STREAMBANK RESTORATION DESIGN WITH VINYL SHEET PILE GRADE CONTROL STRUCTURES

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ABSTRACT

Grade control structures are an effective channel stabilization measure which can eliminate requirements for highly visible structural control measures or streambank protection. Floodplain management procedures which provide opportunities to preserve the natural resource values associated with the riparian and river ecosystem result in improved aesthetics for the community as a secondary benefit. Streambank restoration promotes bank stability and minimizes undesirable adjustment through emulating the natural processes. Advances in new construction material involving a vinyl structural sheet pile offer a new application for streambed grade control structures. The system is an inert material that is extremely lightweight which facilitates the installation. The **vinyl sheet pile system** offers many unique properties for a hydraulic structure including minimizing the normal construction impacts and the heavy equipment. A comprehensive design procedure applied utilizing this unique vinyl sheet pile material and the hydraulic evaluation steps involved in the design of the grade control structures are presented. A unique streambank restoration project for Martin Creek located in Dublin, California which incorporated twenty of these grade control structures, as well as other bioengineering techniques, is reviewed as an actual case study.

INTRODUCTION

Control of long term channel degradation in alluvial streams based upon high sediment transport capacities and excessive velocities can be accomplished through incorporation of grade control structures into a channelization program. Numerous standard structural control measures are available for streambank protection, however, grade control structures offer the advantage of minimizing the impact to the natural stream features through adjustment of the dominant hydraulic forces rather providing measures to resist the forces. The basic planning approach relies on developing a comprehensive baseline analysis of the floodplain hydraulics and sediment transport requirements for the natural stream system. The hydraulic design and placement of these structures requires application sediment transport relationships to evaluate the anticipated long term equilibrium conditions from the stream mechanics. The structure can function to: (1) maintain a specific water surface elevation at the structure crest, (2) operate drop as structure after the channel has achieved the long term equilibrium channel slope, with the maximum net drop of the structure corresponding to the difference between the original stream slope and the equilibrium slope, (3) adjust the natural hydraulic characteristics to reduce the average velocity and improve alluvial channel stability. An important consideration to prevent a common failure mechanism of this type of structure is to adequately protect against undermining downstream from the erosive action of the local scour and also the general long term scour.

Common installations of grade control structures include simple structures which consist of only a vertical breast wall across the channel invert that provides a “fixed” invert elevation at a point along the stream profile. Standard construction materials associated with these structures have included timber piles, reinforced concrete gravity walls, metal sheet piles, soil cement, and grouted rock. Each construction material has specific benefits and limitations which should be considered for each unique application, particularly the longevity of the structure and construction requirements. Interlocking vinyl sheet piles offer numerous advantages, especially for applications with sensitive riparian stream corridors.

KEY DESIGN FEATURES OF GRADE CONTROL STRUCTURES

In-stream grade control structures establish fixed elevations in the alluvial streambed which assists in long term stability and development of the anticipated stream “equilibrium slope” and limit the maximum potential degradation. The location or spacing of the crest elevation or “sills” for each grade control is limited by the maximum allowable net drop height. The net drop is defined as the difference between the natural streambed slope and the predicted long term stable channel slope which is dependent upon the sediment inflow and natural stream bed armoring. Standard design applications utilizing steel sheet piles for grade control are presented in different design manual including the Army Corps of Engineers, *Hydraulic Design Manual EM-1100-2*. The primary components of the vertical sheet pile grade control structure consist of (1) interlocking sheet pile wall, (2) deadman, (3) sill structure across the crest or wale, and (4) streambed armoring downstream. Common features utilized in the current application of the vinyl sheet pile grade control structure are described below and indicated in the following figures.

Vertical Toedown: Avoiding foundation failure of the structure requires embedment of the structure below the maximum local scour depth and providing adequate depth for structural stability. The toedown depth is one of the critical design features in the design which requires evaluating the hydraulic and structural components.

Lateral Embedment: Typical published criteria of various agencies recommend lateral embedment of at least 5 feet into undisturbed soil beyond the maximum water level.

Invert Cap: The top of the sill for the grade control structure conforms to the geometry of the channel section. A horizontal beam across the crest or wale provides a portion of the structural resistance. The sill can be constructed of concrete and also satisfies the hydraulic requirements.

Sheet Pile Tie-back or Deadman: In order to provide structural stability of the sheet pile wall, a dead man anchored at the top of the wall and buried upstream of the wall, is required to assist in resisting the lateral earth loads.

Downstream Revetment/Armor: The dimensions approximating the limits of the downstream streambed protection required to contain the impinging flow can be evaluated using the analytical procedures developed for vertical drop structures.

Moore/Chow (1952) developed relationships for the drop structure using a dimensionless Drop Number (D_n). These dimensions can be used to provide the minimum criteria for providing an artificial armor blanket in the plunge pool area.

Low-Flow Notch: A notch in the center of the crest sill will assist in directing low-flows and minimizing agradation problems with nuisance flows.

