H & H Design MFR

CENWS – EN – HH – HE

May 2011
Walker

SUBJECT: Skagit River PL 84-99

1. INTRODUCTION

NWS is engaged in repair work for multiple levees on the Skagit River in Skagit County. Levees scheduled for repair in summer 2011 are listed in Table 1. All sites were damaged during the November 2006 storm that produced a peak discharge of 145,000 cfs and had a return interval of between 10 and 25 years. Table 2 lists levee sites that will have habitat mitigation work completed in summer 2011 to offset environmental impacts from repair work completed in 2007.

Table 1. Skagit River Levee Repair Sites

Site	Length of repair	River Mile
1-3	75	13.1
1-13	50	13.8
1-14	30	13.44
3-6	150	South Fork Fir Island 2.95
3-8	225	South Fork Fir Island 3.4
3-11	200	12.64
12-4	250	16.8
12-4B	970	16.95
12-6	160	16.3
12-9	1850	16.6
12-11	600	16.15
12-12	50	15.75
12-13	350	15.0
12-14	250	20.51
12-15	180	19.08
12-16	670	17.19
12-17	450	18.16
17-7	800	17.19
17-9	700	16.92
17-10	200	16.82
17-12	925	16.71
17-15	125	16.49
17-16	250	13.1
22-3	110	South Fork Fir Island 5.8
22-7	350	North Fork Fir Island 9.1
22-10	300	South Fork Fir Island 3.81
22-11	800	SF 4.42
22-12	240	NF 5.7
Subtotal	11,310 feet	

Table 2. Skagit River Levee Mitigation Sites

Site	Length of repair	River Mile
1-7 (2007)	100	10.79
3-1 (2007)	382	South Fork Fir Island 6.93
3-5 (2007)	460	South Fork Fir Island 3.25
3-6 (2007)	375	South Fork Fir Island 2.95
12-3 (2007)	500	18.57
12-6 (2007)	651	16.3
12-14 (2007)	150	20.51
17-2 (2007)	100	16.78
17-6 (2007)	400	14.6
22-3 (2007)	273	South Fork Fir Island 5.8
22-7 (2007)	150	North Fork Fir Island 9.1
Subtotals	3,541 feet	

Some of the above sites are proposed to include LWD structures to provide environmental benefit and habitat to mitigate the direct impacts of construction. These sites can be found below in Tables 3 and 4 for repair and mitigation sites respectively.

Table 3. Skagit River LWD and Groin Levee Repairs

					HEC RAS info		
Site	Length of repair	River Mile	Length of LWD	Qty LWD	XS	River	Reach
1-3	75	13.1	75	8	13.1	Skagit	BakertoConcrete
3-6	150	SF 2.95	150	15	295	SOUTHrev PFP3	reach 3
3-8	225	SF 3.40	225	23	340	SOUTHrev PFP3	reach 3
12-9	1850	16.6	1575	158	16.71-16.49	Skagit	BakertoConcrete
17-16	250	13.1	GROIN	GROIN	13.1	Skagit	BakertoConcrete
22-7	350	NF 9.1	350	35	910.3	NORTHrev PFP3	Reach 2
Subtotals	2900		2375	239			

Table 4. Skagit River LWD Mitigation Sites

					HEC RAS info		
Site	Length of repair	River Mile	Length of LWD	Qty LWD	XS	River	Reach
3-5 (2007)	460	SF 3.25	460	46	325	SOUTHrev PFP3	reach 3
3-6 (2007)	375	SF 2.95	375	38	295	SOUTHrev PFP3	reach 3
17-6 (2007)	400	14.6	400	40	14.6	Skagit	BakertoConcrete
Subtotals	1385		1385	124			
TOTALS	4285		3760	363			

The Skagit River levees protect tens of thousands of people and large amounts of very high value infrastructure and commercial development. While it would be beneficial to have all Skagit River levees provide a 100-year flood protection, all the levees in this repair were designed at the

25-year flood protection level. Ownership and maintenance of the levee systems is divided between numerous Diking Districts. Sites listed in Tables 1 and 2 are identified by Diking Districts, then a corresponding site number. Emergency repair for the damaged levees will return each levee to the 25-year protection level, and does not include upgrading levees to obtain FEMA certification.

Skagit River Diking Districts requested NWS to include vegetation plantings at all sites and LWD at some of the repair sites. This request has been strongly supported by NWS ERS. The LWD and vegetation would serve as fish habitat, and will ensure approval of environmental documentation for the repairs.

NWS HE has concerns about including LWD in the levee prism, due to possible levee stability issues, and has designed LWD anchor systems that are removed from the levee prism. Other potential concerns with LWD placement include LWD anchor stability, additional scour created by flow turbulence near LWD and anchors and increased flood elevation problems. The Corps has design standards for levees and revetments, but not for LWD structures. A search of other agency design guidance found some for LWD structures, but very little for combined riprap/LWD structures. The U.S. Department of Agriculture, Natural Resources Conservation Service guidance (2007) cites limited long-term performance information and states that LWD structures incorporated into revetment are not suited for situations where failure would endanger human life or critical infrastructure. Washington's "Integrated Streambank Protection Guidelines" (2002) suggests log jams be placed off the rock face to avoid jeopardizing rock placement and bank protection.

