Research & Technology Transfer

Alaska Department of Transportation & Public Facilities

ALASKA DEPARTMENT OF TRANSPORTATION

The Effects of a Winter Ice Jam Event On Bioengineered Bank Stabilization Along The Kenai River

Prepared by: Kenneth F. Karle, P.E.
Hydraulic Mapping and Modeling

Date
October 2007

Prepared for:
Alaska Department of Transportation
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

FHWA-AK-RD-07-03

REPORT DOCUMENTATION PAGE

Form approved OMB No.

1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
FHWA-AK-RD-07-03	October 2007	Final

4. TITLE AND SUBTITLE

The Effects of a Winter Ice Jam Event on Bioengineered Bank Stabilization Along the Kenai River

5. FUNDING NUMBERS

T2-07-01

6. AUTHOR(S)

Kenneth F. Karle P.E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Hydraulic Mapping and Modeling
Denali Park, Alaska

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

State of Alaska, Alaska Dept. of Transportation and Public Facilities
Research and Technology Transfer
2301 Peger Rd
Fairbanks, AK 99709-5399

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

FHWA-AK-RD-07-03

11. SUPPLENMENTARY NOTES

The research performed for this project was funded by the Alaska Department of Transportation and Public Facilities under Federal Project Number HPR-4000(57). The work was performed by Hydraulic Mapping and Modeling. Kenneth F. Karle, P.E., was the principal investigator. Others who assisted with this project include: Clint Adler, ADOT&PF, Paul Janke, ADOT&PF, Mike Knapp, ADOT&PF, William Frost, ADOT&PF, Lee McKinley, ADNR, and Dean Hughes, ADFG.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

No restrictions.
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report documents and presents the results of a study on the effect of ice forces on bioengineered riverbank protection structures. Following an unusual winter ice jam event on the Kenai River, affected bank revetment structures were evaluated during several field visits. A visual analysis of the structures identified whether or not damage was incurred by the ice event. At two large root wad installations, many suffered damage to the roots or tines forming the wad, though the boles remained firmly in place. Root stems were snapped off by ice floes, generally in a downstream direction. At one site with a well-established willow brushlayering treatment above the root wads, the upper bank appeared to be well-protected against gouging ice floe damage by the willow trees growing there. The findings of this study and others on bioengineered structures in Alaska suggest that some sacrificial damage may be expected to occur if root wads are subjected to direct impacts from large ice floes. Well-established willow brushlayers appear to work well in protecting the upper bank from ice damage on steep banks, and are resilient in recovering from ice jam damage.

14. KEYWORDS : Ice, riverbank protection, Kenai River, root wad, brushlayering

15. NUMBER OF PAGES
34

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	N/A

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

THE EFFECTS OF A WINTER ICE JAM EVENT ON BIOENGINEERED BANK STABILIZATION ALONG THE KENAI RIVER

FINAL REPORT

Prepared for
Alaska Department of Transportation & Public Facilities

Kenneth F Karle, P.E.
Hydraulic Mapping and Modeling
Denali Park, Alaska
October 2007

Table of Contents

List of Figures

Acknowledgements

The research performed for this project was funded by the Alaska Department of Transportation and Public Facilities under Federal Project Number HPR-4000(57).

The work was performed by Hydraulic Mapping and Modeling. Kenneth F. Karle, P.E., was the principal investigator.

Others who assisted with this project include: Clint Adler, ADOT&PF, Paul Janke, ADOT&PF, Mike Knapp, ADOT&PF, William Frost, ADOT&PF, Lee McKinley, ADNR, and Dean Hughes, ADFG.

Abstract

This report documents and presents the results of a study on the effect of ice forces on bioengineered riverbank protection structures. Following an unusual winter ice jam event on the Kenai River, affected bank revetment structures were evaluated during several field visits. A visual analysis of the structures identified whether or not damage was incurred by the ice event. At two large root wad installations, many suffered damage to the roots or tines forming the wad, though the boles remained firmly in place. Root stems were snapped off by ice floes, generally in a downstream direction. At one site with a well-established willow brushlayering treatment above the root wads, the upper bank appeared to be well-protected against gouging ice floe damage by the willow trees growing there. The findings of this study and others on bioengineered structures in Alaska suggest that some sacrificial damage may be expected to occur if root wads are subjected to direct impacts from large ice floes. Well-established willow brushlayers appear to work well in protecting the upper bank from ice damage on steep banks, and are resilient in recovering from ice jam damage.

