Non-Homogeneous Reinforced Earth Fill for Riverbank Stabilization

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NON-HOMOGENEOUS REINFORCED EARTH FILL FOR RIVERBANK STABILIZATION

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ABSTRACT

The paper presents a study of backfill material for the reinforced earth used as riverbank restoration, based on two cases of stabilization with reinforced earth using geogrid type TENSAR reinforcements. The two cases are located one on Blue River in Kansas City, Missouri and the other on Delaware River in Kansas, respectively. Both projects were designed to restore the damaged riverbank due to slope failures in order to protect existing public utilities (water lines) and public roadways close to the failed riverbank, with limited space for excavation or setback the riverbank slope. Geotechnical investigation indicated very low soil strength parameters of the riverbank material being one of the principal causes of the slope instability. The failures occurred during the river rapid drawdown from the top of the riverbank to the normal river stage. The most economical repair alternative was to reconstruct the riverbank to an acceptable stable slope by reinforcing it with geogrid. Due to space restriction and limited funds the reinforcements were placed within 1-foot thick layer of granular material between 3 feet thick layers of cohesive material obtained from riverbank excavation. A sand layer placed behind the reinforced earth mass provides the adequate drainage of the stabilized earth. The horizontal sand layers reduce the length of the reinforcements, preventing additional damages of the adjacent public roads, and consequently the excavation volume and project cost. The horizontal sand layers around the reinforcements and the drainage sand layer behind the reinforced earth mass provided proper drainage of the reinforced earth mass and increased the stability of the riverbank to acceptable level for the case of sudden drawdown of the river stage. The paper presents the subsoil investigation, design analyses, construction aspects and the stabilized riverbank behavior after repair.

INTRODUCTION

<u>Blue River Bank Failure</u> is located in Kansas City along the right bank of the Blue River, close to a high traffic public road (Gregory Blvd.) and affecting a City water line. The repaired slope was restricted to 1(V) on 1:75(H) due to the location of the water line and in order to minimize traffic disturbance on Gregory Blvd. The City of Kansas City requested the slope to be seeded with native grass to minimize the maintenance of a very steep slope. No apparent rock protection was accepted for environmental reasons. Figure 1 shows the failed slope prior repair.

Fig. 1 BlueRriver slope failure prior repair

<u>Delaware River Bank Failure</u> is located at the Northeast corner of Kansas on Delaware River on Kickapoo Indian Reservation land. The failure is located downstream of a concrete water intake structure constructed in 1978 used for water supply of the Kickapoo reservation. The slopes downstream of the concrete structure were set back to 1(V) on 2(H) to match the slopes of the structure wings. Erosions and slope failures downstream of the weir structure started immediately after construction, the left riverbank failure approaching the water supply line and a public road. Numerous attempts to repair the damaged area in the past consisted of reconstructing the failed slope with rockfill, adding additional loading to an unstable slope. The failures occurred mostly after rapid drawdown of the river stage. The geotechnical and hydraulic analyses performed demonstrated that the cause of failures was a combination of subsurface conditions (the riverbank slope too steep for the weak soils in the foundation) and hydraulic conditions (erosion of the riverbank toe due to the turbulent flow immediately downstream of the concrete weir). To prevent erosion of the riverbank toe the slope protection would be 4 feet thick. To stabilize the slope reinforced earth was

considered as the most economical repair alternative. The reinforced earth with reinforcements placed in local material obtained from excavation would require excessive long geogrid layers, and consequently excessive excavation, which would reach the road or water line. Figure 2 illustrates the existing condition.

Fig. 2. Delaware River bank erosion

GEOTECHNICAL CONDITIONS

Subsurface investigation was performed to determine the existing geotechnical conditions. The subsurface investigation consisted of borings drilled at the site to collect disturbed and undisturbed soil samples, Standard Penetration Tests (SPT), and laboratory tests performed on undisturbed or disturbed samples.