HE's LWD design work has been closely coordinated with Civil/Soils to insure the best possible design. The criteria HE adopted for LWD and the designs for the levee repairs are described below.

2. DESIGN CRITERIA

The Skagit River has been confined by levees for a majority of the 20th century, and designs for levee cross sections in the lower floodplain have been utilized for other flood repairs. NWS Civil/Soil section supplied designs for levee repairs to be constructed in 2011. The H&H engineering criteria for the levee repairs included configuration and anchoring of the LWD, design of a small groin / rock ramp and flood elevation impacts from the above structures. The overriding principle of this design process was to provide a safe levee that will protect the people and property in the Skagit River valley.

Bank Protection

Bank protection criteria are described in EM 1110-2-1601, Hydraulic Design of Flood Control Channels (1994). Scour protection at the toe was not investigated since repairs were authorized under the PL 84-99 criteria, and repair / replace in kind without modifications or upgrades to the levee. Riprap size has been specified by civil/soils section based on prior repairs on the Skagit

River, and will utilize matching designs to repair in kind. At sites where LWD is included in the designs, scour analysis was completed since these are now changed conditions.

LWD

Design considerations for incorporating LWD with rock revetments include direct and indirect factors. Direct factors include the environmental benefits, the overall configuration of the LWD structure, the anchoring system, and the potential interaction of the LWD with the revetment. Indirect factors include upstream water surface increases and possible geomorphic changes to the river.

The environmental benefits of LWD in the Skagit River are to provide cover and slow water habitat for fish, especially salmonid species. There were no specific hydraulic requirements, such as depth under the LWD or water velocities, provided for design. A diverse or non-uniform habitat, such as placing LWD at different elevations along the levee, was suggested by some biologists. Anchoring LWD along the edge of water during summer low flows provides cover and slow water habitat.

The configuration of LWD structures could range from a single piece to multi-layer log jams. Large, complex LWD structures are not suitable in the confined channel of the lower Skagit River. LWD has been incorporated at a few levees on the Green River by both King County, and by NWS levee repairs. Designs have ranged from individual logs with long chains to 3 log "rafts" that are permanently anchored at the landward side. The configuration recommended by biologists for the Skagit River was a double layer of logs anchored near the toe of the levee. This will provide cover and habitat for aquatic species during a range of flows from summer low flows to flood events. The potential range of movement generates a variety of forces and actions that must be accounted for in the design. Minimizing the range of movement, and thus forces, was an important reliability consideration in choosing the overall configuration of the LWD.

The anchoring system must hold the LWD securely and not interfere with function of the revetment. In a static condition, the anchor must resist buoyant and drag forces created by the LWD and anchor. However, if the LWD can move, it could generate dynamic forces that can be many times higher than the original static forces. Previous designs by King County have incorporated large rocks buried within the levee toe, however this is direct interaction with the revetment, and is not recommended. The anchoring system also must remain functional over the long term.

Potential water surface increases due to LWD were included in the flood elevation analysis described below. LWD would only be placed where it was not expected to cause stability problems elsewhere along the channel.

Flood Elevations

The potential impacts to 100-year flood elevations must be considered during the design. USACE is not strictly held to the FEMA no-rise requirements, but must provide an evaluation of the water surface impacts. USACE is not required to use FEMA's Flood Insurance Study models to analyze the 100-yr flood profile, if we believe our model accurately represents the river. For this study, NWS used a Skagit River General Investigation (GI) HEC RAS model that accurately represents the river. Our analysis needs to show that the repairs are not causing an increase in water surface or, if an increase occurs, that the impacts have been minimized.

3. DESIGN RESULTS

H&H has worked closely with Civil/Soils to arrive at designs that meet the above engineering and environmental criteria. The general approach was to design a safe levee repairs and add LWD where practical, with minimal risk to the levee.

Bank Protection

Bank protection criteria are described in EM 1110-2-1601, Hydraulic Design of Flood Control Channels (1994). Scour protection at the toe was not investigated at non-LWD repair sites because the authority of repairs is to repair in kind. Riprap size has been specified by civil/soils section based on prior repairs on the Skagit River, and will utilize a 3' blanket of class IV riprap. Safety factors calculated from EM 1110-2-1601 equation 3-3 ranged from 1.7 to 2.3 for a selection of cross sections at the 25 year event.

Since LWD incorporation deviates from in kind repairs, scour protection was investigated at these sites to account for uncertainties such as construction methods, local scour and flow turbulence. In addition, all LWD sites will incorporate class V riprap. Scour calculations included equations Rice for longitudinal scour and Richardson for pier scour. Table 5 contains the estimated scour potential for sites that include LWD in the repairs. Hydraulic depth of the cross section was used in all equations, and approach depth was subtracted from the scour depth to result in scour potential. Approach depth was measured from RAS cross sections as the distance to the bed at the LWD placement to the 25 year WSE. Longitudinal scour was chosen as the most conservative estimate of the scour depth, and was used for the designs.