Summary of Findings

The main objective of this study was to gather field data and other relevant information necessary to supplement existing knowledge of ice forces on bioengineered bank stabilization structures such as root wads, willow brushlaerying, and coir logs. The impetus for this study was an ice-jam and flood on the Kenai River in January 2007. The flood, which was caused by a glacially dammed lake outburst upstream, damaged numerous walkways and stairs used to access the river.

We evaluated existing bank revetment structures on the Kenai River that were affected by the ice jam event, and conducted a visual analysis of the structures by identifying whether or not damage was incurred by the ice jam event.

At two large root wad sites, many of the root wads suffered damage to the roots or tines forming the wad. Generally, the longer stems were damaged, though some stems down to one foot in length were also broken. A substantial number of stems were broken from numerous root wads. Boles were generally undamaged and in place. A smaller root wad site appeared to be in excellent condition, though some root tines were broken.

At a large root wad site with a steep brushlayer treatment, the upper bank appeared to be well-protected by the willow trees growing there, but many of the willow trees were severely bent over in a downriver direction following the ice-jam event. By early summer, the vast majority of the willows appeared to be healthy. Stalks had straightened out, and were in the process of leafing out. At a cribwall site, mature trees in the upper bank were flattened in a downstream direction, and had much of their bark scraped off by ice floes.

We inspected one riprap site at a bridge replacement project, which appeared to be in excellent condition after the ice jam event.

Results from this study indicate that some sacrificial damage may be expected to occur if the root wads are subjected to direct impacts from large ice floes. Healthy and mature willow brush layers appear to work well in protecting the upper bank from ice damage on steep banks, and are resilient in recovering from ice jam damage. However, concern should be noted for reduced protection from ice floes and ice jams in the first few years of a brushlayered stream bank, until root mass and trunk development are well underway.

Though ice floes are common each spring during the breakup season, it is unlikely that the bank protection structures inspected for this project had been subjected to a similar ice loading condition. Because of a lack of field data, we do not know how bioengineered bank protection structures would handle repeated ice jam forces.

Recommendations are presented both for implementation of bioengineered bank protection structures, and for future research needs.

Implementation

- Identification of the potential for annual ice jam formation in the river reach where bank protection methods are proposed is essential prior to design and installation.

- Some bridges with constricting abutments or multiple piers may act to create ice jams on a regular basis. In accordance with current ADOT&PF policy, bioengineered structures should not be used to protect critical infrastructure along these reaches.

- Avoid root wad installations that protrude into the flow.

- Root wad installations that may experience ice forces should be firmly anchored to protect against both lateral impact forces and vertical buoyant forces.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

Problem Statement and Research Objective

In 2003, the Alaska Department of Transportation & Public Facilities (ADOT&PF) published the result of a study that investigated the use of bioengineered erosion control structures on Alaskan streams (Karle et al., 2003). The report focused on the hydraulic and vegetative performance of eleven bio-engineered sites around Alaska. Root wads, live staking, brush layering, and coir logs were the primary bioengineering methods used for erosion control at the study sites.

Hydraulic modeling and the analysis of field data from sites that suffered damage during flood events focused on the potential for toe erosion, and the lack of protection against such erosion, at several of the study's root wad sites. Damage at existing structures was attributed to undermining of toe protection, buoyancy effects, failure of fabrics, and flowing ice. Damage from moving ice to the outer fabric used in fabric encapsulated soil lifts was noted at two locations. However, root wad installations, particularly on the Kenai River, were not considered to be at risk of damage by river ice.

Bank protection structures on the Kenai River near Soldotna, including some structures included in the earlier study, suffered some damage in January 2007 as the result of an ice-jam flood. The flood, which was caused by a glacially dammed lake outburst upstream, damaged numerous walkways and stairs used by anglers and others to access the river, including some that were incorporated into larger bank restoration projects (Figure 1). Initial reports by observers shortly after the event suggested that many of the structures themselves, especially root wads, were severely damaged by ice floes (ADN, 2007).

The design and installation of stream bank protection structures requires an understanding of the many complex and unique processes associated with river behavior in Alaska. Though limited, some information describing the effect of ice forces on riprap is available. However, information within the literature concerning ice forces on bio-revetment structures is almost nonexistent. As a result, the ADOT&PF determined that studies were needed to determine the risk of damage to such structures from ice floes and ice jams in Alaska.

Scope of Study

The ultimate goal of this project is to increase the base knowledge of how bioengineered structures perform in Alaskan conditions. This will increase the confidence of Alaskan agency and industry designers for designing the appropriate structures with confidence, while serving the Public's interest. This guidance will be developed in such a way as to be appropriate for eventual inclusion into Chapter 17 of the Alaska Highway Drainage Manual. The technical questions to be answered by this objective include: What are the selection criteria for bioengineered bank protection structures in Alaska? How does Alaska's unique climate and hydrology affect design parameters? What are the risks to structures from ice flows and ice jams? How does the term 'factor of safety' apply to bioengineered structures?