Blue River

Disturbed samples for laboratory testing were collected from three borings drilled at the site. The soil strength parameters were determined from back calculations of the weakest layer conditions before repair. Figure 3 illustrates the soil parameters based on the laboratory testing, SPT, and back calculations. A sliding surface had been developed through a soft clay layer located between 20 and 50 feet from the surface. The clay layer contains lean clay (CL) material with liquid limit (LL) between 39 and 42, and with the moisture content between 27 and 30%. Back calculations indicated the shear strength c = 300 psf for the lean clay in the foundation. Auger cast piles were driven 5 feet into the shale located at 50 feet below the surface to stabilize the lower slope. Location of the water line an the limited construction space due to busy City road (Gregory Blvd) required a slope no milder than 1(V) on 1.75(H) for the upper bank above the auger cast pile stabilization.

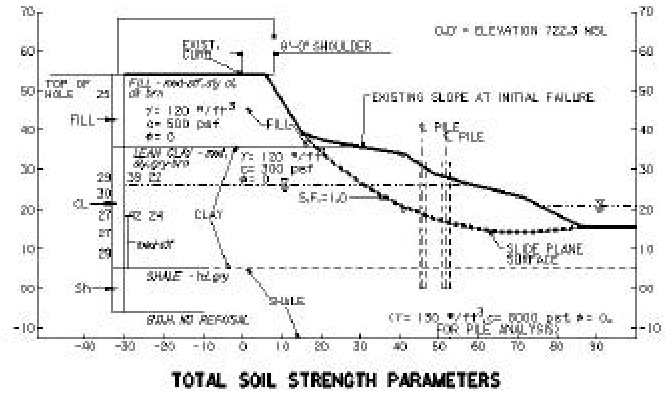

Fig. 3. Blue River soil strength parameters

Delaware River

Undisturbed samples and jar samples were collected from the two borings drilled on the left bank of the Delaware River. The groundwater elevation was measured 4 hours after drilling. SPTs, pocket penetrometer tests and laboratory testing on undisturbed and jar samples were performed and used for the determination of the soil strength parameters. The laboratory tests consisted of determination of the moisture content of the jar samples, Atterberg limits and grain size distribution test for soil classification, and triaxial (consolidated undrained tests with pore pressure measurement) and unconfined compression tests for the determination of the soil strength parameters. The boring log shown on Figure 4 was considered characteristic for the site description.

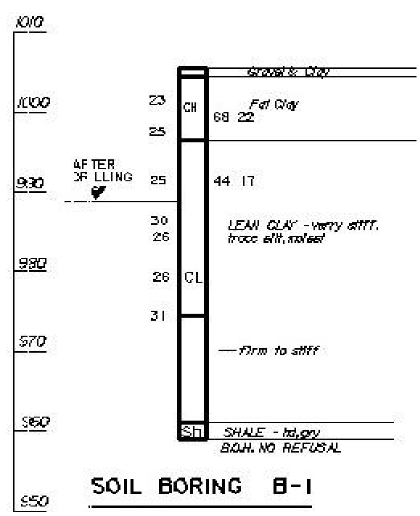

Fig. 4. Delaware River boring log

The soil in the upper 16 feet consisted of high plasticity clay material (with LL = 68) followed by a low plastic clay material on the next 9 feet (with LL = 44). The last 25 feet to the top of the rock contained silts and sandy materials. The moisture content of the upper 25 feet from the surface varied between 21 and 30% and the degree of saturation between 79 and 100%. The dry density varied between 92 and 100 pcf, and the moist unit weight between 119 and 125 pcf. The unconfined compression strength varied between 400 psf and 3400 psf, with the weaker material between 14 and 25 feet from the surface. The total strength parameters obtained by the triaxial compression test performed on a sample collected from the depth of 15 to 16.5 feet from the surface were F = 12.8°, c = 600 psf and the effective strength parameters F ' = 19.6° and c' = 0 psf.

BLUE RIVER RESTORATION

Alternatives of the 23.5 feet high riverbank restoration considered the restricted space due to the proximity of a public road and existing utilities. The selection of the repair alternative was based on the local stability of the reinforced earth mass and the global stability of the riverbank at the end of construction and during the rapid drawdown of the river. Economical considerations also controlled the repair alternatives.

