Experimental studies and analysis of stress condition of silty sand embankment reinforced with geotextile

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ABSTRACT: Raoyanghe's Qidagang Dangerous Engineering of Liaoning province is a typical wind erosion sandy embankment segment in Liaohe river basin. The embankment is 550m long and ranks level 2 in the dyke flood control safety scale. The embankment body is composed of silt sand, eroded acutely by wind, and influence greatly flood control security. This dangerous sandy embankment segment has been comprehensively dealt with by the use of various geosynthetics. The embankment body was constructed by reinforced silt sand with geotextile, the embankment toe protected by masonry structures and earthwork package with geotextile, the embankment slope protected by fabricform concrete, and drained water back embankment with plastic strainer and pipes. For 3-year's performance, the results are quite ideal. During the period of construction, many observation sensors had been installed in embankment body such as displacement sensor, sedimentation meter and stress analyzer to carry our detailed observation and analysis of the reinforced geotextile displacement, distortion and stress condition. Through the reorganization analysis on more than two years' observed data, the relations between geotextile stress condition and displacement under reinforcement are discussed.

1 GENERAL INTRODUCTION

Qidgangzi Dangerous Engineering, situated on the left bank of the upstream of Zhengjia Sluice Gate on Raoyang River, Liaoning Province, is a typical wind erosion sandy embankment segment. It is on the alluvial plain area of Raoyang River with a high upstream and low down stream chorography with both banks inclined into the Raoyang River, whose embankment on the mainstream has a level 2 flood control standard, ready for a flood that occurs once in 50 years. If this segment fails to meet the set requirement, the whole floodwall will prove useless. The Dangerous-Segment Engineering is 550 meters long and there is no clay but mainly arenosols around the axial line of the embankment. Complied with *Norms on Dyke Constructions,* arenosols should not be used as filling material. When necessary, technological argumentation is required and corresponding construction technology should be specifically planed. In the case of the engineering in question, if outside clay is used, it involves expropriation of farmland, long distance transportation, and removing of native clay particle，thus resulting in expensive cost of more than 20 Yuan/ m^3 in clay. In addition, the unwanted clay particles, if left untreated, are new sources of aeolian sand, which can be carried away by wind, causing destruction of the ecological system by creating in a vicious circle.

In Liaoning Province, filling material is obtained from local sources in most dyke projects, with the dams being heightened and thickened gradually. Limited by the local geological conditions, the material used for the earth embankment is silty clay, silt mix, while sandy dykes use fine silty sand or silt mix. In the present embankment, most segment is sandy, and the dike body and the dike foundation is made up mainly of fine silty sand. In studies on embankment constructions of fine silty sand, the principle of using material from local sources should be followed so as to make full use of rich supply of the local fine silty sand so as to cut down the cost of the project while meeting the requirement of flood prevention and at the same time the ecological environment is preserved through soil solidification and sand retention. Undoubtedly, studies on technology of dyke constructions of fine silty sand have great significance to areas short of clay.

2 DESIGN OF REINFORCED SILT SAND EMBANKMENT CROSS SECTION

Summarizing the experience and lessons of construction of sandy dykes and the practice of reinforced silt sand embankment both at home and abroad, the team of the project puts forward a new technology for wind erosion sandy embankment, which consists of four sections: embankment of reinforced silt sand, the embankment slope protected by fabricform concrete, back embankment with plastic strainer and pipes and side shoal strengthening through biological protection. By wrapping silt san with reinforced geotextile, its shear strength can be enhanced.

When building the embankment by reinforced silt sand, the following measurements are adopted: the height of the dyke is 4.5 meters; the ratio between the riverside slope and the downstream slope is 1:2; the section area of the dyke is 67.5 m^2 ; the reinforcement is composed of 9 layers; the vertical distance of the geosynthetics is 0.45m~0.60m; the length of the reinforcement is 2m~4m; the recovery length is 1.35m~1.40m; both the riverside and the downstream slopes are protected by fabricform concrete with the foundation of the embankment foot strengthened by a stone wall with grouting on a two-layer blocked reinforcement, so as to prevent the downward movement of fabricform concrete as well as the damage of the embankment foot by scour from floods, the downstream slope is drained by buried plastic blind tubes, each of which is 8 meters long with a space of 2 meters between each other. The embankment top is protected by a 30cm installation of crushed rocks. The riverside face and the downstream face are protected by grass-shrub mixed with ecological conservation in an area 50 meters within the embankment foot. This project, which started in October, 2004, was completed in May, 2005.

In the trial section project, 30 of DS-50B (displacement measurement of datum point:100 mm, measurement range:0~30mm) geotextile strain sensors were installed, together with 6 TY-2 vertical strain sensors(thickness/diameter ratio:0.8, measurement range:0~2MPa), 2 SST-2 horizontal strain sensors (specs:215mm*98mm*8mm, measurement range:0~2MPa), 2 MD-1layer-divided sinking apparatus(interior diameter:50mm,depth range:30mm). Through field prototype observation test, systematic observation and analyses of the integrated control technology by reinforced silt sand embankment were made to test the scientificalness and rationality of the integrated technology of wind erosion sandy embankment so as to assess the construction quality of the engineering with the purpose of further validating and improving the design principle and method of reinforced silt sand embankment. Standard design of the embankment cross section and layout of the observation instruments are shown in Figure 1.

