Stream Bank Remediation; Not Just a Geotechnical Problem

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ABSTRACT: Slope failures along stream banks are caused by a combination of unfavorable conditions. Geotechnical engineers often focus on soils and groundwater issues and develop remedial schemes that are derived from a two dimensional stability analysis without giving due consideration to geologic conditions. Remedial solutions that do not account for stream dynamics may not have the anticipated life cycle and may exacerbate erosion upstream and downstream of the site under repair. Remedial solutions that consider the stream dynamics improve the slope stability and can be applied in an ecologically friendly manner.

This paper presents two case histories that illustrate the geotechnical and geomorphic causes of slope failures along streams. For one case history, geotechnical issues, such as weak soils, steep slopes, high groundwater levels, and poor drainage, are the predominant causes of the slope instability. For the second case history, stream dynamics, particularly erosion of the slope's toe, caused the slopes to fail. The case histories illustrate how remedial methods are developed to address both the geotechnical and geomorphic issues. This includes traditional methods to improve geotechnical conditions and some non-traditional methods such as using the dry-mix method to improve the strength of soft sensitive clay soil. Remedial methods to address the stream conditions include measures such as river training, bank armoring, and revegetation.

INTRODUCTION

Western New York is populated with stream systems that drain a variety of geologic environments. Many streams eroded their valleys into relatively uniform gradients, making the valleys an ideal location for road construction. The meandering nature of the streams through these valleys, however, results in constantly migrating stream banks that can destabilize the slopes that support the roads.

The approach to remediating stream bank failures can be different than that for slope failures that are not influenced by a stream. Stream bank remediation requires a combined approach that considers the geotechnical conditions of the slope and geomorphic conditions of the stream system. The engineer remediating a failed stream bank must have an understanding of the degree that each of the conditions contributes to the slope instability.

This paper presents a discussion of a systematic approach to slope stability problems and stream bank remediation techniques. Some of the geotechnical and geomorphic methods are well documented, but briefly presented in this paper to demonstrate their applications, advantages, and disadvantages for use in stream bank remediation projects. An understanding of these methods is necessary to follow the systematic approach to remediation that follows.

We follow the discussion with two case histories of stream bank failures that were caused by a variety of geotechnical and geomorphic factors.

STREAM BANK REMEDIATION APPROACHES

Stream bank remediation should be approached from two different perspectives: 1) from a geotechnical standpoint (i.e., the roles that soil, rock, and groundwater play in the failures) and 2) from a geomorphic, or stream dynamic, standpoint (i.e., the role that the stream dynamics play). It can be useful to think of bank stability problems on a spectrum with these extremes (purely geotechnical issues and purely stream dynamics issues) at either end. Most projects involve at least a minor element of each. This section provides discussions on each of these approaches and how they can be used together to tailor the appropriate response to each project.

Geotechnical Issues and Approaches to Mitigation

Geotechnically, Why Do Stream Banks Fail?

At one end of the stream bank failure spectrum are geotechnical conditions that lead to failures. It has been the authors’ experience that, from a geotechnical standpoint, slopes fail near streams in Western New York due to one, or a combination, of three reasons.

Soft Clays - There are several areas in Western New York that are underlain by soft clay deposited in glacial lakes. Many of the streams that have formed since the last glacial period, particularly in northern Erie and Niagara Counties, flow through these soft deposits. As the stream erodes a valley, the banks are supported by silt and clay formations with low undrained shear strengths (observed to be 200 pounds per square foot, or less). Further loss of support, due to toe erosion or changing groundwater levels, can cause these banks, already in place with a low factor of safety, to fail.

Elevated Groundwater Levels - The second main geotechnical culprit is elevated piezometric pressures. Western New York is located in the foothills of the

Appalachian Mountains. The topography of the southern half of Western New York is hilly with streams flowing through the valleys. Groundwater tables in many locations are recharged by precipitation infiltrating from higher elevations. Many of the valleys are underlain by silt and clay deposits over sand and gravel. The silt and clay can act as an aquitard confining the piezometric head in the sand and gravel. As a result, artesian conditions are common in many of the stream valleys across the region. These conditions can act to reduce the effective weight of the soil and reduce the bank's stability.