Analyzed Alternatives

The setback of the riverbank slope was not an option for the riverbank restoration due to the vicinity of Gregory Blvd. The limited construction space and steep slope (1 on 1.75) were favorable for reinforced earth stabilization. Two alternatives of reinforced slope were analyzed. The selection of the alternative was based on economical analysis and constructibility of the reinforced earth.

Alternative 1 consisted of a reinforced earth slope with the reinforcement placed in local cohesive materials obtained from excavation of the existing slope. This alternative required long reinforcements at lower elevations to assure the local stability, and consequently excavation beyond the public road limits, disturbing the traffic on the road. The alternative was not economical due to high cost based on long reinforcement with high tensile strength and disturbance and reconstruction of the adjacent road. Technically this alternative would not provide proper drainage of the reinforced soil backfill and the stability of the riverbank during rapid drawdown of water in the river was not assured.

Alternative 2 consisted of placing the reinforcement within 1 foot of granular fill obtained from a quarry and using the local excavated cohesive material excavation for the remaining of the backfill. This alternative would require shorter reinforcement with lower strength to assure the local stability. A drainage layer placed behind the reinforced soil mass will assure the drainage of the reinforced earth and consequently, will increase the global stability of the riverbank during rapid drawdown of the river. The short reinforcements will reduce the excavation and will prevent the disturbance of the traffic on the adjacent public road. A variant of this alternative was to use granular material for the entire backfill. This variant was less economical, requiring 2500 cubic yards of sand versus the 500 cubic yard of sand if local material would be used for backfill between the sand layers.

Stability Analyses

Local stability of the reinforced earth was verified for the two analyzed alternatives, using the computer program TENSL01 provided by TENSAR, Inc., the geogrid reinforcement manufacturer. Global stability of the riverbank was analyzed with the Modified Bishop Method using the computer program UTEXAS3 developed at the University of Texas.

Alternative 1. The reinforcement required to assure the local stability of the alternative 1 consisted of geogrid with the tensile strength of 3000 lb/ft, which corresponds to an expensive reinforcement (type TENSAR UX1600). The geogrid spacing was 3.7 feet, the minimum length of the upper reinforcement layer 13 feet and the length of the lowest reinforcement 43 feet. Since the length of the upper geogrid layer was restricted to 6 feet to avoid excavation and reconstruction of the road and traffic disturbance, this alternative was not considered feasible. The global stability factor of safety for the end of construction was Fs = 1.2 (less than the required Fs = 1.4) and for the rapid drawdown of the river from the top of the bank to the normal river stage was Fs = 0.8 (less than the required Fs = 1.0).

Alternative 2. The reinforcement required to assure the local stability consisted of geogrid with the tensile strength of 1000 lb/ft, corresponding to a less expensive reinforcement than with Alternative 1 (type TENSAR UX1500). The length of the upper reinforcement layer was reduced to 4 feet (sufficient to protect the street traffic and the existing water line), and the lower reinforcement layer to 16 feet, which required less excavation of the riverbank, and consequently less disturbance of the adjacent road. The global factor of safety for the end of construction condition was increased to Fs = 1.42 (the minimum admissible being Fs = 1.4) and for the rapid drawdown to Fs = 1.3.

Riverbank Restoration

The selected alternative consisted of construction of a reinforced earth mass with the reinforcement placed within 1-foot thick layer of granular material on the top of the Auger cast piles. The reinforcements were placed at 4-foot intervals, using the locally excavated soil as additional backfill between the reinforcements. A layer of granular material was placed between the excavated slope and the reinforced earth mass to provide drainage of the reinforced earth during rapid drawdown of the river stages. The drainage layer was connected with the rockfill layer placed on the top 3 feet of the auger cast piles, above the normal river water elevation. The face of the reinforced slope was covered with 1-foot thick layer of uncompacted soil suitable for vegetation growth, and seeded with native grass and wildflowers, for a minimum maintenance of the riverbank slope. Figure 5 illustrates the selected alternative.

