Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Application of a large strain gauge to measure the deformation of composite geomembrane in the Three Gorges Project cofferdam

Bao, C.G. & Li, Q.Y.
Key Laboratory of Geotechnical Mechanics and Engineering of the Chinese Ministry of Water Resources
Yangtze River Scientific Research Institute, China

Gong, L.H.
Institute of Rock and Soil Mechanics, The Chinese Academy of Science, China

Keywords: large strain gauge, composite geomembrane, cofferdam, cut off wall, monitoring

ABSTRACT: The stage II cofferdam of Three Gorges Dam Project (TGDP) is a protective barrier for the construction of the Three Gorges dam. The maximum height of it is 88.5 m. The cofferdam body was filled with decomposed granite sand, a loose and pervious material, dumping into deep water (60 m deep). The composite geomembrane was selected to be a part of the seepage proof system connected to the high plastic concrete cut-off wall in the body from the elevation of 71.5 m up to the top of seepage proof system in elevation of 86.2 m, totally 15 m high. For measuring the deformation of the geomembrane and thus detecting the working situation of the cofferdam during constructing and operating period, a new type of large strain gauge was specially developed and total 18 pieces of such strain gauges were set on the geomembrane in different elevations of the geomembrane cut-off wall. The monitoring work was lasted about 3 years and a large amount of data was obtained. According to the data analysis, it is realized that the tensile strain of geomembrane in cofferdam is commonly about 11%. The largest strain (20%) appeared in the point where the geomembrane was bended in a right angle form, it means the displacement of geomembrane at one end was restricted, but at another end of geomembrane, the deformation was enlarged. The result shows the fact that not only the deformation pattern was clarified, but the safety of the cofferdam was demonstrated, moreover, the effectiveness of the new type of large strain gauge was examined as well.

1 INTRODUCTION

The stage II cofferdam of Three Gorges Dam Project (TGDP) is a high earth-rock cofferdam with the maximum height of 88.5 m. The cofferdam body was filled with decomposed granite sand dumping into deep water (60 m deep). In order to control seepage condition for the cofferdam, two vertical and plastic concrete diaphragms were built in the body, and were installed into the bedrock 1 m at the bottom. However, the top of one concrete wall was connected with composite geomembrane (Fig. 1), the elevation of connecting point is 71.5 m, and then the composite geomembrane goes up to reach the elevation of 86.2 m. To ensure cofferdam safety, the deformation monitoring on geomembrane is very important.

In the past 20 years, different products of geosynthetics have been widely used even in every civil engineering field in China. Nevertheless, the study on working mechanism, such as deformation of geosynthetics, and its monitoring techniques are not developed very well. In this paper, a new kind of large strain gauge for measuring the deformation of geosynthetics (geotextiles or geomembranes) was described and the corresponding key technique was presented as well (Gong Lu-hua, Li Qing-yun, Bao Cheng-gang, 2005), which including: (1) seeking an appropriate glue to get a best sticking effect, and this glue after dried should be with the property of lower modulus as the same as strain gauge; (2) developing a new calibration method in order to determine two important parameters of strain gauges and (3) solving the problems related to installation and protection of strain gauges. This paper reports mainly on the properties of large strain gauge and its application in field monitoring for composite geomembrane at the high earth-rock cofferdam of TGDP.

2 BRIEF INTRODUCTION OF GEOMEMBRANE AND LARGE STRAIN GAUGE

The large strain gauge (LSG) is a new kind of instrument developed by Authors. It is specially used to measure the strain of composite geomembrane. The composite geomembrane consists of a PVC membrane in the centre and non-woven geotextile

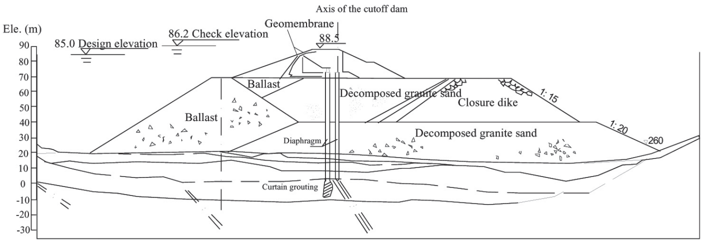

Figure 1. Sketch of the section of stage II cofferdam of TGDP.

adhered to both sides of geomembrane. It has a large percentage elongation up to 30%, and can meet the needs of engineering purpose (for TGDP, the largest strain for composite geomembrane will not be exceed 15%).

The working mechanism of LSG is similar to the common strain gauge, i.e. the measured strain value, ε_s, is basically proportion to the resistance of gauge (Slumen, G 1982):

$$\varepsilon_s = (1/K)(R - R_0)/R_0 \tag{1}$$

Where R = the reading of resistance, R_0 = the initial value of resistance, K = coefficient of sensitivity.