Silt Lenses - The third main geotechnical condition that can lead to bank failures along streams is the presence of silt lenses. The silt lenses range from fractions of an inch to several feet thick vertically, and they are separated horizontally by clay deposits. The silt deposits become problematic when they are inhibited from draining at the bank's surface and cannot drain into the stream. Excess porewater pressures in the lenses can build and force the deposits along the bank to fail.

These factors highlight the need for an adequate subsurface exploration program to gain insight into the factors at play at the site of interest. Commonly, the subsurface exploration program might consist of multiple borings to understand the spatial variation of conditions across the site, sample collection, including split-spoon and Shelby tubes, instrumentation (e.g., piezometers, inclinometers, etc.), field testing (e.g., vane shear tests, rising/falling head permeability tests, etc.), and laboratory testing. The goal is to construct a model of the subsurface conditions and to understand their role in the failure of the stream banks.

Traditional Geotechnical Approaches to Stabilizing a Slope

Traditionally, there are four general approaches to stabilizing a slope that has failed due to geotechnical problems. These approaches are:

Change the Slope's Geometry - This can be accomplished by removing weight from the top (to reduce the driving forces), adding weight to the toe (to increase the resisting forces), or flattening the slope (to accomplish both). While effective, this approach might be limited due to spatial constraints at the site with a stream at the toe and a road at the top. Changes in vertical curvature of the road alignment might not be feasible and there could be restrictions on the amount of fill that can be placed in the stream.

Construct a Retaining Structure - A retaining structure can be used to support and stabilize the creek banks. This can include a mechanically stabilized earth (MSE) wall, soldier pile and lagging walls, or sheet piles. This approach is effective in proper settings, but can be problematic along streams. MSE and soldier pile and lagging walls can erode in the moving stream. Sheet pile walls along streams can exacerbate the problem because they can concentrate energy and direct it along other locations in the project. The authors have observed sheet pile walls that direct the flowing water down to the stream bed. The concentrated energy then accelerates the scour process to remove toe support from the sheets, which eventually rotate into the channel.

Lower the Groundwater Levels in the Slope - This is a good practice to integrate into the design for nearly any slope mitigation project. It has been the authors' experience that most slope stability problems have groundwater and drainage issues as components of the problem. Lowering the groundwater levels can be accomplished by excavating finger drains into the slope and backfilling them with drainage stone or by constructing a drainage blanket across the entire slope to collect seeping groundwater and direct it away from the project.

Strengthen the Soil Along the Failure Surface - This can be accomplished in several ways. First, the soil can be treated to improve its shear strength. Examples of soil improvement methods include jet grouting, dry soil mixing, and wet soil mixing. Second, the effective stress along the failure plane can be increased to provide additional frictional resistance. This can be accomplished using tensioned soil or rock anchors.

A Look at Stream Geomorphology

At the other end of the spectrum, stream geomorphic features can be just as significant, if not more so, of a contributing factor to the instability of banks as the geotechnical factors described above. The geomorphology must be well understood before a solution can be developed. This section describes the techniques used for assessing the conditions of a stream bank using what the authors refer to as a scale variant approach.

Understanding the Stream; the Scale Variant Approach

The scale variant approach begins with looking at the site of interest from a larger, regional scale and then successively zooms in until the site itself is the focus of the assessment. Each successive step in magnified scale can provide important information about the site.

The first step in the approach, and widest view of the site, is a look at the regional geologic and geomorphic setting of the river system (regional scale). The bedrock and surficial geology of most areas in the United States are well understood and clearly presented in a variety of mapping formats. Zooming in, the engineer and geologist delineate the basin or watershed (basin scale) to determine where in the regional setting the engineer should focus attention. Individual reaches within the basin (reach scale) are then identified and grouped together through association of similar stream planforms, or plan view of the stream, and interaction with the stream valley. Finally, the site is considered as a single point within the reach (engineering scale). The stream cross section and profile are surveyed to assess the stream geometry and dynamics, and the rock, soils, and groundwater conditions (observed during the geotechnical explorations) are considered with respect to the properties of the channel and slope.

The following describes each scale in further detail.