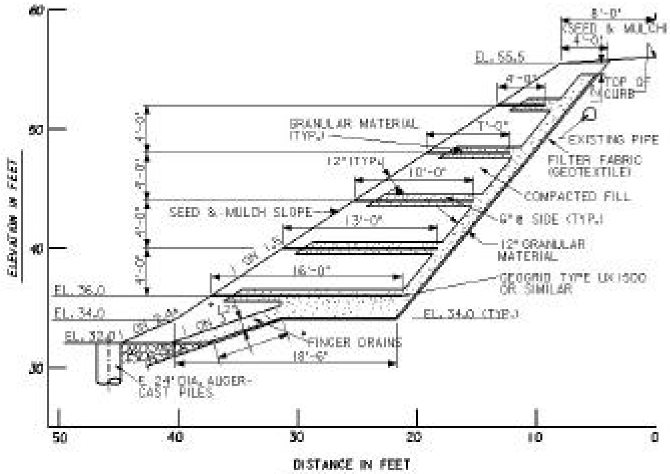

Fig. 5. Blue River bank stabilization typical cross section.

A general plan view is shown in Figure 6.

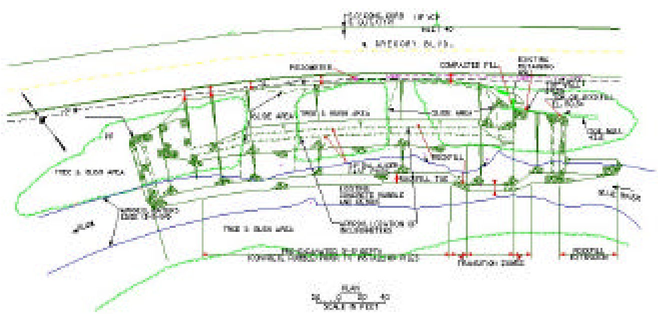

Fig. 6 Blue River bank restoration general plan view

Construction Aspects and Monitoring after construction

The construction was performed above the river normal elevation. The excavated slope was covered with geotextile before placement of the granular drainage layer used as filter material. Aspects during construction are illustrated in Figure 7. A slope indicator was installed to monitor the movements of the entire riverbank. Measurements performed indicated the displacement was uniform throughout the reinforced portion, with a maximum of about 1 inch in 6 years after remediation. Figure 8 illustrates the Blue Riverbank 4 years after the restoration.

DELAWARE RIVER

A couple of alternatives were considered for the restoration of the 24 high riverbank failure. Excavating beyond the failed area and restoration of the riverbank to the original 1(V) on 2(H) slope protected with a 4-foot thick riprap would result in an unstable slope during rapid drawdown of the river from the top

Fig. 7. Blue River construction aspects

Fig. 8. Blue River 4 years after construction

of the bank to the river normal elevation. The corresponding theoretical stability factor of safety was 0.5. Considering the vicinity of a public road and the water line close to the failed left bank, a reinforced earth slope would create a stable and also an economical riverbank slope.

Analyzed Alternatives

The selection of the repair alternative was based on geotechnical analyses and on economical justification. Hydraulic analyses were also performed to determine the protection of the riverbank against erosion created by the turbulent flow immediately downstream of the concrete weir of the intake structure. The alternative were designed to obtain a stability factor of safety of minimum Fs = 1.0 for the rapid drawdown of the river from the top of the riverbank to the normal water elevation and a factor of safety greater than 1.4 at the end of construction.

Alternative 1 consisted of construction of a reinforced slope using cohesive material obtained from the slope excavation as backfill material. The proposed reinforcements were geogrid type TENSAR UX1500 with uniaxial tensile strength. The reinforced earth slope was protected against erosion with 4–foot thick riprap. The reinforced earth would be constructed on a rock platform above the normal river elevation. This alternative required long reinforcements and consequently extensive excavation, which would reach the existing water line and the adjacent public road. The alternative would not provide drainage of the reinforced earth slope.

Alternative 2 consisted of placing the reinforcement in a 1-foot thick layer of granular material and using the local material obtained from the slope excavation for the remaining of the backfill. The reinforced earth would be constructed on a rockfill platform above the normal water elevation. A 4-foot thick riprap layer should be placed on the slope for protection against erosion. A one foot thick drainage layer will be placed between the reinforced earth and the excavation to provide drainage during the rapid drawdown of the river. This alternative would require shorter reinforcements and will reduce the excavation. A variant of this alternative was also considered, using granular material for the entire reinforced earth backfill.