Table 5. Scour Calculations

River Sta		13.1	13.1	16.6	14.6	NF 910.3	SF 340	SF 325	SF 295
Site		17-16 (Groin)	1-3 (LWD)	12-9	17-6	22-7	3-8	3-5	3-6
Profile		25 yr	25 yr	25 yr	25 yr	25 yr	25 yr	25 yr	25 yr
Froehlich 1989	Abutment	33.2							
Rice 1994	Longitudinal	33.6	33.6	33.7	31.6	31.8	7.8	7.5	6.6
Richardson et al 1975	Pier		7.9	8.6	8.1	7.7	4.3	4.5	4.9
Scour potential	(ft)	3.4	5.6	5.7	3.6	5.8	-7.2	-7.5	-8.4
Launchable toe vol req'd per Method D (EM 1110-2-1601)									
Minimum Design (class II)	(ft^3/ft)	19.0	31.4	31.6	20.2	32.4	-40.3	-41.8	-46.8
Less Design Surplus (Class V)	(ft^3/ft)	NR req'd	8.1	8.3	NR req'd	9.1	NR req'd	NR req'd	NR req'd

NR Req'd = No Rock Required

Required launchable toe volumes were calculated based on the minimum riprap size that provides adequate bank protection (Class II provides a minimum safety factor of 2.1 for the repair sites). However, since repairs are being constructed with Class V riprap, the additional blanket volume provided by the larger rock compensates for a portion of rock volume required per method D in EM 1110-2-1601. At site 17-6, a launchable toe volume was calculated, however the additional rock provided by the class V blanket negates the need for a launchable toe volume to be included in the designs. Site 1-3 is on the inside of a bend, and covers a total length of 75 feet. Additional excavation and transitions to provide a launchable toe for such a short repair site does not make the extra effort worthwhile, and would provide only slight benefits due to the small volume of riprap required.

Sites 12-9 and 22-7 have deep scour holes at the toe, and will be filled with an additional volume of class V riprap to provide a launchable toe. The remaining slope will be regraded to the design 2:1 H:V before the protection blanket of class V riprap is installed.

At sites 3-5, 3-6 and 3-8, the low velocities did not predict scour from occurring and therefore do not require a launchable toe. Furthermore, this was investigated for class IV riprap, which is predicted to provide a safety factor of over 100:1 due to the low velocities and flow depths. At these locations, repairs will be constructed with class IV riprap to match other repair sites under this authorization.

The habitat groin to be constructed at 17-16 was also investigated for scour potential by the Froehlich abutment scour equation. Results matched well with the Rice longitudinal scour estimates, and an average was compared to the approach depth. The full length of the repair site will use class V riprap for both bank protection and groin construction. Stability analysis using equation 3-3 in EM 1110-2-1601 estimates a safety factor of 7.7 using a velocity coefficient of 1.5, and 5.8 with a velocity coefficient of 2.0. Rock stability using momentum forces and the weight of the rock were also completed to ensure long term stability of the structure.

LWD

Environmental and engineering factors were considered in the configuration of the LWD pieces. The LWD will consist of 20 ft long logs, with an average 5' rootball and will be placed along the edge of the natural channel. Large anchor rocks will be placed as far away from the toe as possible to maintain separation of LWD and the toe of the revetment. LWD will be secured to the anchor rocks at two locations; 1. near the rootwad, and 2. near the center of the log.

To meet mitigation requirements for habitat credit, a double row of individually anchored LWD pieces will be utilized at all sites that incorporate LWD into the design. Rootwad placement will alternate between the double rows, and will be on 10 foot center-to-center spacing. This will provide a nearly 100% overlap. Logs are individually anchored to remove the potential danger of large scale movement of connected logs. LWD will be at or near the water surface during summer low flows, and will be submerged up to 30 feet below the water surface during large storm events. Details of the LWD configuration are shown on the LWD detail sheet accompanying the plans and specifications.

The LWD will be anchored by 4-6 ft diameter rocks placed riverward of the toe of the revetment. The anchor rocks will not be embedded into the riverbed due to environmental concerns. While this may initially reduce suspended sediment into the flow, this orientation will cause increased scour around the boulders initially with higher flows. There is potential that as the bed beneath and near the anchor rocks scours out, the anchors and therefore the LWD may shift slightly with moderate flows. This is not expected to damage the LWD or its effectiveness in providing habitat, but may cause the rows of LWD to detract from parallel configuration. Anchor rocks will be located depending on size, utilizing larger / heavier rocks in areas with higher velocities, and smaller rocks in areas with lower velocities.