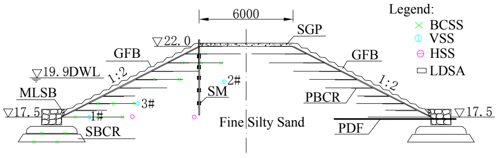


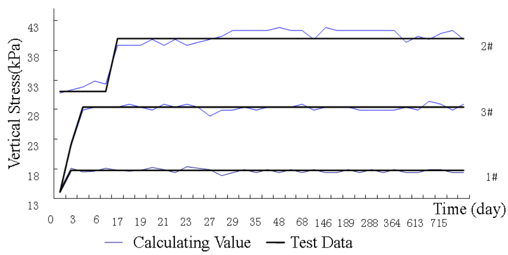
Figure 1. layout of the embankment prototype observation instruments

Initials in Figure1:

GFB(Geotechnical Fabric Bag), DWL(Design Water Level), MLSB(Mortal Laid Stone Buttress), SBCR(Sealed Braiding Cloth Reinforcement), SGP(Sand-Gravel Pavement), SM(Settlement Molding), PBCR(Packaged Braiding Cloth), PDF(Plastic Drainage Filter), BCSS（Braiding Cloth Strain Sensor）, VSS（Vertical Stress Sensor）, HSS（Horizontal Stress Sensor）, LDSA（Layer-Divided Sinking Apparatus).

3. RESULTS AND ANALYSIS

Figure 2. Changes of the vertical stress over time



3.1 *analysis of the vertical stress observation results*

Observation of the vertical stress was made from September 29, 2004 to December 19, 2006 and the changes of the vertical stress over time are shown in Figure 2. The vertical stress equals the meter reading multiplies the probe calibration factor.

Analysis of the data from observation shows that with the heightening of the embankment after the installation of the observation instruments, the vertical stress increases with small fluctuations. By the completion of the construction of the sand-gravel pavement at the embankment top on December 11, 2004, the maximum loads appeared and the vertical pressures on the pressure cell reach their own maximum values. In operation, under stable loads, the fluctuations of the vertical stress decline with time. The longer the time, the smaller the fluctuations. Seven months after the completion of the construction, the pressures are stabilized and show no significant changes.

For 1# instrument, the discrepancy between the measured data and the value of theoretical calculation ranges from -3.82% to 4.66%; for 2# instrument, the discrepancy ranges from -3.82% to 4.66%; for 3# instrument, from -3.82% to 4.66%. The coincidence between the measured data and the values of theoretical calculation shows the reliability of both.

3.2 analysis of the horizontal stress observation results

For observation, one 2SST-2 horizontal strain sensor was installed on the RY60L4+421and the RY60L4+221 cross sections respectively. The Total Pressure Cell (TPC) for the cross section RY60L4+421is numbered 4011# and that for cross section RY60L4+22 is numbered 4012#.The observation is conducted between October 1, 2004 and Decmber 19, 2006. The Changes of the still lateral pressure coefficients over time are shown in Figure 3.

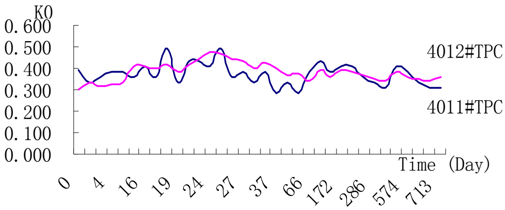


Figure 3. The Changes of the still lateral pressure coefficients over time

TPC (Total Pressure Cell)

The still lateral pressure coefficients of soil are calculated by the following formula.

$$k_0 = \alpha \frac{\sigma_{hc} - u_w}{\sigma_{vo} - u_w}$$

k_0— The still lateral pressure coefficients of soil;

σ_{hc}— the total horizontal stress of stable soil layers(kPa);

σ_{V0}—the total press of the soil's dead weight (kPa);

u_w—still water pressure (kPa);

α—correction coefficient, α=0.80

The following is an analysis on the characteristics of the horizontal strain. After the start of the construction, with the heightening of the embankment, the horizontal strains show an upward tendency with small fluctuations. When the construction of reinforced embankment was completed on December 15, the strains reach their maximum values. In operation, at the observation spots of the two cross sections , the still lateral pressure coefficient (K_0) calculated on the basis of observed data is a changing value, with the changes on the RY60L4+421 cross section range from 0.282 to 0.488 , with the average being 0.374, and those for RY60L4+221 from 0.300~0.471, with the average being 0.383. Generally, the still lateral pressure coefficients of sandy soil are between 0.33 and 0.43.