The objectives of this study are to:

1. Gather field data and other relevant information necessary to supplement existing knowledge of ice and water forces on bioengineered structures such as root wads and others,

2. Improve understanding of the factors and conditions that govern successful implementation of bioengineered structures in Alaska to satisfy both engineering and environmental goals, and

3. Develop preliminary guidance for eventual inclusion into the AKDOT&PF Alaska Highway Drainage Manual as part of a technical discussion on the design, installation, and maintenance of bioengineered stream bank stabilization projects.

Figure 1. Elevated walk at Soldotna Park damaged by ice jam event, January 2007. ADOT&PF photo.

Research Approach

To accomplish these objectives, we evaluated existing bank revetment structures on the Kenai River. The structures were situated within the reach of river that was affected by the January 2007 ice jam event. We conducted a visual analysis of the structures by identifying whether or not damage was incurred by the ice jam event.

The project was initiated by examining the literature review conducted for the 2003 report (Karle et al., 2003) and searching for new information concerning ice forces on bioengineered bank revetment structures. However, papers and reports specifically presenting comprehensive engineering performance data from bioengineered bank projects are few, and we found almost no discussion at all concerning ice forces for such projects.

An informal Project Advisory Team was formed in early 2007, and consisted of the Contractor (Hydraulic Mapping and Modeling) and several ADOT&PF employees with an interest in bioengineered bank protection structures. ADOT&PF set up a meeting in Soldotna, Alaska on May 7, 2007, and invited all agencies and parties familiar with and/or interested in the January 2007 ice jam event and its effects on bank protection structures to discuss the project. Following the morning meeting, participants traveled to a number of agreed-upon sites to observe conditions at the projects within the ice jam flood zone. The team visited additional sites on May 8, 2007. At each site, the focus was to determine whether or not structures were damaged by the event, and if so, the method or mechanism that caused the ice damage. The resulting damage analysis was qualitative only, as the team determined that there were too many unknown variables and missing field data to perform a meaningful quantitative analysis.

The project advisory team conducted a second field trip on June 20, 2007, and team members were accompanied by several personnel from the Alaska Department of Fish and Game (ADFG) and Alaska Department of Natural Resources (ADNR). For this trip, sites were accessed by traveling on the Kenai River in an ADNR power boat. Sites from the May trip, as well as several new sites, were visited to allow observers to view conditions after green-up and during a flow period with water elevations approaching ordinary high water.

CHAPTER 2 – FINDINGS

A winter ice-jam flood in late January 2007 caused water levels in the Kenai River at Soldotna, Alaska, to rise 15 feet in 24 hours. The flood was the result of a glacial lake outburst. Glacial outburst occurs when glacial movement opens a pathway for water trapped behind a glacier to escape. Skilak Glacier dams the unnamed lake, which commonly breaks out in late summer or fall approximately every two years. Winter releases are rare; two previously documented January outbursts occurred in 1969 and 1994 (David Meyer, USGS, personal communication).

The lake began releasing around January 16. The Kenai River at Skilak Lake rose about 3.8 feet beginning on January 18, and experienced a broad crest below Skilak Lake on January 27 (Kenai Borough, 2007). The rise in water levels caused the existing ice cover on the Kenai River to break up and form a series of ice jams that moved downstream over a period of several days, causing localized flooding in the Soldotna vicinity. Ice jams were noted upstream of the Sterling Highway Bridge near the confluence of Soldotna Creek; that ice moved downstream and jammed at the Sterling Highway Bridge by January 29. The bridge jam broke loose and moved downstream early January 30, allowing the water level at the bridge to decrease from 20 feet to 11.20 feet, which is just under flood stage. Ice was jammed at Centennial Park on the morning of January 30, but open channels allowed water to flow through and not back up behind the jam (Peninsula Clarion, 2007). By the afternoon of January 30, the Centennial Park jam cleared and reformed downstream near Slikok Creek, two miles below the Sterling Highway Bridge; this jam was over a mile in length (DHS, 2007). See Figure 2.

Figure 2. Ice jam on the Kenai River January 28, 2007. ADOT&PF photo.

A USGS gaging station is located adjacent to the Sterling Highway Bridge, just upstream of the large ice jam location. The hydrograph at that station for a 14-day period surrounding the event is found in Figure 3. The flood peaked at 20.26 feet. The generally accepted elevation of ordinary high water in this reach is 9.1 feet.