For a 20 ft long, 1.5 ft diameter log, two 5 ton rocks provide a factor of safety of 2.1 for lifting and 1.7 for sliding (Example for site 12-9). The analysis for sliding assumed a debris capture factor of 2.0 which doubles the area of the rootwad exposed to the flow velocity. This was compared to rotating the log 90 degrees to the flow, i.e. have the maximum cross section exposed to the river currents, and the highest drag force was used for stability calculations. Log rotation is an unexpected condition given the anchoring system, but it also provides a substantial allowance for additional drag caused by future debris accumulation. Not much debris is expected to accumulate on these LWD structures as they will be submerged up to 30 feet during flood events. The analysis does not account for additional sliding resistance that may be provided by the soil surrounding the rock.

The double layer of LWD will provide habitat function, and will minimize potential boater obstructions by sheltering 50% of the rootwads from the navigable channel. Any incorporation of rootwads into the channel will create hazards to navigation, which will hopefully be minimized. While there is boat traffic on the Skagit River, a majority of this is motorized, and will likely travel near the thalweg. LWD structures will be anchored near the bank, and will be well away from the river thalweg. There is no direct human use (tubing, kayaking, etc) expected.

If flow depth allows, LWD will be placed vertically above the anchor rocks. In areas with lower flow depths, LWD may be placed horizontal to the anchor rocks to ensure submergence in the water. All attachments shall be as tight as possible in order to reduce log movement. By tightly anchoring 2 points on the log to anchor rocks, there will be limited potential for the logs to rotate upward during high river stages. The restricted movement is important for minimizing the potential of unpredictable dynamic forces being generated by the logs.

Placing the anchor rocks outside the levee toe minimizes any opportunities for the LWD to interfere with the revetment. There are no chains extending into the riprap that could move and displace material. The logs will be anchored to the riverward side of the rocks to keep them away from the riprap.

LWD sizes are not uniform across all repair / mitigation sites. At sites 17-6 and 12-9 (just below the 3 bridge corridor), channel velocities are higher than the remaining sites due to narrow cross sections. At these sites, the maximum rootwad width recommended is 5 ft instead of the 7 ft maximum rootwad size per contract specifications. At site 22-7, a 5 ft rootwad is also recommended due to increased velocities as the flow splits between the North and South forks at Fir Island. Design calculations at this site utilized a velocity coefficient of 1.5 to account for velocity around a bend.

It is theorized by construction representatives that a sufficient quantity of smaller LWD will be obtained, and can be used at location with reduced sizes. Rootwads can also be trimmed to match the site specific criteria if needed. These sites also require the largest anchor rocks (5 ton each). The remainder of sites can use the full size of LWD, and will have varying anchor rock sizes depending on site conditions and found below in Table 6.

Table 6. Site materials

Max Recommended LWD size			
Site	LWD max RB	Minimum Anchor size	Qty
12-9	5'	5 ton	2 ea
17-6	5'	5 ton	2 ea
1-3	7' (full spec)	4 ton	2 ea
22-7	5'	5 ton	2 ea
3-6	7' (full spec)	3 ton	2 ea
3-8	7' (full spec)	3 ton	2 ea

Flood Elevations

Flood elevations are expected to be essentially unchanged throughout the reach. Sites without LWD were not investigated, because the levee footprint will not be altered with any repairs completed in 2011. Water surface elevations were modeled with HEC-RAS, and geometry files were created for the existing conditions, and with the 2011 repairs. While not used for the design parameters, flows modeled included events up to the 100 year event at the Skagit River near Concrete USGS gage (#12194000).

Due to the large river cross sectional area, and the small volume occupied by LWD structures, water surface elevations are estimated to change within 0.01 ft at all sites with LWD structures. This amount of change is undetectable, and is well below the threshold of measurement error. LWD structures were modeled as permanent ineffective flow areas, and were set at elevations that are likely from analysis of low flow conditions during the summer construction window.

At site 17-16 (groin construction), a sensitivity analysis was performed to estimate the percentage of cross section area that would need to be blocked to result in a 0.1 ft change in the upstream water surface elevations. The current design blocks 3.8% of the OHW width at cross section 13.1. This results in a flow area obstruction of 2.1% at the 25 yr flow event, and an upstream cross section water surface elevation gain of 0.01 ft.

To analyze uncertainties due to 3 dimensional flow around bends, groin designs that blocked cross section widths of both 10% and 15% were investigated. At both of these widths, the groin obstructed the thalweg of the channel, and resulted in high percentages of flow area blockage. At 10% width, the flow area blocked was 12.2%, which resulted in a water surface elevation change of 0.06 ft at the upstream cross section during the 25 yr flow event. Groin blockage of 15% resulted in 19% of flow area being blocked at the 25 yr flow event, with an upstream cross section change in water surface elevation of 0.12 ft.

While this location will be impacted by 3-dimensional flow around bends, it does not appear overly sensitive to flow obstructions. Actual water surface elevations will vary from the 1-dimensional model assumptions, but are not expected to produce backwatering in upstream cross sections due to small values of width and area blocked.

