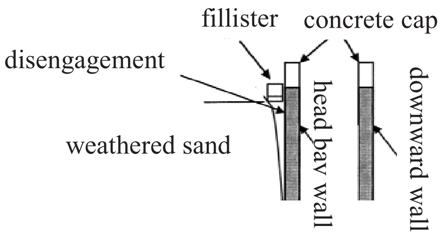


Fig. 1 Connecting form of geomembrane, sub cofferdam and cutoff wall.



(a) top view



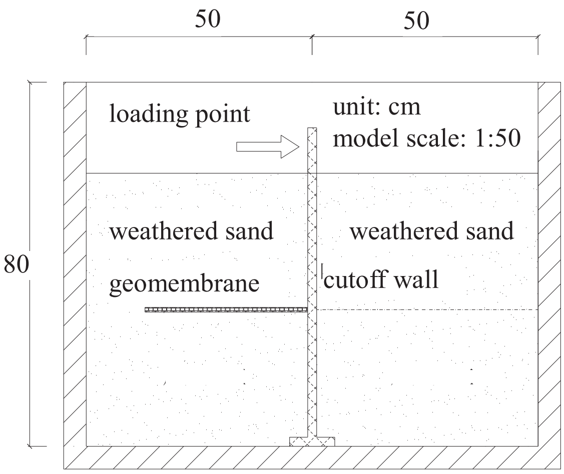
(b) front view

Fig. 2 Scheme of disengagement between the fillings and the cutoff wall

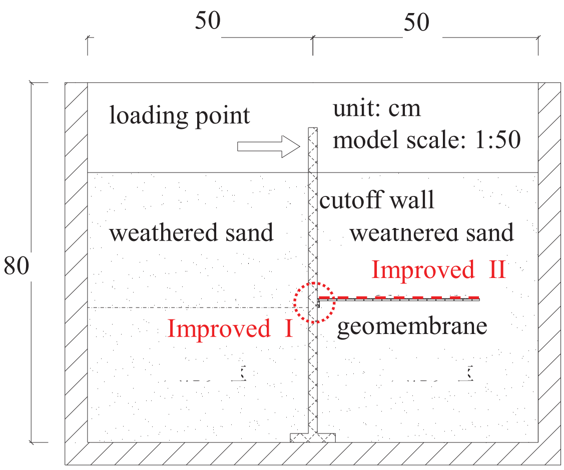
CENTRIFUGE MODEL TESTS

Generalized model

In stage II cofferdam of TGP, the height of the overlying the fillings on the top of the geomembrane is fifteen meter, and that below the geomembrane is also fifteen meter. The length of geomembrane is eighteen meter long with a 0.1 meter expansion joint, which is 3 meter far away from the connection site. In the present study, Table 1 demonstrates that three 1:50 scale centrifuge model tests were performed using a 3.7 m balanced beam centrifuge at Changjiang River Scientific Research Institute. In the centrifuge tests, the weathered sand used is excavated from the site cofferdam, and the length of geomembrane is 30 centimeter long, with a 2 centimeter expansion joint 6 centimeter far from the connecting site. Scheme of centrifuge model tests of connecting form of cofferdam cutoff wall and geomembrane is shown in Table 1. The dimension and arrangement of geomembrane and the cutoff wall is shown in Fig. 3. The effect of the settlements of the underlying the fillings below the geomembrane is modeled in SX-1; the effect of the disengagement displacement between the cutoff wall and the fillings is modeled in SX-2; an improved method of the connecting form of the cutoff wall and composite geomembrane is validated by centrifuge testing in SX-3.



(a) Cross-section of SX-1 and SX-2



(b) Cross-section of SX-3

Fig. 3 Cross-section profile of the models

Table 1 Scheme of centrifuge model tests of the connecting form between cutoff wall and composite geomembrane.

Tests No.	Direction of membrane	Influencing factors	
		Settlement	Disagreement
SX-1	upstream	Yes	No
SX-2	upstream	No	Yes
SX-3	downstream	Yes	Yes

Equipments

Changjiang River Scientific Research Institute is one of the earliest institutes where geotechnical centrifuge was researched. And the first geotechnical centrifuge equipment with largest available capacity was successfully developed and built in 1982, which played an important role in several Chinese National Programs for Science and Technology Development and Large-Scale Engineering Projects, and lots of pioneering research achievements were obtained through these tests carried out in this centrifuge. In 2006~2008, the second modernized multifunctional geotechnical centrifuge equipment was upgrading and reconstructed at different place. The payload capacity is 200 gt, with a maximum acceleration of 200g for static tests. The effective radius is 3.7 meter. There are two kinds of model boxes, which are 0.1m×0.1m×0.1m and 0.1m×0.4m×0.8m (Cheng et al. 2011).

Model materials

The model the fillings of the cofferdam is weathered sand excavated from the field, of which the density is 17.5kN/m^3. Because it is used to provide boundary displacement conditions, of which the stress and strain are not the research emphasis, the model cofferdam here is simply modeled as a rectangle plate, whose thickness is 0.2 centimeter, the height 70 centimeter, the width 39 centimeter. There exists a platform welding with the plate in order to fix the bottom of the plate. A gripping device is developed at the 30 centimeter height of the plate with the purpose of connecting the geomembrane and the plate.