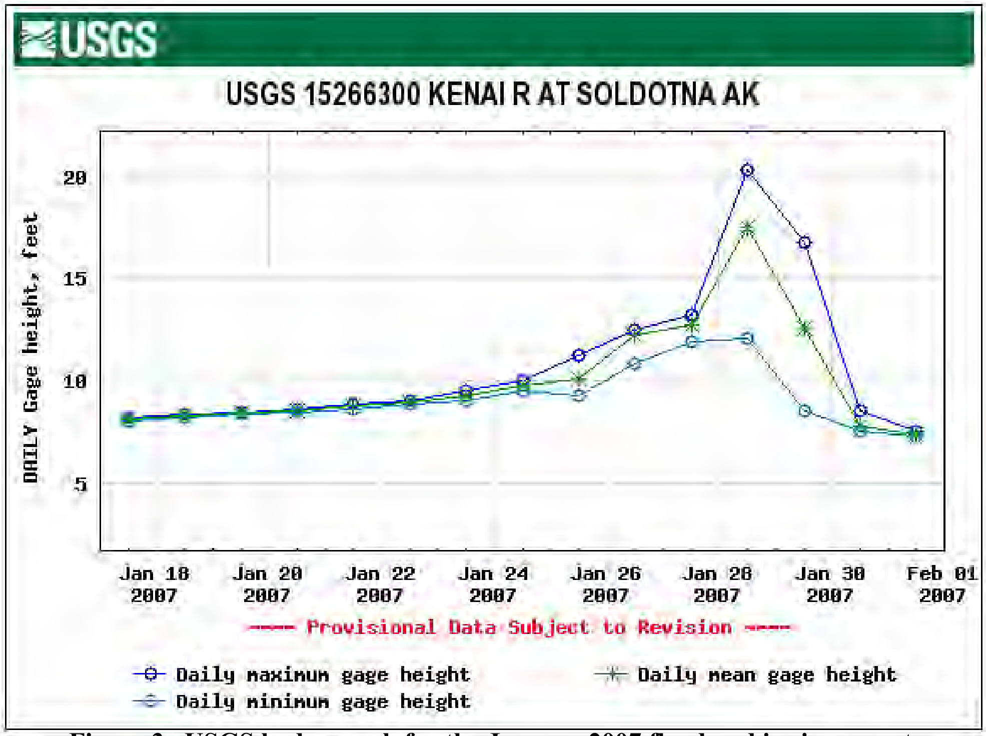

Figure 3. USGS hydrograph for the January 2007 flood and ice jam event.

As the ice jams moved downriver, they damaged or destroyed a large number of manmade structures, including staircases, handrails, fish-cleaning tables, docks, fishing platforms, and other items (Peninsula Clarion, 2007). Many of these structures were either crushed by the ice as it pushed onto the banks, or were ripped from their pilings and taken downriver in the ice floe movement. Many of the staircases that provide access to the river were bent downstream or torn off completely by ice jam forces. See Figure 4.

A number of habitat restoration sites that incorporate bioengineering techniques, along with one riprap site, are located within the reach of river impacted by the localized flooding and ice floe movement. The project team inspected these sites in May and June 2007 to assess the level of damage. The list of inspected sites is found in Appendix A.

Figure 4. Damaged folding aluminum staircase at Soldotna Park. ADOT&PF photo.

Root Wads

Root wads are a major component of several of the project inspection sites, including Centennial Park, Soldotna Park, and several smaller sites. The ADFG includes the following description of root wads in its streambank revegetation guide (ADFG, 2005):

> "Root wads are a streambank protection technique that provides immediate riverbank stabilization, protects the toe-of-slope and provides excellent fish habitat, especially for juveniles. They provide toe support for bank revegetation techniques and collect sediment and debris that will enhance bank structure over time."

At Centennial Park, many of the root wads suffered damage to the roots or tines forming the wad (Figure 5). Root stems up to 8 inches in diameter were snapped off by ice floes, generally in a downstream direction. Generally, the longer stems were damaged, though some stems down to 1 foot in length were also broken. A substantial number of stems were broken from numerous root wads.

Figure 5. Root wad with damaged root tines at Centennial Park.

With one exception, the boles appeared to be undamaged in any way. At Centennial Park, one root wad bole had been pulled away from the bank approximately 1 foot. In many root wad installations, header and/or footer logs are used to secure and anchor the individual boles. However, such logs were not used in this section of the Centennial Park project.

In Figure 6, a photographic comparison of several individual root wads at the Centennial Park site shows their condition before the ice jam event (July 2002) and after (May 2007).