The actual strain of geomembrane can be calculated from the following equation:

$$\varepsilon_i = A + B\varepsilon_s \tag{2}$$

Where A = a coefficient related to geomembrane, as shown in Table 1 and $B = 1/K$.

There are two important technical points should be solved for LSG as follows.

(1) *Seeking an appropriate glue*

The glue for adhering the strain gauge on geomembrane is a key technique for developing LSG. The selected glue should have some properties as: high bonding strength, easy to dry and less shrinkage during drying, the modulus as same as the strain gauge after it solidification.

(2) *Developing a new method for calibrating the gauge*

The parameters of K and A should be calibrated using geomembrane samples adhered with strain gauge. The calibrating results by 6 samples with the size of 220 mm × 180 mm are shown in Table 1.

3 MONITORING RESULT AND ANALYSIS

To detect the deformation of the geomembrane, 18 pieces of strain gauges (ST01~ST18)were placed at different elevation at the sections 0 + 500 and 0 + 930 in May 1998, as shown in Figure 2.

Among 18 gauges, 10 of them were destroyed by construction after three months installed and the others worked well until August 22, 2001, i.e. monitoring period lasted 3 years and 3 months. As can be seen from Figure 3~Figure 5, the deformation of geomembrane with time can roughly be divided into three stages:

Table 1. The calibrating results of the geomembrane used in TGDP.

No	A	B (sensitivity coefficient $k = 1/B$)	Correlation coefficient
1	0.94	0.86	0.999 6
2	0.97	0.75	0.998 5
3	1.01	0.81	0.998 0
4	1.07	0.82	0.998 6
5	1.03	0.80	0.999 6
6	1.12	0.80	0.998 6
Mean	1.02	0.84	0.998 8

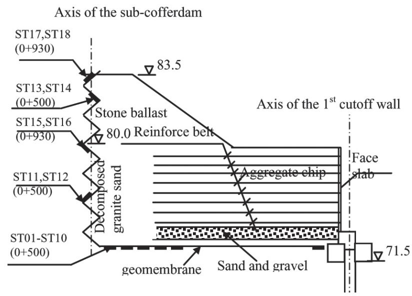

Figure 2. Sketch of embedded location of the geomembrane and the strain gauges.

(1) The first stage is characterized with the little and undulation increment of strain, because the covered soil layer is thin and the load on geomembrane is not great. Besides, the influence of the compaction roller has not completely disappeared.
(2) In the second stage, the strain of the geomembrane is relatively steady. At that time, the load on the geomembrane is great but stable.
(3) The third stage is characterized by rapid increment of strain of the geomembrane, mostly reach up to 11%~19%, several large strain gauges were destroyed due to the large strain exceeded its capacity limit. The appearance of the third stage

is not at the same time for different gauges, and the measured strains in this stage have a feature of diversity in deferent position. This is because of the actual filling time and filling height in deferent position is not the same.

The measured results by the large strain gauge at three sections are discussed as follows:

(1) 0 + 500 section (the main cofferdam section)

In section 0 + 500, the geomembrane was placed on the elevation of 73.5 m in horizontal form. Ten strain gauges (ST01~ST10) were destroyed in July or August 1998 after installed 3 months later, due to quick filling work at the construction time. The measured date and the results of strain are shown in Figure 3. From Figure 3, it indicates that the second stage (at that stage the strain is stable) is relatively short (45~50 d). According to the data, the deformation of geomembrane is up to 11%-19%.

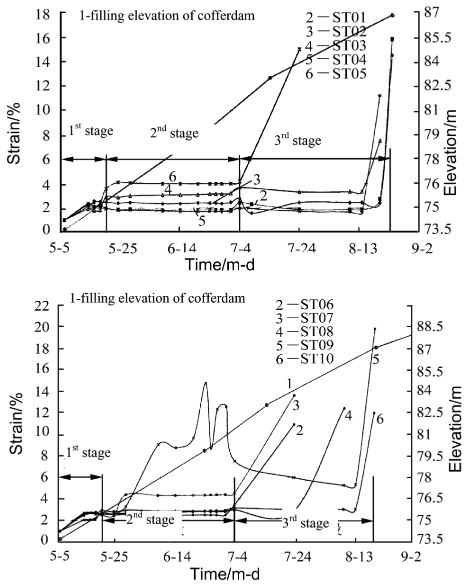

Figure 3. Observed results of large strain in the geomembrane at the section 0 + 500 (in the main cofferdam section) during 1998.

Beside the 10 strain gauges, the other eight were worked continually till 2001, the life-spans was more than 3 years.