Regional and Basin Scales - The regional and basin scales are assessed because they can provide a big picture snapshot of the regional geologic and hydrologic conditions to provide a starting point to understanding the conditions at the site. These assessments are usually made through reviewing published data, through discussion with those familiar with the conditions, and by preliminary site reconnaissance. They are a necessary first step to tailor further assessments at closer scales. For example, if the regional and basin scale assessments show that a site is located within an alluvial fan, later reach and engineering scale assessments and the subsurface exploration program might seek to further define the areal extent of the deposit or to estimate if the entire length of the site is situated within the deposit. In this example, the engineer can estimate the area of the site where additional slope drainage might be the most critical.

Reach Scale - The reach scale assessment focuses on the past and current conditions of the lateral and vertical stability of the river (i.e., its propensity to meander and incise, or scour). Areas of active channel migration, sediment transport, and sediment deposition are used to identify the changes that have occurred in the past, to estimate the changes that will continue to shape the river reach, and how site mitigation might affect the stream. The primary tool for a reach scale assessment is a time-lapse overview of the river reach using a series of historic aerial photographs.

Engineering Scale - The engineering scale assessment for a stream bank remediation is comprised of a topographic and fluvial geomorphic survey. The components and the importance of each are described in this section.

Rivers frequently change their course and alter the topography of their valley. The terms bankfull flow, channel forming flow, and effective flow are used synonymously throughout current literature to represent the discharge that exerts the most work on the channel boundary. This flow occurs on average, every 1.5 to 2 years (Werrity, 1997). It is the frequency of this flow, rather than the magnitude, that exerts a dominating force on the landscape by the processes of sediment erosion, transport, and deposition. As such, an up-to-date topographic survey of the site serves as the basis of understanding the existing stream and slope geometry.

Topography and stratigraphy are both considered to estimate how the original landform has evolved into the current landform. Current stream geometry is compared to the topography and stratigraphy to complete the geomorphic survey. The data collected for the geomorphic survey include flow velocity, sectional area, wetted perimeter, hydraulic radius, bend radius, width, depth, slope, and hydraulic roughness. The methods and procedures for performing the geomorphic survey are summarized in the guidance manuals Hydrologic Engineering Centers (HEC) -18

(Ameson, et. al. 2012), HEC-20 (Lagasse, et. al. 2001), and HEC-23 (Lagasse, et. al. 2009). There is additional information available in other published literature.

The discharge of the river can be estimated using several methods based upon the data collected from the topographic and fluvial geomorphic surveys. Flows estimated from these methods should be compared to estimate a reasonable value that will serve as the baseline for design. For example, Manning's equation is used to estimate the discharge of a flow that reaches a known elevation through a measured cross section and profile. Additionally, the USGS has published regionally-specific regression equations that estimate the discharge from a range of recurrence intervals (Lumia, et. al. 2006). Data from local gauging stations provide another source of information. These data are used to statistically estimate the recurrence of a range of discharges. If there is agreement among the different methods for a known discharge, they can be used to estimate the design discharge through the measured cross section. These analyses are used to design for the selected flood elevation and boundary shear stress conditions.

Linking the Geotechnical and Geomorphic Assessments

Now that the scale variant approach has been focused to the engineering scale, the data from the subsurface exploration program and the geomorphic survey are integrated to further refine our model. The model has now become extremely effective to help the engineer assess the geotechnical and geomorphic characteristics that are causing the stream bank instability.

Once the causes of the stream bank instability are understood, the model input variables are adjusted to estimate how they interact. The results of the interactions between input variables provide the basis for judging whether the stream bank mitigation will require traditional geotechnical repair measures, applied fluvial geomorphic measures, or a combination thereof. Further, quantitative results of the modeling provide the baseline for designing each of the individual measures. Some of these typical measures are described in the next section.

Stream Bank Remediation Techniques

Once the engineer has modeled the site and understands the interactions between the geotechnical and geomorphic conditions, and each factor's role in the bank instability, they can begin to focus on the design to stabilize the stream bank and slope. A discussion of some environmentally sensitive streambank remediation techniques from HEC-20 (Lagasse, et. al. 2001) follows.