Steady Flow, RAS model, 2011 levee repairs and habitat plan

River	Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Hydr Dep	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
					(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
REPAIR SITE 12-9 (US Boundary)														
Skagit River	BakertoConcrete	16.78	2yr	ExistCond	70000	3.4	28.19	20.82	28.61	0.000198	5.22	13413.72	644.41	0.2
Skagit River	BakertoConcrete	16.78	2yr	2011Repairs	70000	3.4	28.21	20.83	28.63	0.000198	5.22	13422.56	644.47	0.2
Skagit River	BakertoConcrete	16.78	25yr	ExistCond	165000	3.4	40.09	28.22	41.01	0.000241	7.72	21958.46	778	0.24
Skagit River	BakertoConcrete	16.78	25yr	2011Repairs	165000	3.4	40.1	28.23	41.02	0.00024	7.72	21966.76	778	0.24
Skagit River	BakertoConcrete	16.78	100yr	ExistCond	210000	3.4	44.37	32.51	45.5	0.000254	8.61	25290.28	778	0.25
Skagit River	BakertoConcrete	16.78	100yr	2011Repairs	210000	3.4	44.38	32.52	45.51	0.000253	8.61	25297.83	778	0.25
REPAIR SITE 12-9														
Skagit River	BakertoConcrete	16.708*	2yr	ExistCond	70000	3.48	28.06	20.49	28.47	0.000207	5.12	13681.25	667.85	0.2
Skagit River	BakertoConcrete	16.708*	2yr	2011Repairs	70000	3.48	28.07	20.41	28.48	0.000209	5.13	13633.78	667.9	0.2
Skagit River	BakertoConcrete	16.708*	25yr	ExistCond	165000	3.48	39.95	28.34	40.83	0.000247	7.53	22418.82	791.2	0.23
Skagit River	BakertoConcrete	16.708*	25yr	2011Repairs	165000	3.48	39.96	28.27	40.84	0.000249	7.55	22369.75	791.2	0.24
Skagit River	BakertoConcrete	16.708*	100yr	ExistCond	210000	3.48	44.23	32.62	45.31	0.00026	8.4	25805.8	791.2	0.25
Skagit River	BakertoConcrete	16.708*	100yr	2011Repairs	210000	3.48	44.24	32.55	45.32	0.000262	8.42	25755.84	791.2	0.25
REPAIR SITE 12-9														
Skagit River	BakertoConcrete	16.6	2yr	ExistCond	70000	3.6	27.87	20.33	28.25	0.000219	4.92	14237.05	700.21	0.19
Skagit River	BakertoConcrete	16.6	2yr	2011Repairs	70000	3.6	27.88	20.21	28.26	0.000223	4.95	14151.83	700.26	0.19
Skagit River	BakertoConcrete	16.6	25yr	ExistCond	165000	3.6	39.74	28.69	40.55	0.00026	7.23	23264.45	811	0.23
Skagit River	BakertoConcrete	16.6	25yr	2011Repairs	165000	3.6	39.75	28.58	40.56	0.000264	7.25	23177.17	811	0.23
Skagit River	BakertoConcrete	16.6	100yr	ExistCond	210000	3.6	44.02	32.96	45.02	0.000274	8.06	26733.88	811	0.24
Skagit River	BakertoConcrete	16.6	100yr	2011Repairs	210000	3.6	44.02	32.86	45.03	0.000277	8.09	26645.69	811	0.24
REPAIR SITE 12-9 (DS Boundary)														
Skagit River	BakertoConcrete	16.4867*	2yr	ExistCond	70000	3.87	27.77	20.42	28.12	0.000205	4.78	14647.35	717.42	0.19
Skagit River	BakertoConcrete	16.4867*	2yr	2011Repairs	70000	3.87	27.77	20.31	28.13	0.000209	4.8	14572.43	717.44	0.19
Skagit River	BakertoConcrete	16.4867*	25yr	ExistCond	165000	3.87	39.63	29	40.4	0.000245	7.06	23844.96	822.34	0.22
Skagit River	BakertoConcrete	16.4867*	25yr	2011Repairs	165000	3.87	39.63	28.9	40.4	0.000247	7.08	23768.32	822.34	0.22
Skagit River	BakertoConcrete	16.4867*	100yr	ExistCond	210000	3.87	43.9	33.27	44.86	0.000258	7.88	27360.52	822.34	0.23
Skagit River	BakertoConcrete	16.4867*	100yr	2011Repairs	210000	3.87	43.91	33.18	44.86	0.000261	7.9	27283.08	822.34	0.23
REPAIR SITE 17-6 (US Boundary)														
Skagit River	BakertoConcrete	14.7951*	2yr	ExistCond	70000	-5.8	25.74	20.16	26.11	0.000215	4.87	14386.71	713.53	0.19
Skagit River	BakertoConcrete	14.7951*	2yr	2011Repairs	70000	-5.8	25.75	20.16	26.12	0.000214	4.86	14393.27	713.81	0.19
Skagit River	BakertoConcrete	14.7951*	25yr	ExistCond	165000	-5.8	36.98	27.24	37.77	0.000265	7.22	23709.25	870.5	0.23
Skagit River	BakertoConcrete	14.7951*	25yr	2011Repairs	165000	-5.8	36.99	27.24	37.78	0.000265	7.22	23715.36	870.5	0.23
Skagit River	BakertoConcrete	14.7951*	100yr	ExistCond	210000	-5.8	41.04	31.3	42.02	0.00028	8.06	27242.83	870.5	0.24
Skagit River	BakertoConcrete	14.7951*	100yr	2011Repairs	210000	-5.8	41.04	31.3	42.03	0.00028	8.06	27248.15	870.5	0.24
REPAIR SITE 17-6														
Skagit River	BakertoConcrete	14.6	2yr	ExistCond	70000	-6	25.65	19.02	25.99	0.000181	4.62	15266.73	802.76	0.18
Skagit River	BakertoConcrete	14.6	2yr	2011Repairs	70000	-6	25.66	18.9	26	0.000185	4.65	15182.21	803.16	0.18
Skagit River	BakertoConcrete	14.6	25yr	ExistCond	165000	-6	36.89	27.51	37.61	0.000232	6.92	25175.88	915	0.21
Skagit River	BakertoConcrete	14.6	25yr	2011Repairs	165000	-6	36.89	27.42	37.62	0.000235	6.95	25089.25	915	0.21
Skagit River	BakertoConcrete	14.6	100yr	ExistCond	210000	-6	40.95	31.58	41.84	0.000247	7.73	28892.94	915	0.22
Skagit River	BakertoConcrete	14.6	100yr	2011Repairs	210000	-6	40.95	31.48	41.85	0.00025	7.75	28805.29	915	0.23
REPAIR SITE 17-6 (DS Boundary)														
Skagit River	BakertoConcrete	14.4641*	2yr	ExistCond	70000	-6.94	25.52	19.51	25.87	0.00019	4.76	14772.45	757.22	0.18
Skagit River	BakertoConcrete	14.4641*	2yr	2011Repairs	70000	-6.94	25.53	19.51	25.88	0.00019	4.76	14779.09	757.71	0.18
Skagit River	BakertoConcrete	14.4641*	25yr	ExistCond	165000	-6.94	36.68	27.59	37.46	0.00025	7.2	24129.07	874.6	0.22
Skagit River	BakertoConcrete	14.4641*	25yr	2011Repairs	165000	-6.94	36.68	27.6	37.47	0.00025	7.19	24135.65	874.6	0.22
Skagit River	BakertoConcrete	14.4641*	100yr	ExistCond	210000	-6.94	40.71	31.62	41.68	0.000268	8.05	27655.95	874.6	0.23
Skagit River	BakertoConcrete	14.4641*	100yr	2011Repairs	210000	-6.94	40.72	31.63	41.69	0.000268	8.05	27661.96	874.6	0.23
REPAIR SITE 1-3 & 17-16 (US BOUNDARY)														
Skagit River	BakertoConcrete	13.2133*	2yr	ExistCond	70000	-17.78	23.36	16.36	23.63	0.000193	4.2	17182.94	1050.17	0.17