Figure 6. Root wads at Centennial Park. Top photo taken July 2002, bottom photo taken May 2007.

Root wads at Soldotna Park were installed in the spring of 2006. These root wads also showed signs of damage, though not as severe as the Centennial Park site. Again, root wads suffered damage to the roots or tines forming the wad, and the boles appeared to be undamaged. Header logs were used at this site. See Figure 7.

A few smaller root wad installations located within the reach affected by the ice jam event were also inspected. A small root wad revetment is located at the Soldotna B&B Lodge bank upstream of the Sterling Highway Bridge, and is approximately three to

Figure 7. Root wads with broken root stems at Soldotna Park.

four years old. Though some root tines were broken, most of the installation appeared to be in excellent condition. A tree on the bank above the root wads shows the effects of bark being stripped off the trunk by the ice floes. See Figure 8.

Figure 8. Root wad installation at Soldotna B&B Lodge.

Upper Bank

At many root wad installations, the upper bank and slope above the bank are protected and stabilized with layers of willow separated by fabric-encapsulated soil lifts. Upper banks were inspected at several sites to determine if damage occurred during the ice-jam event.

At the Centennial Park root wad installations, the upper bank above the root wads appeared to be well-protected by the willow trees growing there. The willows, planted as part of the brush-layering structure built on top of the root wads, are up to 1.5” diameter breast height (dbh), and up to 12 feet in height. During the May 2007 field visit, many of the willow trees were severely bent over in a downriver direction. This appeared to be the result of the ice-jam event; ice floes either knocked the willows over as they moved downstream, or flattened them as the water levels receded and the floes were left on the bank. During the late June visit, the vast majority of the willows appeared to be healthy. Stalks had straightened out, and were in the process of leafing out. See Figure 9.

Figure 9. Upper bank brushlayering at Centennial Park. Left photo taken May 2007, right photo taken June 2007.

At Centennial Park, the bank above the root wad installation is steep along much of the length. In the steep section, we observed new bank scars in the form of scrapes in several locations, most likely the result of impacts from large ice floes. The scrapes were located seven to nine feet in elevation above the level of the root wads.

At the new rootwad section of the Soldotna Park installation, the bank above the root wads is much lower than and not as steep as the Centennial Park site. The upper soil wraps appeared to be in good condition. The fabric used to construct the soil lifts was generally intact and in place. The short willow cuttings installed with the rootwads were in good condition, and appeared to be vigorously leafing during the June 2007 visit. Older and taller willow trees behind the new section are sparse, and had been flattened in a downriver direction. In June, these trees were leafing poorly or not at all.

The upstream section of the Soldotna Park installation was constructed in 1997, using cribwalls to protect the toe of the bank. On this bank, the trees are mature, 15 to 20 feet in height, and a 2 to 3 inch dbh. Following the ice jam, many of these trees were flattened in a downstream direction, and had much of their bark scraped off by ice floes. In June 2007, they were in poor condition, still flattened, and were not leafing. See Figure 10.

Figure 10. Bark stripped from trees at the Soldotna Park cribwall site.

Other Installations

Several smaller bioengineered installations were inspected during the 2007 field visits. A small coir log/brush layer installation is located on the bank adjacent to a commercial guiding operation, at approximately Mile 16 on the Kenai River. This structure is approximately 10 years old. Some damage to the coir logs was noted. Coir logs were displaced and pulled out away from the bank. The culprit for the damage was likely ice floes moving downstream. The installation is still functional; however, it is scheduled for replacement soon using more current techniques. The original near-vertical installation may have contributed to the damage that occurred, and such an installation is now generally discouraged. See Figure 11.

Figure 11. Ice damage to coir log installation.

The Soldotna Lodge root wad installation described earlier also includes a spruce tree revetment section, located downstream from the root wad section. The spruce trees cabled to the bank appeared to be in excellent condition, and were not damaged by the ice jam event. See Figure 12.

Figure 12. Spruce tree revetment at Soldotna B&B Lodge.

Another site of interest was the Kenai River replacement bridge project on the Sterling Highway. Class 2 and Class 3 riprap was placed at the bridge abutments prior to the January 2007 ice jam event. We inspected the riprap during the May 2007 field trip to assess how well the rock performed during the flood.

Though pre-flood photographs were not available, the post-flood inspection showed the riprap installation to be in excellent condition. There was no indication that any of the rock was displaced by either the water or the ice floe movement. See Figure 13.

Figure 13. Riprap beneath the new Sterling Highway Bridge.