Slope Stabilization and Protection

Several traditional slope stabilization techniques were described above, and many are appropriate for use to mitigate a stream bank. However, once the slope is stabilized it also has to be appropriately protected against further damage from the stream.

Protecting the stream bank toe must be considered as part of the final design. With an understanding of the geomorphic conditions of the stream, its erosive power (i.e., velocity and shear stresses) can be estimated to complete an appropriate design for protection. Riprap fill is typically used as longitudinal protection along the toe for scour and erosion protection.

The material used to construct a buttress that will protect (and potentially stabilize) the slope should be sized considering the tractive forces of the stream. The riprap should be placed to limit scour below the original stream bed elevation where a wedge of the buttress is subject to future down-slope translation, or launching. The riprap must be sized such that it is not transported by the design flow and also the riprap must be placed on a graded filter so that fine-grained soils are retained behind or beneath the riprap.

River Training

The primary objective of river training is to direct flow past a site in a way that does not destabilize the stream bank slope. River training is accomplished using a suite of techniques including transverse structures (e.g., dikes, groins, jetties, bendway weirs, rock vanes, J-hooks, bank barbs, etc.) and longitudinal structures (e.g., longitudinal stone toe protection, cribwalls, vegetated mechanically stabilized earth, etc.). The goal of most river training structures is to manage, or realign the thalweg (i.e., deepest, highest velocity region of the cross-section of the stream) within the field of the river training structures, and to reduce velocities and shear stresses acting on the bank. In many cases the diversity of velocity, depth, substrate, and flow complexity result in improved ecological functions.

Transverse structures such as dikes, rock vanes, and bendway weirs are effective in redirecting the course of the thalweg and adjusting the locations of erosion and sediment deposition. These structures work by introducing traction in the channel that dissipates some of the thalweg's energy and directs it away from the bank and towards the center of the stream channel. Typically, these are constructed as stone structures that extend at an angle from the bank into the channel. Details of the geometry, orientation, and spacing depend on their relative position along the protected bank (e.g., upstream or downstream end of the project) and their specific function (e.g., changing the thalweg's direction or managing it to exit the site).

Longitudinal structures placed some distance from the original bank-line are effective at conveying the flow past a site while providing resistance to stream meandering. Examples include longitudinal stone toe, cribwalls, and MSE walls. In engineered river floodplain bench environments, dense vegetative plantings such as live siltation, live brush layering, and living dikes oriented both parallel and perpendicular to the path of high flow are also effective at providing resistance to lateral channel migration by dissipating excess energy along the bank. While longitudinal structures are effective, the designer must understand that local scour rates can increase if significant roughness is not added along the structure. A conceptual stream reach with river training structures is shown in Figure 1.

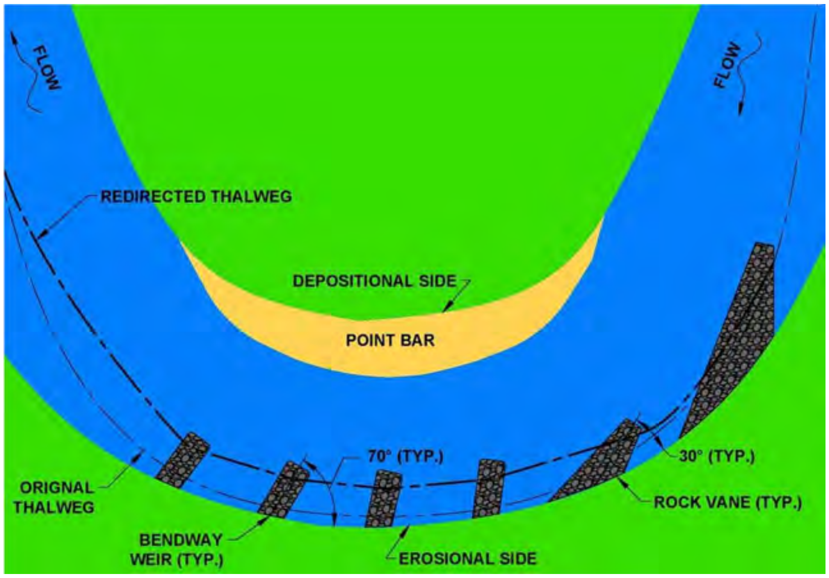

Figure 1 – Typical stream reach with river training structures

Bank Armor and Protection

Bank armor and protection includes groundcovers and revetments. Riprap or other hard structures are used in areas where high shear stresses will likely be concentrated while the remainder of bank protection is accomplished through vegetative techniques or rolled erosion control products. Erosion control blankets and turf reinforcement mats are used primarily to stabilize the soil in the time immediately following construction before robust vegetation is established. Vegetation reduces near-bank velocities by increasing the roughness along the bank, and it reduces particle entrainment by growing root systems that bind the soil together.