The model geomembrane is the key point in these centrifuge tests, which determined the reliability of the tests results. The composite geomembrane used in the field was “two fabrics and one membrane”, whose tensile strength is 20kN/m (both longitudinal and latitudinal direction), the elongation rate larger than 30%, thickness larger than 0.5 millimeter. For the model geomembrane used in centrifuge tests, the tensile strength, the elongation rate and the fiction coefficient between the geomembrane and weathered sand should resemble with those of the prototype material. Through the comparison and selection of many geomembrane materials, the one whose tensile strength is 0.75kN/m, the elongation rate is 45% and the fiction coefficient is 0.25 can nearly satisfy the test requirements.

Monitoring Items and Measurement Equipments

As shown in Fig. 4, the settlement at the top of the fillings and the geomembrane and the lateral displacement of the cutoff wall are measured through high precision laser displacement sensors. The layered settlement markers are arranged at the flank of the model, which can be measured from the front perspex window. As shown in Fig. 5, many strain gauges are arranged at different sections. A jack is placed at the top of the rectangle plate, which can cause the rectangle plate the given displacement.

Fig. 4 High precision laser displacement sensors

CENTRIFUGE TESTS RESULTS

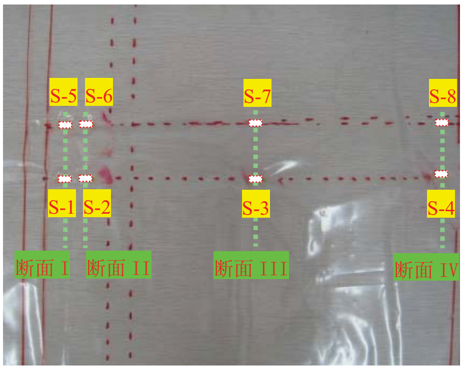
In the analysis of the three centrifuge tests results, the photos of the geomembrane at the connection after every test qualitatively show the cracking of the geomembrane and changing situation of the expansion joint. And then the relationship curves between the geomembrane strain and settlement at the top of the fillings, the relationship curves between the geomembrane strain and the disagreement of the fillings and the cutoff wall quantitatively are given to reveal the failure process of the geomembrane.

The Effect of the Fillings Settlement in SX-1

Figure 6 shows the connection between geomembrane and the cutoff wall. The crack appears just at the connecting line and the indentation of the whole geomembrane is obvious. The expansion joint is not stretched.

Figure 7 shows the relationship curves between the geomembrane strain and settlement at the top of the fillings. The more the distance to the connection line, the less the tension of the geomembrane. The stain of the point 2 centimeter far from the connecting line increases with the increase of the settlement, and reaches the maximum value of 4500με when the settlement is about 10 millimeter, and decreases after the settlement is larger than 12 millimeter, from which the prediction got that the geomembrane could be tensile fracture.

(a) Layout of the composite geomembrane



(b) Eight strain gauges

Fig. 5 Arrangement of geomembrane and strain gauges

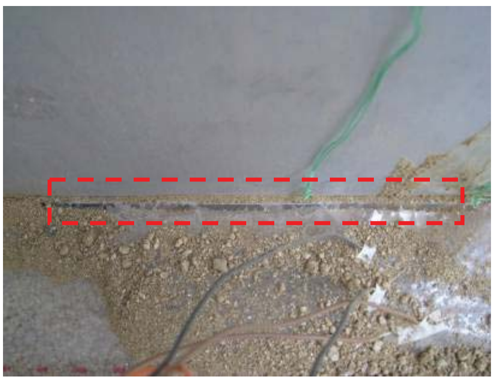


Fig. 6 Geomembrane of SX-1 after operation

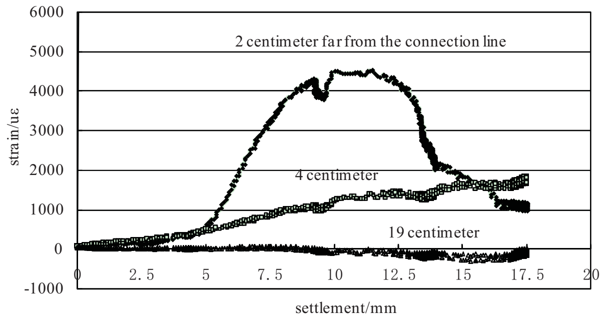


Fig. 7 Strain-settlement of SX-1

THE EFFECT OF THE DISAGREEMENT BETWEEN THE FILLINGS AND THE CUTOFF WALL IN SX-2

Figure 8 shows the connection between geomembrane and the cutoff wall. The geomembrane is totally stretched to failure, except two narrow connected bands.

Figure 9 shows the relationship curves between the geomembrane strain and the disagreement between the fillings and the cutoff wall. All the strains of the three sections are relatively minor, of which the largest value is less than 700με. The stain of the point 2 centimeter far from the connecting line increases with the increase of the disagreement, and reaches the maximum value when the settlement is about 1.5 millimeter, and then decreases.