Stability Analysis

The local stability of the reinforced earth was analyzed using the computer program TENSL01. The global stability of the riverbank was analyzed using Spencer method and the computer program UTEXAS4.

Alternative 1. The local stability required reinforcement tensile strength of minimum 2200 lb/ft (type TENSAR UX1500), the minimum bottom length of the reinforcement of 43 feet, and the minimum top length of 25 feet. Global stability analyses required the excavation slope to be 1(V) on 2(H) to assure the stability during the end of construction, considering the total soil strength of c = 600 psf as obtained by unconfined compression tests. Stability analysis performed for the river rapid drawdown, between the top of riverbank and the normal elevation, resulted in a factor of safety of Fs = 1.3, as shown on Figure 9. The effective strength obtained by triaxial compression test on the existing clay material (F ’ = 20°, c=0 psf) was used for the rapid drawdown stability. The stability was performed in two stages: the first stage considering the river elevation at the top of the riverbank and the embankment saturated; the second stage considered the river at normal elevation (4 feet above the river bottom) and the embankment saturated because the drainage possibility of the reinforced earth slope would be difficult and slow. Stability analysis results are illustrated in Figure 9.

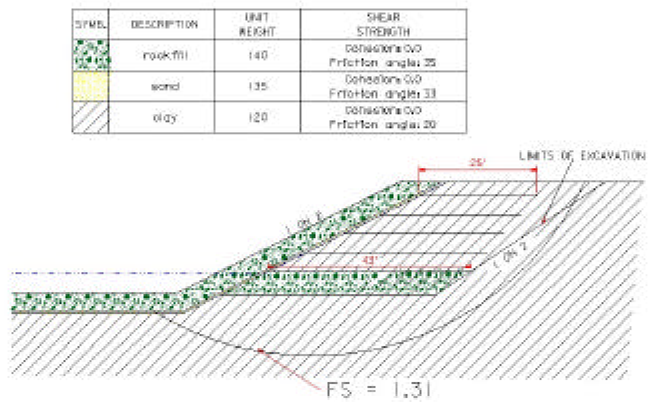

Fig. 9 – Delaware River alternative 1 stability analysis for rapid drawdown conditions.

This alternative would require 2700 square yards of geogrid and a large volume of excavation. The excavation would be extended beyond the existing water line, or into the adjacent public road.

Alternative 2 consisted of a reinforced earth slope with the reinforcements placed within 1-foot thick granular material and the remaining of backfill using the local cohesive material obtained from slope excavation. The local stability will require geotextile with tensile strength of 1000 lb/ft, type TENSAR uniaxial geogrid UX900. The maximum length of the lower reinforced layer was reduced to 25 feet and the top layer to 17 feet. A 1-foot thick drainage layer was placed behind the reinforced earth mass to provide drainage during rapid drawdown of the river stages. Geotextile will be placed between the excavated slope and the drainage layer to prevent piping of the fine material into the drainage layer. The slope will be protected by a 4-foot thick layer of riprap. A 4-foot thick rockfill platform will be constructed at the base of the reinforced earth to assure dry working conditions. Global stability analysis for the rapid drawdown conditions was performed for two cases to determine the impact of the drainage of drainage: (1) disregarding the drainage effect of the sand layers and (2) considering the drainage of the reinforced earth mass during rapid drawdown. The stability analyses considered the effective strength obtained by triaxial compression tests for the cohesive soil material. The factor of safety was increased from Fs = 1.02 to Fs = 1.3 when the drainage effect of the granular material was considered.

Stability analysis considering the draining effect of the granular material is presented in Figure 10.