Riparian and Stream Opportunities

All of the river training and protection techniques described above can be used to enhance the ecological function of stream sites and reaches. The techniques sometimes serve the dual purpose of training the stream as well as creating habitat for aquatic organisms by oxygenating the water and providing feeding places, resting places, dwelling places, and refuge during high energy events.

Other techniques are used exclusively as habitat improvement within the channel and in the overbank area. While these techniques don't often provide structural assistance to slope stabilization, their value is maintaining or enhancing the aquatic habitat that existed before stream disturbance. Many practitioners are using habitat improvement in combination with river training techniques with substantial success.

Examples include anchoring coarse woody debris beneath riprap, hydraulic cover stones, LUNKERS, and riparian vegetation integrated within and around riprap.

CASE HISTORIES

The following are two case histories of projects that illustrate approaches to stream bank remediation near each extreme of the geotechnical/geomorphic spectrum. The first, along Tonawanda Creek, is a project where the banks failed due to unfavorable geotechnical conditions that could no longer support the stream banks, even with little interaction from the adjacent waterway. Conversely, the second case history, along Cattaraugus Creek, demonstrates that even with favorable subsurface conditions, the stream dynamics can undermine the slope to the point of failure.

Tonawanda Creek Road, Tonawanda Creek, Clarence, New York

Tonawanda Creek forms the northern border of Erie County with the southern border of Niagara County in New York. It is a bi-modal meandering channel through most of its downstream reach, meaning that there are small meanders within larger ones. Through most of its downstream reach, it flows through the soft silts and clays that were deposited in Lake Tonawanda near the end of the last glacial period. Silty sand was deposited over the soft clays. Its bed has a low gradient and the banks are mostly stiff desiccated clay, over the softer deposits.

Tonawanda Creek has a history of bank failures, particularly on the outside bends and after heavy rains. In 2004, a slope failure along the southern bank, at an outside bend, damaged a 250-foot long portion of Tonawanda Creek Road in Erie County. The road and surrounding ground surface dropped approximately 10 feet in elevation and the slope rotated and translated into the stream.

Problem

A subsurface exploration program, which included soil sampling, instrumentation (monitoring wells and inclinometers), and in-situ and laboratory testing, indicated that, prior to the failure, the slope was supported by soft silt and clay deposits (see Figure 2). The clay deposits extend approximately 35 feet deep to a till layer and have undrained shear strengths between 200 and 600 pounds per square foot.

Beyond the geotechnical issues leading to the bank failure, the engineers also studied the stream using an early form of the scale variant approach to understand the role of fluvial geomorphic issues. The most significant revelation from the approach was the failure's relative location along a meander. Studying the failure's location, and other failures along Tonawanda Creek, a familiar pattern became evident. The location of nearly all of the failures was on the outside bend of the waterway. The outside bend is where the thalweg is directed toward the bank and erodes its toe. Therefore, even though Tonawanda Creek is relatively slow moving, its flow can provide enough erosive energy to reduce the bank's support.

Combining the geotechnical study with the scale variant approach helped the engineer understand the causes of failure. The upper silty sand zone became saturated due to precipitation and poor drainage. Scour at the outside bend removed the bank's toe support. The combination of a heavy, saturated bank, soft silty clay support, and reduced support along the toe eventually caused the bank to fail along a rotational plane.