CHAPTER 3 - INTERPRETATION, APPRAISAL, AND APPLICATIONS

Bank revetment structures, both traditional and bioengineered, are subjected to a variety of forces which can act to damage or destroy the structure. Some information is available to provide engineering design guidance for the effects of river ice on riprap bank protection (Vaughan et al., 2002). However, a cursory literature review of ice forces on bioengineered structures such as root wads and fabric-encapsulated soil lifts revealed a paucity of published information on the subject.

Specific discussion of the effects of flowing ice was found only in the 2003 report (Karle et al., 2003). Damage at existing structures was attributed to undermining of toe protection, buoyancy effects, failure of fabrics, and flowing ice. Though damage from moving ice to the outer fabric used in fabric encapsulated soil lifts was noted, the root wads, particularly on the Kenai River, were not considered to be threatened by river ice.

Ice and ice jams are factors to consider when assessing bank protection methods, not just for Alaska but for a number of states in the northern tier of the U.S. Ice jams occur in 30 states (USCOE, 1994). Within the U.S., ice-jam related damage to river training structures is estimated to cost millions of dollars annually. Ice jams create scouring and river bed and bank erosion that may lead to bridge or river bank failure, and can damage stream channels and improvements so that overall vulnerability to flooding is increased (USCOE, 1994). Ice-related damage to riprap includes undermining and moving rock out of place. When placed in rivers where ice floes and ice jams present a hazard to their structural integrity, structures such as bridge piers and bank protection should be designed to withstand the forces generated as a result of ice floes moving against them.

Ice Forces

As part of this project, one objective was to determine whether the ice forces imparted by ice floes onto the root wad installations could be quantified. The determination of ice forces on a structure is an extremely complex task. The forces generated during floe impact against a structure depend on the mass and the initial velocity of the ice floe, and the angle of impact. However, ice floes may fail when impacting a structure, limiting the forces from being transmitted to the structure. The failure modes of an ice sheet are crushing, splitting, bending, buckling, or a combination of these. As the strength and brittleness of ice increase with decreasing temperature, ice forces also depend on the temperature of the ice (Sodhi and Haehnel, 2003). As such, the magnitude of the force from the impacting ice floes during the Kenai ice jam event is very difficult to estimate.

Field evidence indicates that the root wads and other bank protection structures may have been substantially underwater during much of the ice jam event. Scars found gouged into the upper steep bank at Centennial Park were situated 7 to 9 feet above the level of the root wads. The elevation of these scars coincide with bark scraped from trees along the bank, indicating that much of the movement of large ice floes occurred at a water surface elevation considerably higher than that of the root wads.

Though the root wads were substantially submerged at the peak of the ice jam flood, they did suffer some damage by ice floes, whether by crushing as water levels dropped, or by direct impact as the floes moved downstream with the current. The roots that were damaged were relatively small in diameter when compared to their respective boles. For a given force exerted by an impacting ice floe, the small contact area of those roots increases the effective pressure, increasing their vulnerability to damage by ice floe impact.

In addition to direct impacts from ice floes, ice jams may also damage bank revetment through bed and bank scour and erosion. Jams often form temporary dams that act to increase water velocities beneath the dams and ice cover. Investigators in Alaska have proposed methods to modify the stability factor in HEC-11 calculations to account for the ice-jam based tractive shear stress (Vaughn et al., 2002).

We found no evidence during the field investigations of damage to any of the sites that could be specifically attributed to increased water velocities. Such evidence would be in the form of unexpected bed erosion or toe scour at the base of a rootwad structure. It is unlikely that increased water velocities alone were responsible for damage to structures such as broken root tines or staircases which were bent downstream or torn off completely.

Some local observers reported that bank ice may have covered some of the root wads prior to and during the event. This could have significantly reduced the ice and water forces on the root wads and other lower level bioengineered structures.

Some local observers reported that bank ice may have covered some of the root wads prior to and during the event. In fact, root wads and other bioengineered structures encased in shelf ice may offer significantly greater resistance to impact forces than unfrozen structures. However, without traditional anchors such as header and footer logs, even ice-encased root wads may be subject to movement from vertical and horizontal forces.

The age of the root wad may also be a factor when assessing their potential for damage. Wood rots and weakens over time with exposure to the elements. Though damage was noted at sections of installations with newer root wads, the older root wads at Centennial Park, 10 years or more in age, suffered the most damage of all the installations observed for this project.

The tines or roots on a root wad provide the key elements for the root wad's purpose as a bank revetment. They act to: 1) reduce flow velocities at the toe and over a range of flow elevations, 2) trap organic material and provide colonization substrates for invertebrates and refuge habitats for fish, and 3) prevent people from walking onto the bank at the project site (FISRWG, 1998, ADFG, 2005). During root wad installation projects, the diameter and condition of the root fan are often specified in construction contracts to insure that the root wads will function as desired.