VINYL SHEET PILE MATERIAL

Vertical interlocking vinyl sheet piles, Shoregaurd® and GeoGaurd® manufactured by Materials International, are unique construction material which had been typically utilized for seawall and coastal installation on the east coast. The sheet piles can be driven with standard pile driving equipment, but driveability of the soil should be evaluated. The vinyl sheet piles offer the advantages of (1) low cost material costs, (2) exceptional service life compared to other material especially in corrosive environments, exceeding 100-year design life requirements and (3) reduced installation requirements and costs. The sheet piles consist of standard "Z-pile" section dimensions, including 12" x 7" and 10.5" x 5". The piles are manufactured with a special formulation of polyvinyl chloride which has excellent strength, creep performance, chemical inertness, weatherability, UV resistance, stiffness, impact properties, and environmental friendliness. The pile lengths can easily be field adjusted since they can be cut with chain saws or reciprocating saws, and drilled using conventional hand drills.

HYDRAULIC DESIGN REQUIREMENTS

Maximum Net Drop Height: The application of grade control structures are generally limited to "low-drop" heights and most published jurisdictional guidelines limits the maximum drop height to 3.0 feet. Net drops heights which exceed this range it is recommended that a different type of structure be considered which includes a rigid stilling basin or end sill.
Structure Spacing: Maximum distance between consecutive structures is based upon the difference in the equilibrium slope for the channel and the natural streambed slope which should not exceed the maximum net drop. Structures should be adjusted to account for local geomorphic conditions including meanders.

SEDIMENT TRANSPORT CONSIDERATIONS

Long Term equilibrium Slope: Evaluation of the general scour provide an estimate of the anticipated long term streambed profile and the resulting degradation. Equilibrium slope is defined as the slope at which the sediment transporting capacity of the channel is equal to the sediment supply. Analysis of the equilibrium slope can be accomplished through the application of the sediment continuity principle and a representative sediment transport relationship. Another procedure which can be applied utilizes the tractive force and the minimum velocity required for incipient motion. The potential for development of natural bed armor should also be accounted for in the analysis through estimates of the depth of bed armor.

Local Scour Depth Estimates: A critical element of the grade control structure design is the prediction of the local scour which will occur downstream of the structure based the maximum drop occurring at the structure. The structure must be embedded vertically beyond this maximum anticipated scour depth and the structural analysis of the sheet pile should use this worst case erosion. The depth associated with the local scour can be evaluated utilizing many of the available empirical procedures and equations. Most of the existing scour depth equations are summarized by Mason and Arumugam (1985). The Veronese method is one common empirical procedure and as

$$D_s + Y_T = 0.202\, H^{0.225}\, q^{0.54}\, d_m^{-0.42}$$

reported in Mason and Arumugam, is:

STRUCTURAL DESIGN AND SPECIAL FEATURES

The structural design of the grade control structure needs to evaluate the most extreme condition as an earth retaining which corresponds to the full development of the local scour hole downstream of the structure. The common analysis of sheet piles utilizes the "equivalent beam method" (after Teng). The structural analysis should evaluate: (1) determination of tie rod requirements, (2) depth of vertical pile penetration or embedment, (3) size of counter weight or deadman, (4) location and spacing of tie rods, (5) whaler requirements. A point of fixity is assumed at the depth of maximum scour downstream of the structure.

PROJECT APPLICATION: MARTIN CREEK (DUBLIN, CALIFORNIA)

Martin Creek is the primary natural drainage feature within the proposed Hansen Hill Ranch residential project which is located in the City of Dublin, Alameda County, California. The proposed development was conditioned to provide a streambank stabilization program. The study reach for this portion of Martin Creek consists of approximately 4,400 feet of stream, which has a tributary watershed area of **** acres and consists of a well incised watercourse with mature oak trees and other vegetation. The dynamics of the stream geomorphology has developed a rather sinuous alignment with numerous meanders that have exhibited historical streambank migration and lateral erosion. These features are the primary focus of the recommended improvement program, providing control measures to mitigate the erosion potential and assist in the long term stability of the creek which will allow adjacent residential development to occur.

A total of 20 invert control structures will be provided to limit the long term degradation and assist in maintaining the streambank stability rather than utilize some form of structural revetment which would significantly damage the natural resources of the stream corridor and the important aesthetic features. The structures will be constructed utilizing the GeoGaurd® vinyl sheet piles, extending the full width of the channel and embedded 5-feet beyond the top of channel banks to prevent potential flanking. The structures have been located utilizing a maximum net drop of 3.0 feet to ensure the structure was a "low drop" and satisfies most standard criteria regarding recommendation of maximum drop height for structures without fixed end sills. Initially the crest of the structure will extend 1.5 feet above the existing stream flowline. A six-inch depression in the center of the crest will provide the low-flow notch to assist in controlling nuisance flows. An armor blanket has been provided downstream in the location of the scour hole development and the amount of armor is based upon the nape length for a horizontal jet impingement.

It is anticipated that the erosion process will slowly expose the drop structure further and develop the maximum drop in the streambed elevation at the structure. The degradation process will tend to develop a natural bed armor for the channel through the natural mechanical sorting process of the bed material. A unique feature which is part of the reason for the selection of the vinyl sheet piles is the flexibility in the installation, eliminating the requirement for pile driving equipment. The proposed construction installation will utilize excavated piles, rather than driven, and after installation the piles will be backfilled with a slurry mix.

REFERENCES

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