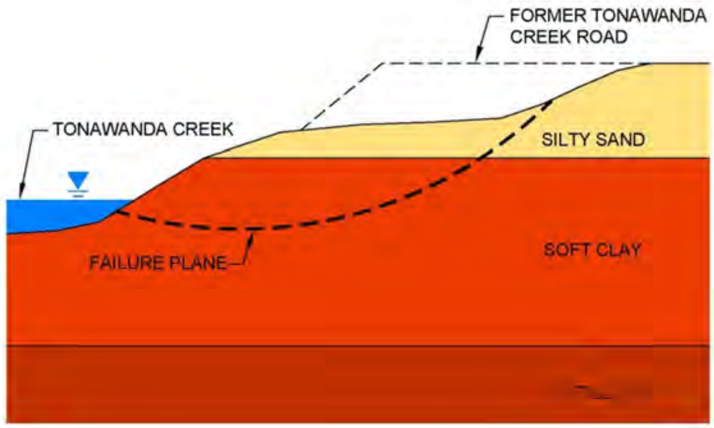

Figure 2 – Simplified subsurface profile at Tonawanda Creek Road failure

Solution Approach

Once the county and its consultants understood the causes of the failure, it could develop a plan to stabilize the slope and protect the banks from future erosion at this site.

The engineers elected to remediate the slope failure by addressing the geotechnical and hydraulic factors that contributed to the problem. First, the slopes were stabilized by improving the drainage of the silty deposits above the soft zone. This lowered the driving forces on the slope by removing weight. Second, the engineers increased the shear strength of the soft silt and clay deposits using a dry soil mix method. Third, longitudinal stone fill and vegetation were placed along the bank's toe to address future erosion.

Drainage

The design incorporated improvements in surface and subsurface drainage. After the silty soil was removed to accommodate construction of the dry mix columns (described below) it was replaced with free draining, open-graded drainage stone. The drainage stone directed groundwater away from the bank and into the stream. Surficial drainage was improved through grading and the addition of drop inlets.

The improved drainage lowered the groundwater level in the bank, even during wet seasons and following heavy rain events. This helped lower some of the driving forces leading to bank instability.

Increased shear strength

The stability analyses showed that improving drainage and lowering the groundwater level was not enough to provide an acceptable factor of safety for the remediated slope. The soft silt and clay deposit did not have enough shear strength to resist the driving forces. As such, the engineers elected to improve the shear strength of the soft deposits using soil cement columns constructed using a dry soil mix method.

The dry mix method, first used in northern Europe, involves inserting rotating mixing blades into the soft deposit and injecting dry cement using air pressure. The mixing blades mix the cement with the soft deposit as they are withdrawn to form a 2 to 3-foot diameter column. The cement is hydrated from the moisture in the soil and the columns become stiffer over time.

The soil-cement columns improve stability in two ways. First, the column formed by this method has shear strengths that are 10 to 50 times stronger than the native soils. These higher strengths provide additional resistance against failure. Second, since the columns extended into a harder deposit below, they also act to transfer the load of the replaced embankment to the more competent deposit. This removes weight from the top of slope and some of the driving forces that destabilize the slope.

At this site, the design required over 2,200 30-inch diameter columns that extended approximately 35 feet deep to the bottom of the soft deposits. The columns were treated with approximately 125 pounds of cement per cubic yard of treated soil. Laboratory and field tests showed the improved composite undrained shear strength (a weighted strength considering the columns and the remaining soft deposits) to be between 2,000 and 3,000 pounds per square foot.

Erosion Protection

Since the stream eroding support from the bank’s toe also contributed to the slope failure, the design incorporated erosion protection. The erosion protection included longitudinal stone fill along the toe, parallel to the stream bank, and vegetative plantings. Both of these techniques act to reduce energy along the stream bank and provide habitat for riparian species.

River training using transverse structures (rock vanes and bendway weirs) was considered as an additional erosion control mechanism for remediating the stream bank. However, the soft clay stream bed that leads to the bi-modal meandering pattern limited the applicability of the river training techniques.

Results

The multi-faceted approach that considered the geotechnical characteristics and stream dynamics was successful in remediating the failed stream bank. Improving the strength of the soil deposits supporting the road dealt with the condition that caused the failure. Further improvements, such as improved drainage and erosion protection helped limit the potential for future slope movements in this area. Construction on this project was completed in 2009 and the road has successfully remained open and has not shown signs of further distress.