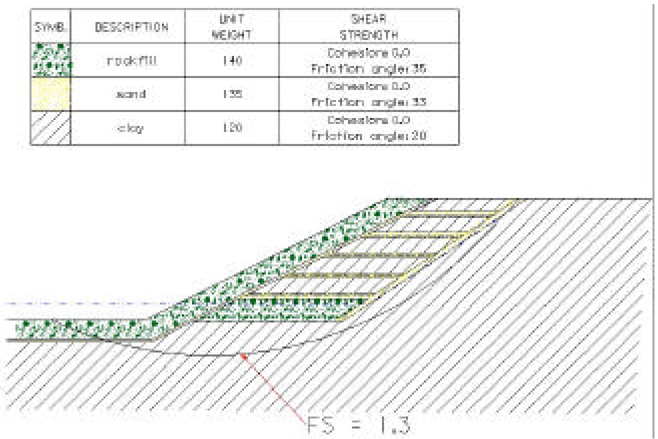

Fig. 10. Alternative 2 stability analysis for rapid drawdown

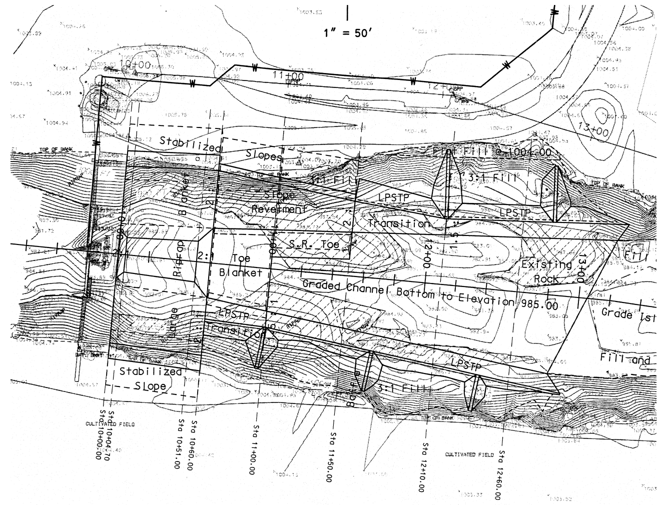

Fig. 13. Delaware River general plan view

Proposed Delaware Riverbank Restoration

Alternative 2 was proposed for the Delaware riverbank restoration, based on technical and economical analyses. Figure 11 illustrate a typical cross section of the proposed reinforced slope.

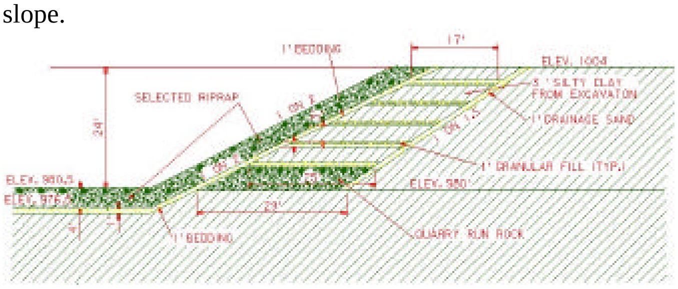

Fig. 11. Delaware River bank restoration typical cross section.

A cross section of both riverbanks is illustrated in Figure 12.

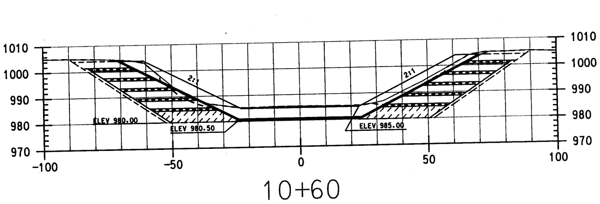

Fig. 12. Delaware River bank restoration

A general plan view of the restored riverbank is presented in Figure 13.

CONCLUSIONS

The study results indicated that reinforced earth using a drainage layer around reinforcement for riverbank restoration is more technically and economically efficient than using only local material obtained from the slope excavation or only granular material imported from a quarry. The technical advantages of the reinforcements placed in thin layers of granular material are:

? the local stability is provided using shorter reinforcements with less tensile strengths;

? global stability for the rapid drawdown of the river is increased by providing free drainage of the reinforced riverbank.

The economic advantages are:

? reduced volume of excavation and backfill;

? reduced work space (which is important in locations where the work space is limited by existing roads or utilities);

? less expensive backfill, using extensively locally excavated material;

? reduced quantities of reinforcements and less expensive reinforcements;

? reduced quantities of granular material hauled from quarries.

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