Plan Legend	
ExistCond	Baseline conditions
2011 Repairs	LWD and Groin as designed
10% Groin	Groin design with 10% of OHW width blocked
15% Groin	Groin design with 15% of OHW width blocked

RESULT

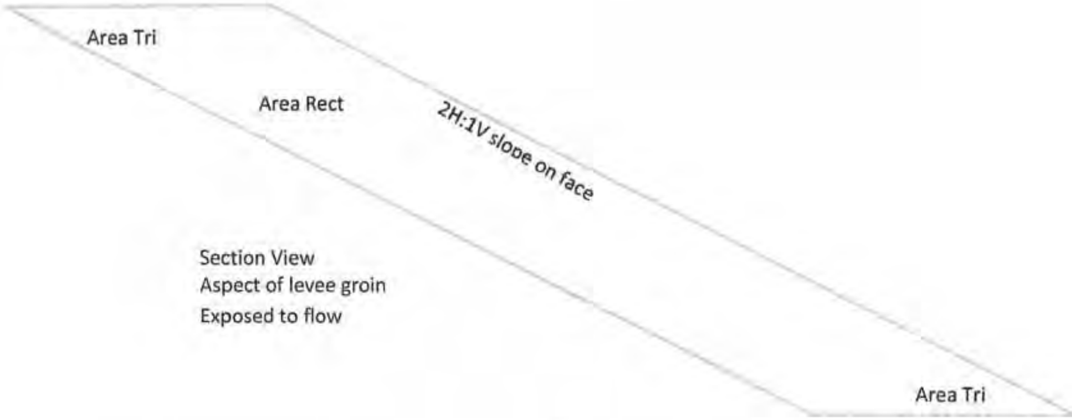
Groin needs to block about 15% of total OHW width to create a 0.1 foot rise in water surface elevations at design discharge (25 yr, 165kcfs) at the upstream cross section. Design blockage of 3.8% and LWD on opposite bank result in 0.01 feet of water surface rise in the upstream cross section based on 1D model water surface elevations. Actual results will likely vary due to 3D flow around bends. Groin blockage of 10% of OHW width resulted in 0.06 foot gain in upstream WSE.