Creek Road, Cattaraugus Creek, Town of Yorkshire, New York

A very different problem occurred at the site of the second case history. This site is situated along Cattaraugus Creek in northern Cattaraugus County. Unlike the slow, meandering reaches of the lower Tonawanda Creek described in the first case history, the upper Cattaraugus Creek flows along a steep profile.

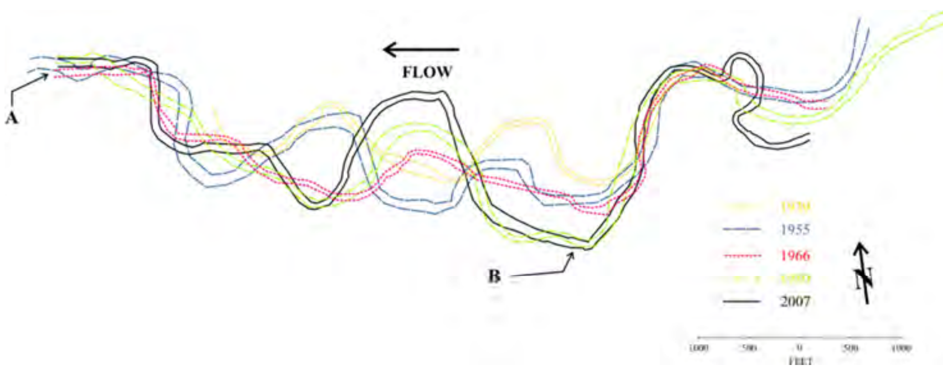

Figure 3 - Time lapse overview of Cattaraugus Creek; Arrow at A indicates the location of a bridge over the river, Arrow at B indicates the location of the site.

The contributing area upstream of the Cattaraugus Creek at Creek Road site covers approximately 187 square miles. In some reaches, the channel meanders through its valley, often reaching laterally to interact with the higher topography of the valley sides. In other reaches, the channel is deeply incised as much as 200 feet into bedrock. Cattaraugus Creek is a high energy stream, as illustrated in Figure 3, which shows that the channel has meandered through its valley as much as 1,000 feet laterally in the Creek Road reach between the years 1939 and 2007.

Sometime between 1966 and 1980, Cattaraugus Creek at the Creek Road site meandered south until it encountered the valley wall near Creek Road. A sheetpile wall was constructed in an attempt to protect the roadway, but over time the toe of the wall was undermined and the wall rotated into the channel. Migration toward the roadway continued until erosion reached the shoulder of Creek Road.

Problem

A subsurface exploration program indicated that Creek Road is underlain by sand and gravel, which is underlain by silty clay that extends below the elevation of the channel bottom. Groundwater flows from the sand and gravel, along the valley sides, and into the channel.

The geomorphic assessment indicated that during high flow conditions, the silty clay was scoured from the toe of the slope and the water surface inundated the sand and gravel by as much as 10 feet, causing erosion of the mid-slope. Groundwater seepage, primarily following significant precipitation or rapid drawdown of flood water, further contributed to mid-slope erosion that caused slumping in the upper slope at the shoulder of Creek Road.

The geotechnical and geomorphic assessments indicated that Cattaraugus Creek was the major contributing factor in the failing bank. The geotechnical conditions could be improved, but the stream dynamics had to be addressed to protect the road for a long-term solution.

Solution Approach

Once the causes of the slope instability were understood, the engineer developed a plan to mitigate the bank by improving slope drainage, river training, and providing erosion protection. Figure 4 shows the remediation plan at Creek Road.

Slope Drainage

Prior to flattening the bank, a blanket of drainage stone was placed along its face to direct groundwater from the slope and into the stream. A graded filter was used between the silty sand subgrade and the bank armor to allow adequate drainage while retaining finer grained materials.

River Training

A series of rock vanes and bendway weirs were constructed to redirect the thalweg away from the bank. One vane was placed immediately upstream of the bend, three vanes were placed in the bend, and three bendway weirs were placed downstream of the bend. The intention was to use the vanes to guide the thalweg around the bend while maintaining the thalweg away from the bank, and then use the bendway weirs to direct the thalweg toward the center of the channel as it exits the site. The vanes were extended one foot above the bankfull flow elevation and the bendway weirs were extended two feet above the base flow elevation.