(2) 0 + 500 section (the sub-cofferdam section)

In the upper part of cofferdam, there was a small dike (10 m high) temporally to withstand the 98'flood water. In that area, the geomembrane was placed in zigzag form with the rising of cofferdam filling (Fig. 2). Four strain gauges (ST11~ST14) were installed on the geomembrane at the elevation of 77 m and 82 m. The result is shown in Fig. 4.

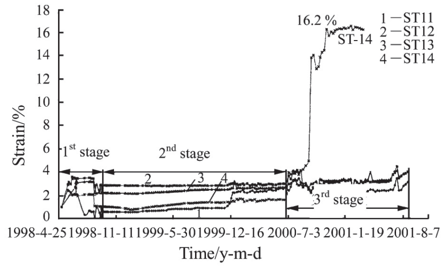

Figure 4. Observed results of large strain in the waterproof geomembrane at the section 0 + 500 (in the sub-cofferdam section).

The monitoring work was last 3 years and 3 months. The strain of the geomembrane on elevation of 77 m is relatively low and the largest value is less than 4.5%. It means that the temporal dike is stable during flood season.

After the flood season of 2000, the measured value of the strain gauge ST14 was rapidly increased to 16.2% then maintained for long time until the gauge was broken. It seems that large deformation (even exceeded the limit of strain gauge capacity) occurred in the direction perpendicular to the major axis of the strain gauge on the elevation of 82 m. This point was confirmed by the investigation during the removal of stage II cofferdam in May 2002 (Li Qing-yun, Cheng Zhan-lin. 2005)

(3) 0 + 930 section

In section 0 + 930, the geomembrane was also placed in zigzag form with the rising of cofferdam filling. Four strain gauges (ST15~ST18) were installed on the geomembrane at two elevations of 80 m and 83 m. The measured results are shown in Fig. 5. The monitoring period spanned 3 years and 3 months. As can be seen from Fig. 5, all 4 strain gauges reached their highest value rapidly to 8.0%,19.5%, 20.2% and 19.7% during the flood season in the summer of 2000 and 2001 respectively. The largest strain (20%)

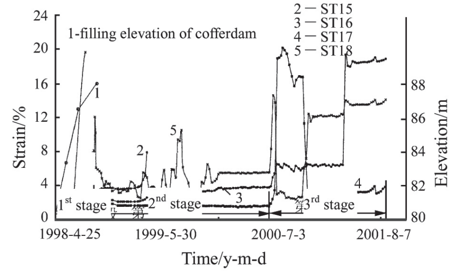

Figure 5. Monitoring results of large strain in the geomembrane at the section 0 + 930.

occurred in the point where the geomembrane was bended in a form of right angle. It seems the large deformation, even cracks, probably also occurred in the soil mass at the cofferdam, which is consistent with the measured results of earth pressure by pressure cell at the same area.

4 CONCLUSIONS

(1) The geomembrane strain gauge is a new kind of instrument developed to measure strain of geomembrane. It is firstly to be used at the field in the 2nd-stage upstream cofferdam of the TGDP and the performance is satisfied. The gauges are reliable and durable under rigorous environmental condition.

(2) The monitoring work was lasted about three years and a large amount of data was obtained. According to the data analysis, it is realized that the tensile strain of geomembrane is commonly about 11%, and the largest strain (20%) appeared in the point where the geomembrane was bended in a right angle. It means that such placement form should be avoided in the future.

(3) The measured strain of the geomembrane reveals the relationship between the strain increment of the geomembrane and the filling rate of the cofferdam. It also shows that the influence of water fluctuating on the cofferdam deformation during flood season. This indicates that the strain monitoring of geomembrane is very important to the safety of the cofferdam.

REFERENCES

Bao Cheng-gang. 2003. Solutions about some key technical problems involved in construction of the stage II upstream confferdam of TGP. Collection of relevant papers in design of TGP. Beijing: Chinese Hydraulic and Hydroelectric Publishing Press, 2003: 1085-1092. (In Chinese). Gong L-hua, Li Qing-yun, Bao Cheng-gang. Development of geomembrane strain gauge and its application (I): Gauges. Rock and soil mechanics, 2005(9): 1502~1507 (In Chinese).

Gong Lu-hua, Li Qing-yun, Bao Cheng-gang. Development of geomembrane strain gauge and its application (II): Application. Rock and soil mechanics, 2005(12): 2035~2040 (In Chinese).

Li Qing-yun, Cheng Zhan-lin. 2005. The actual situation investigation and analysis of the stage II upstream confferdam of TGP after its service finished. Chinese Journal of Geotechnical Engineering. 2005, 27(5). (In Chinese).

Slumen G. A strain-gauge technique for measuring deformation in geotextiles[A]. In: Proc. of Second International Conference on Geotextiles, Las Vegas, U.S. A[C]. [s. l.], [s. n.], 1982: 836~838.