Skagit River	BakertoConcrete	13.2133*	2yr	2011Repairs	70000	-17.78	23.38	16.37	23.65	0.000192	4.2	17195.94	1050.23	0.17
Skagit River	BakertoConcrete	13.2133*	2yr	10% groin	70000	-17.78	23.46	16.45	23.73	0.000189	4.18	17284.38	1050.65	0.17
Skagit River	BakertoConcrete	13.2133*	2yr	15% Groin	70000	-17.78	23.57	16.56	23.84	0.000186	4.15	17402.71	1051.2	0.17
Skagit River	BakertoConcrete	13.2133*	25yr	ExistCond	165000	-17.78	33.57	25.25	34.14	0.00024	6.18	28226.54	1118	0.2
Skagit River	BakertoConcrete	13.2133*	25yr	2011Repairs	165000	-17.78	33.58	25.26	34.15	0.00024	6.18	28238.79	1118	0.2
Skagit River	BakertoConcrete	13.2133*	25yr	10% groin	165000	-17.78	33.63	25.31	34.2	0.000238	6.17	28295.17	1118	0.2
Skagit River	BakertoConcrete	13.2133*	25yr	15% Groin	165000	-17.78	33.69	25.37	34.25	0.000237	6.15	28360.31	1118	0.2
Skagit River	BakertoConcrete	13.2133*	100yr	ExistCond	210000	-17.78	37.3	28.98	38	0.000254	6.88	32397.19	1118	0.21
Skagit River	BakertoConcrete	13.2133*	100yr	2011Repairs	210000	-17.78	37.31	28.99	38.01	0.000253	6.88	32408.38	1118	0.21
Skagit River	BakertoConcrete	13.2133*	100yr	10% groin	210000	-17.78	37.34	29.02	38.04	0.000252	6.87	32448.13	1118	0.21
Skagit River	BakertoConcrete	13.2133*	100yr	15% Groin	210000	-17.78	37.4	29.08	38.09	0.000251	6.86	32506.56	1118	0.21
REPAIR SITE 1-3 & 17-16														
Skagit River	BakertoConcrete	13.1	2yr	ExistCond	70000	-20.8	23.25	15.88	23.49	0.000182	4	18279.36	1151.13	0.16
Skagit River	BakertoConcrete	13.1	2yr	2011Repairs	70000	-20.8	23.24	15.51	23.5	0.000208	4.13	17681.7	1140.04	0.17
Skagit River	BakertoConcrete	13.1	2yr	10% groin	70000	-13.7	23.17	13.84	23.54	0.00035	4.97	14786.96	1068.76	0.22
Skagit River	BakertoConcrete	13.1	2yr	15% Groin	70000	-6.6	23.11	12.68	23.61	0.00052	5.76	12830.9	1011.55	0.26
Skagit River	BakertoConcrete	13.1	25yr	ExistCond	165000	-20.8	33.46	24.93	33.96	0.000216	5.78	30343.81	1217	0.19
Skagit River	BakertoConcrete	13.1	25yr	2011Repairs	165000	-20.8	33.45	24.42	33.96	0.000239	5.89	29720.52	1217	0.2
Skagit River	BakertoConcrete	13.1	25yr	10% groin	165000	-13.7	33.36	21.88	33.99	0.000352	6.57	26629.62	1217	0.23
Skagit River	BakertoConcrete	13.1	25yr	15% Groin	165000	-6.6	33.26	20.12	34.01	0.000469	7.14	24484.99	1217	0.27
Skagit River	BakertoConcrete	13.1	100yr	ExistCond	210000	-20.8	37.2	28.67	37.8	0.000226	6.41	34891.58	1217	0.2
Skagit River	BakertoConcrete	13.1	100yr	2011Repairs	210000	-20.8	37.19	28.16	37.81	0.000248	6.52	34267.12	1217	0.2
Skagit River	BakertoConcrete	13.1	100yr	10% groin	210000	-13.7	37.09	25.61	37.83	0.000346	7.15	31168.53	1217	0.24
Skagit River	BakertoConcrete	13.1	100yr	15% Groin	210000	-6.6	36.99	23.85	37.85	0.000441	7.67	29022.38	1217	0.26
REPAIR SITE 1-3 & 17-16 (DS BOUNDARY)														
Skagit River	BakertoConcrete	13.0200*	2yr	ExistCond	70000	-12.9	23.02	20.15	23.36	0.000228	4.7	14884.68	738.81	0.18
Skagit River	BakertoConcrete	13.0200*	2yr	2011Repairs	70000	-12.9	23.02	20.15	23.36	0.000228	4.7	14885.83	738.81	0.18
Skagit River	BakertoConcrete	13.0200*	2yr	10% groin	70000	-12.9	23.02	20.15	23.36	0.000228	4.7	14885.83	738.81	0.18