3.3 analyses on the observed results of reinforced geotextile deformations

The observation by geotextile displacement sensors began on September 13, 2004 when the construction of the embankment started and ended at the end of 2006. The measured maximum deformation of the geotextile is 5mm, with an elongation rate of 5%; the minimum deformation measured is 0.9 mm with an elongation rate of 0.9. The reinforced geotextile has an indoor maximum tension of 51 KN/m and the corresponding elongation at 23%.

The following conclusions can be drawn on the basis of analyses of the measured data of the stress on the geosynthetics

(1) The strains of the different layers of geotextiles are different, suggesting different extent of their play of the tensile strength, with strains at the base understratum > strains at the base upperstratum, and strains at the middle layer of the embankment > strains at the understratum of the embankment > strains at the upperstratum of the embankment

(2) The strains at the different spots of the geotextile in the same layer are different, suggesting different extent of the play of the tensile strength at different spots, with the maximum strains invariably close to the embankment side.

(3) Geosynthetics at different layers are in different stress fields, resulting in differences in tensile stress and mobilization factor among geosynthetics at different layers. The mobilization factor at the understratum and the upper stratum is about 0.3~0.5 while that at the middle layer reaches the maxium ,0.8~0.9.

(4) Complied with *the Application Technical Standards on Geosynthetics* (GB50290—98), allowable tensile strength for geosynthetics is determined through dividing the ultimate tensile strength by the safety coefficient. When lacking in experience, a safety coefficient of 2.5~5.0 is preferred. Based on the measured results of this project, it is desirable to set the allowable tension of reinforced material at 1/3 of the ultimate tensile strength

3.4 analyses on the measured data of subsidence

The compression of the soil takes time. The earth material for the reinforced silt sand embankment is silt sand, which has a different subsidence from clay. The consolidation of clay is a process in which pore water pressure decreases gradually and the soil skeleton stablizes under external pressure. By contrast, the earth material of the silt sand embankment has a low moisture content and a quick dissipation of pore water and thus its compaction is largely determined by the pressing power. Although reinforcement of silt sand may enhance the soil strenth the reinforcement of the slope cannot decrease the vertical displacement while effectively decreasing the soil's differetial settlement and at the same time restricting its lateral deformation, decreasing its side pressure coefficient，inhibiting the development of the plastic zone in the embankment, so that the embankment will be more stable. To validate this assumption, the settlement quantity is calculated first as non-reinforced embankment based on the quality of the earth material, which is then analyzed in comparision with data from the prototype observation test in reinforced embankment. The embankment filling material in Qidagang is fine silty sand. The average dry density from field detection is 1.81g/cm^3 and the measured maximum stable settlement quantity is 97mm. The calculation of the final sink value is based on *the Design Code for Rolled Earth-rockfill Dam*, （SL274-2001） and the calculated result by the subsidence formula for unviscous earth dam body and foundation is 98.3mm.

Based on an analysis of the measured results of settlement, the following conclusions can be drawn.

(1) During soil filling in the construction , the fine silt sand at various layers is rolled and compacted so that the bearing capacity of the fine silty sand is enhanced, which results in small instantaneous settlement quantity during further soil filling and compaction. During construction, the settlement quantity is not increasing with the enhancement of filled soil, while sudden gain in settlement quantity occurs when loads increase. The increase of the general settlement quantity lags behind the overlying loads. The settlement tends to be stable after the lasted time of loading 303d.

(2) Judged from the compression curve and the subsidence curve, the calculated values from theoretical analysis are well concidental with the measured data, from which two conclusions can be reached. On the one hand , the settlement value of fine silty sand embankment from lab tests based on theoretical analysis is well concidental with the measured data, which suggests that there is good quality control of construction. On the other hand, the reinforcement of fine silty sand does not decrease the vertical displacement of the embankment, suggesting that reinforcement does not affect the settlement of fine silty sand.

(3) There is linear correlation between the stable settlement quantity of reinforced fine silty sand embankment and the height of the filled soil. The settlement quantity on Cross Section RY60L4+421is 2.45%~2.50% of the height of the embankment, that of Cross Section RY60L4+22 is 2.42%~2.56% the height of the embankment, and the average settlement quantity is about 2.5% of the height of the embankment.

3 ANALYSIS

After three years of propotype observation and operation, the practical results from the integrated project on the wind erosion sandy embankment at Qidagang show that the design and the construction technique of reinforcement structure of the embankment are scientific and rational. Reinforced silt sand embankment can not only decrease effectively the section area of the embankment, thereby decreasing the occupation of land, it can also shorten construction time, save investment and yield desirable results in flood prevention and safety effectiveness by making full use of the fine silty sand from the local sources. Due to the relatively fewer number of embeded observation instruments and the limits of systematicness and profoundness of the experimental investigation, fortuity and randomness exist in the obtained results. There is still improvement to be made in the prototype observation test and the analysis on the observed data. Future efforts should be made to improve the summarization and analysis of the observed data. If we put more emphasis on the study of the applied technique of geosynthetics to make full and effective use of its special characteristics in water conservancy and irrigation works, we can promote the better development of geosynthetics.

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