Though the root wads inspected showed significant tine damage, personnel familiar with root wad design and installation observed that the root wads still had sufficient shape and material to function properly (William Frost, ADOT&PF, personal communication; Dean Hughes, ADNR, personal communication).

General Recommendations

Ice floes and ice jams are ubiquitous on Alaskan rivers and streams. Results from this study and from previous studies on bioengineered structures in Alaska indicate that root wads effectively act to protect the bank from ice jams and ice floes. However, some sacrificial damage may be expected to occur if the root wads are subjected to direct impacts from large ice floes. It is unknown how much of a root wad mass can be damaged without impairing the function of the root wad.

Healthy and mature willow brush layers appear to work well in protecting the upper bank from ice damage on steep banks, and are resilient in recovering from ice jam damage. However, willow brushlayering may not be as effective for the first several years after construction, as the root mass has not yet developed sufficiently to provide the full bank stabilization capability. Similar concern should be noted for reduced protection from ice floes and ice jams in the first few years of a brushlayered stream bank, until root mass and trunk development are well underway.

In the 2003 report, field evidence at one site indicated some damage to coir fabric used in fabric-encapsulated soil lifts from ice floes moving downstream. Though we found no examples of such damage for this project, the potential for such damage on streams that experience ice floes and ice jams should be of concern to project planners. The installation of root wads in front of such fabric-encapsulated soil lifts could be one potential solution for providing protection against annual ice floes.

Large ice jams, such as the January 2007 event, are relatively rare along the Kenai River. In response to speculation that climate change may be responsible for winter ice jam events on the Kenai River, the USGS noted that there are insufficient data to support such a theory (David Meyer, USGS, personal communication). However, some scientists note that ice regimes of rivers are highly sensitive to climatic factors, and potential future climatic changes could alter river ice processes (Beltaos and Burrell, 2003). Those who design structures for the river environment must have an understanding of possible long-term changes to the river ice regime.

Though ice floes are noted each spring during the breakup season, it is unlikely that the bank protection structures inspected for this project had been subjected to a similar ice loading condition. Because of a lack of field data, we do not know how bioengineered bank protection structures would handle repeated ice jam forces.

Engineers have developed guidelines to minimize the effects of ice jam forces on bridges, which often act to impede the passage of river ice and promote formation of ice jams. Beltaos et al. (2006) note that such guidelines can also be applied to similar situations where constrictions occur. We have adapted several of these in a list of preliminary recommendations for the design and implementation of bioengineered bank stabilization structures. As more information becomes available, quantitative engineering guidelines should be developed.

- Identification of the potential for annual ice jam formation in the river reach where bank protection methods are proposed is essential prior to design and installation.

- Avoid root wad installations that protrude into the flow.

- Root wad installations that may experience ice forces should be firmly anchored to protect against both lateral impact forces and vertical buoyant forces.

- Some bridges with constricting abutments or multiple piers may act to create ice jams on a regular basis. Additionally, some rivers such as the lower Yukon and Kuskokwim Rivers experience periodic (annual or bi-annual) ice jams. In accordance with current ADOT&PF policy, bioengineered structures should not be used to protect critical infrastructure along these reaches.

CHAPTER 4 - CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

Ice floes and ice jams are a common occurrence on many Alaska rivers and streams. However, ice forces that are exerted on root wad structures during an ice jam event are difficult to quantify, and little information concerning the performance of bioengineered bank structures is available in the literature.

Results from field observations from this study and previous studies on bioengineered structures in Alaska indicate that some sacrificial damage may be expected to occur if root wad installations are subjected to direct impacts from large ice floes. It is unknown how much of a root wad mass can be damaged without impairing the function of the root wad.

Healthy and mature willow brush layers appear to work well in protecting the upper bank from ice damage on steep banks, and are resilient in recovering from ice jam damage. However, willow brushlayering may not be as effective for the first several years after construction, as the root mass has not yet developed sufficiently to provide the full bank stabilization capability. Similar concern should be noted for reduced protection from ice floes and ice jams in the first few years of a brushlayered stream bank, until root mass and trunk development are well underway.

Suggested Research

Additional research is needed to continue the evaluation of ice forces on bioengineered erosion control structures. Specific research topics are outlined below.

- Acquisition of data from other areas in the United States and Canada where bioengineered structures are subjected to ice jams and ice floes.

- Assessment and comparison of wood rot rates for various tree species (spruce, cottonwood, birch, etc.) both for ice force situations and for overall life expectancy rates for root wad structures.