A longitudinal stone toe was constructed in the bank to further train the water around the bend, to dissipate additional energy, and to provide extra riprap protection in the event of toe scour and subsequent riprap adjustment. The longitudinal stone toe was keyed below the channel invert elevation and it was extended two feet above the base flow elevation.

Erosion Protection

Riprap was placed along the streambank above the longitudinal stone toe to reduce soil erosion. The design called for extending the riprap from the toe of the slope up to the estimated elevation of the 10-year recurrence interval flood elevation. Vegetation was established above the elevation of the riprap to protect the soil from intense precipitation and from extreme high flows. Temporary erosion mat was installed to protect the soil between the time construction was completed and the time a dense stand of vegetation was established.

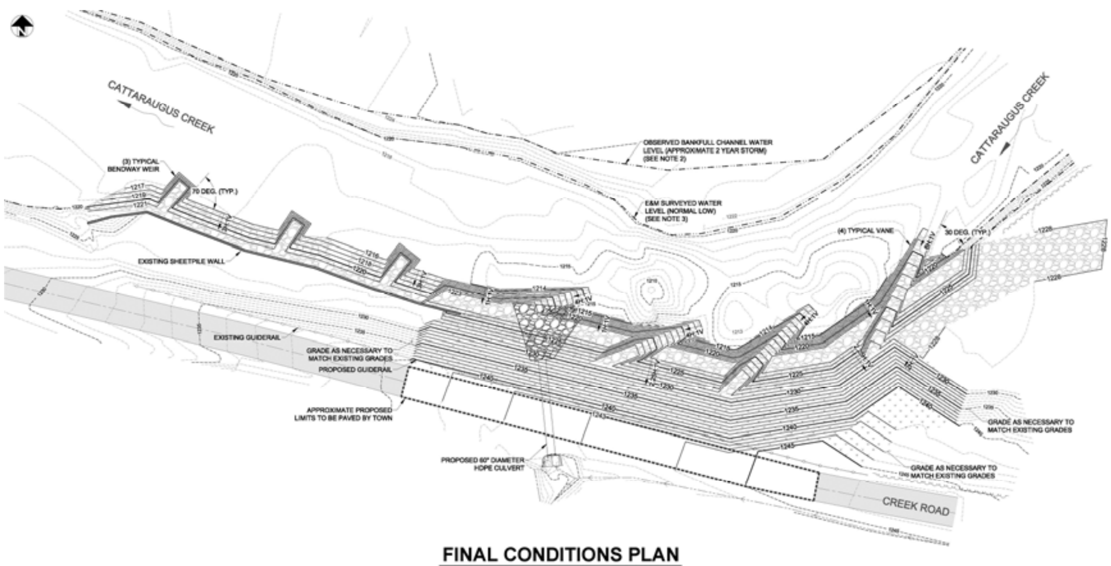

Figure 4 – Remediation plan at Creek Road

An upstream key was extended back into the floodplain terrace to an area of existing dense vegetation to prevent the channel from migrating and eroding behind the revetment and protection works. The upstream key was excavated as deep as the invert of the channel and the riprap was extended up to one foot above the bankfull elevation.

Results

Construction of this project was completed in 2011 and the work has successfully protected the stream bank from erosion. Observations during high flows indicate that the discharge velocity at the bankline is non-erosive and the thalweg follows a very favorable alignment around the bend. Observations during low flows (see Figure 5) indicate that the area upstream of the upstream vane has become an area of coarse gravel deposition, the area in the wake of the downstream bendway weirs has also become an area of coarse gravel deposition, and all of the transverse structures can accumulate coarse woody debris. The areas of clean coarse gravel bars and coarse woody debris provide habitat to aquatic organisms.

CONCLUSIONS

These two case histories illustrate a systematic approach to remediating stream bank failures. Without the understanding both the geotechnical and the fluvial geomorphic factors that contribute to the problems, neither would have been successful over the long term. By first understanding the nature of the problems and the importance of each of the factors causing these problems, the engineer can then begin developing a solution that will be appropriate for their site.

Figure 5 – Note the thalweg location off the river-end of the rock vanes

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