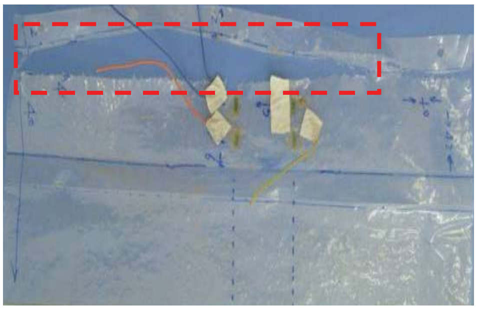


Fig. 8 Geomembrane of SX-2 after operation

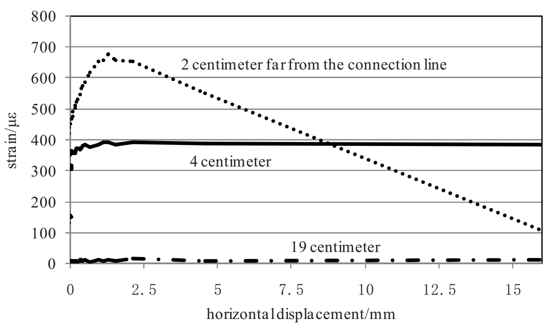


Fig. 9 Strain-lateral displacement of SX-2

An Improved Method of the Connecting Form of the Cutoff Wall and Composite Geomembrane Validated in SX-3

The first two centrifuge tests show that both the fillings settlement and the disagreement between the fillings and the cutoff wall can make the geomembrane failure. In order to avoid the geomembrane tensile failure, it is better to lay out the expansion joint at the connection and arrange the membrane at the downstream side, as shown in Fig. 10. And then two centrifuge tests on both the effects of the fillings settlement and the disagreement between the fillings and the cutoff are carried out successively. It shows the connection between geo-membrane and the cutoff wall after tests, as shown in Fig. 11. The geo-membrane is totally unbroken. The strains of all the gauges at different sections are less than 200με, which means that there are no stress concentration occurs.

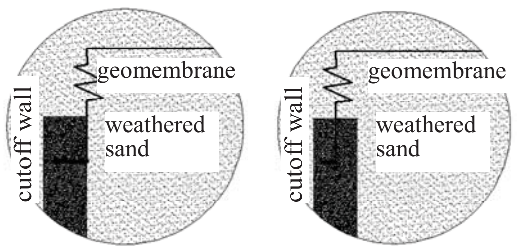


Fig. 10 Improvement of geomembrane paving method

Fig. 11 Geomembrane of SX-3 after operation

CONCLUSIONS

The first two centrifuge tests show that both the fillings settlement and the disagreement between the fillings and the cutoff wall can make the geomembrane failure.

The relationship curves between the geomembrane strain and the settlement at the top of the fillings, and those between the geomembrane strain and the disagreement of the fillings and the cutoff wall quantitatively reveal the failure process of the geomembrane. There exist a critical settlement of the fillings and a critical disagreement between the fillings and the cutoff wall. When the fillings settlement or the disagreement between the fillings and the cutoff wall is larger than this value, the geo-membrane will be tension crack or tensile failure.

An improved method of the connecting form of the cutoff wall and composite geomembrane is proposed and validated by centrifuge testing. The geo-membrane is firstly lay vertically, appressing to the cutoff wall, and then lay down at the downstream side. The improved method provides a reliable evidence for cofferdam engineering designing and construction.

REFERENCES

Taeyoon Lee and Craig H. Benson. 2000. Flow past bench-scale vertical ground-water cutoff walls. Journal of Geotechnical and Geoenviromental Engineering, 126(6):511–520.

Gu Gan-chen. 2002. Review of dams and dikes with composite geomembrane impervious structure. Water Resources and Hydropower Engineering, China, 33(12): 26-32.

Cen Wei-jun, Shen Chang-song, Dong Jian-wen. 2009. Study of construction behavior of composite geomembrane rockfill dam on thick alluvium deposit. Rock and Soil Mechanics, China, 30(1): 175–180.

Zhang You-xiu , XU Wei , WANG Jun-xing. 2011. An analysis of calculation results for the seepage stability of the upstream cofferdam of the shenxigou hydropower station. China Rural Water and Hydropower, China, 5:169−171.

Zheng Shou-ren, CHEN Gong-xin. 1999. Design, construction and operation of phase-II transverse cofferdam. China Three Gorges Construction, China, 5:21-24.

Li Qing-yun, CHENG Zhan-lin. 2005. Analysis of the behavior of stage II cofferdam of TGP. Chinese Journal of Geotechnical Engineering, China, 27(4) : 410−413.

Cheng Yong-hui, LI Qing-yun, RAO Xi-bao, etc. 2011. Application and development of geotechnical centrifuge in Yangtze River scientific research institute. Journal of Yangtze River Scientific Research Institue, China, 28(10):141-147.