- Quantification of ice jam forces on bioengineered bank structures.

REFERENCES

Alaska Department of Fish and Game (ADFG). 2005. Streambank revegetation and protection: a guide for Alaska. Revised 2005. April 2005, Alaska Department of Fish and Game, Division of Sport Fish.

Anchorage Daily News (ADN). 2007. Fishing access and habitat restoration are wrecked; flood destroys years' worth of expensive projects. Article published: February 8, 2007.

Beltaos, S., L. Miller, B.C. Burell, D. Sullivan. 2006. Formation of breakup ice jams at bridges. Journal of Hydraulic Engineering, Vol. 132, No. 11, pp 1229-1236.

Beltaos, S., and B.C. Burrell. 2003. Climatic change and river ice breakup. Canadian Journal of Civil Engineering, Vol. 30, No. 1, pp 145-155.

Department of Homeland Security (DHS). 2007. State of Alaska Division of Homeland Security and Emergency Management. Situation report 07-30. Last accessed August 10, 2007. < http://fc.ak-prepared.com/dailysitrep/I00CF3608>.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream corridor restoration: principles, processes, and practices.

Karle, K.F. N. Moore, and W.W. Emmett. 2003. Evaluation of bioengineered stream bank stabilization in Alaska. FHWA-AK-RD-0303. Prepared for Alaska Department of Transportation and Public Facilities, Statewide Research Office, Juneau, AK.

Kenai Borough. 2007. Kenai River Center January 2007 flood event. http://www.borough.us/KenaiRiverCenter/CurrentEvents/Flood2007/January2007FloodA.htm. Viewed September 30, 2007.

Peninsula Clarion. 2007. Ice jam moves downriver. Article published: January 31, 2007.

Sodhi, D.S., and R.B. Haehnel. 2003. Crushing ice forces on structures. Journal of Cold Regions Engineering, Vol. 17, No. 4, pp. 153-170.

U.S. Army Corps of Engineers (USCOE). 1994. Engineering and design: ice jam flooding: causes and possible solutions. Engineer Pamphlet 1110-2-11. Washington, D.C.

Vaughan, N, J. Albert, and R.F. Carlson. 2002. Impacts of ice forces on stream bank protection. FHWA-AK-RD-0203. Prepared for Alaska Department of Transportation and Public Facilities, Statewide Research Office, Juneau, AK.

APPENDIX A-STUDY SITES

Figure 14. Map of project inspection sites along the Kenai River near Soldotna, Alaska.

A-Centennial Park
B-Soldotna Park
C-Kenai River Bridge #0671
D- Private Coir Log Installation
E-Soldotna B&B Lodge

A-Centennial Park. The Centennial Park site was constructed in 1997, and is approximately 500 feet in length. An addition was added in 2002. The project was constructed using root wads, coir logs, brush layering, live siltation, and live willow staking. Design documents show the root wad trunks to be 8 feet long, 12 inches in diameter, and a root fan diameter of 5 to 12 feet. Root wads were spaced every 5 feet, and the wad centers were to be installed at an elevation of ordinary high water. Header or footer logs were not noted on the design drawings or during project inspections.

B-Soldotna Park. A 650 foot section of streambank at Soldotna Creek Park was stabilized in 1994 using several bioengineering methods. A live cribwall was constructed up to 3 feet in height, and live siltation techniques were used to provide over-hanging cover. In wet areas, native sod rolls and live fascines were used to stabilize the bank line and reestablish vegetation. Large rocks, placed randomly in the shallow water in front of the live cribwalls, and small rootwads, anchored further out, were used to create additional fish cover. In the spring of 2006, a long section of root wads was installed downstream of the cribwall section. Fabric encapsulated soil lifts with willow brushlayering were used to protect the upper bank.

C-Sterling Highway Bridge #0671. A new 5-lane bridge was constructed at this site and finished during the summer of 2007. Abutments were protected with a riprap blanket, consisting mostly of Class II and some Class III rock.

D-Private Coir Log Installation. This private business/residence is approximately 10 years old, and consists of coir logs and fabric encapsulated soil lifts with an upper willow brushlayer treatment. An elevated light-penetrating walkway protects the structure from foot traffic.

E-Soldotna B&B Lodge. A small root wad revetment is located at the Soldotna B&B Lodge bank upstream of the Sterling Highway Bridge, and is approximately three to four years old. This project also includes a spruce tree revetment section, located downstream from the root wad section. A row of spruce trees is cabled to the bank. The root wads were installed approximately 3 to 4 years ago, and the spruce tree revetment was added in the spring of 2006.