Skagit River	BakertoConcrete	13.0200*	2yr	15% Groin	70000	-12.9	23.02	20.15	23.36	0.000228	4.7	14885.83	738.81	0.18
Skagit River	BakertoConcrete	13.0200*	25yr	ExistCond	165000	-12.9	32.96	26.11	33.76	0.000324	7.24	23561.53	902.5	0.23
Skagit River	BakertoConcrete	13.0200*	25yr	2011Repairs	165000	-12.9	32.97	26.11	33.76	0.000324	7.23	23562.31	902.5	0.23
Skagit River	BakertoConcrete	13.0200*	25yr	10% groin	165000	-12.9	32.97	26.11	33.76	0.000324	7.23	23562.31	902.5	0.23
Skagit River	BakertoConcrete	13.0200*	25yr	15% Groin	165000	-12.9	32.97	26.11	33.76	0.000324	7.23	23562.31	902.5	0.23
Skagit River	BakertoConcrete	13.0200*	100yr	ExistCond	210000	-12.9	36.59	29.73	37.59	0.00035	8.13	26832.24	902.5	0.25
Skagit River	BakertoConcrete	13.0200*	100yr	2011Repairs	210000	-12.9	36.59	29.73	37.59	0.00035	8.13	26833.06	902.5	0.25
Skagit River	BakertoConcrete	13.0200*	100yr	10% groin	210000	-12.9	36.59	29.73	37.59	0.00035	8.13	26833.06	902.5	0.25
Skagit River	BakertoConcrete	13.0200*	100yr	15% Groin	210000	-12.9	36.59	29.73	37.59	0.00035	8.13	26833.06	902.5	0.25
REPAIR SITE 22-7 (US BOUNDARY)														
NORTHrev PFP:	REACH # 2	925	2yr	ExistCond	38253.38	-9.6	17.06	15.86	17.34	0.000205	4.24	9155	577.26	0.17
NORTHrev PFP:	REACH # 2	925	2yr	2011Repairs	38237.21	-9.6	17.06	15.86	17.34	0.000205	4.24	9157.92	577.44	0.17
NORTHrev PFP:	REACH # 2	925	25yr	ExistCond	78951.59	-9.6	25.49	21.37	25.99	0.000236	5.77	14640.38	685	0.2
NORTHrev PFP:	REACH # 2	925	25yr	2011Repairs	78932.44	-9.6	25.49	21.38	25.99	0.000236	5.77	14642.5	685	0.2
NORTHrev PFP:	REACH # 2	925	100yr	ExistCond	97302.03	-9.6	28.44	24.33	29.03	0.000244	6.29	16664.14	685	0.2
NORTHrev PFP:	REACH # 2	925	100yr	2011Repairs	97281.68	-9.6	28.45	24.33	29.03	0.000244	6.29	16666.15	685	0.2
REPAIR SITE 22-7														
NORTHrev PFP:	REACH # 2	910.348*	2yr	ExistCond	38253.38	-9.6	16.94	15.86	17.22	0.00021	4.27	9084.91	572.84	0.17
NORTHrev PFP:	REACH # 2	910.348*	2yr	2011Repairs	38237.21	-9.6	16.93	15.7	17.22	0.000217	4.32	8990.16	572.71	0.18
NORTHrev PFP:	REACH # 2	910.348*	25yr	ExistCond	78951.59	-9.6	25.35	21.24	25.85	0.000241	5.8	14547.44	685	0.2
NORTHrev PFP:	REACH # 2	910.348*	25yr	2011Repairs	78932.44	-9.6	25.34	21.1	25.85	0.000246	5.84	14450.75	685	0.2
NORTHrev PFP:	REACH # 2	910.348*	100yr	ExistCond	97302.03	-9.6	28.3	24.19	28.89	0.000249	6.33	16567.55	685	0.2
NORTHrev PFP:	REACH # 2	910.348*	100yr	2011Repairs	97281.68	-9.6	28.29	24.04	28.89	0.000254	6.37	16470.52	685	0.21
REPAIR SITE 22-7 (DS BOUNDARY)														
NORTHrev PFP:	REACH # 2	897.674*	2yr	ExistCond	38253.38	-9.6	16.81	15.86	17.1	0.000214	4.3	9013.86	568.32	0.18
NORTHrev PFP:	REACH # 2	897.674*	2yr	2011Repairs	38237.21	-9.6	16.8	15.7	17.1	0.000222	4.35	8919.03	568.04	0.18
NORTHrev PFP:	REACH # 2	897.674*	25yr	ExistCond	78951.59	-9.6	25.2	21.1	25.71	0.000245	5.84	14452.64	685	0.2
NORTHrev PFP:	REACH # 2	897.674*	25yr	2011Repairs	78932.44	-9.6	25.19	20.96	25.71	0.000251	5.88	14356.05	685	0.2
NORTHrev PFP:	REACH # 2	897.674*	100yr	ExistCond	97302.03	-9.6	28.15	24.04	28.74	0.000253	6.36	16469.16	685	0.21

NORTHrev PFP3	REACH # 2	897.674*	100yr	2011Repairs	97281.68	-9.6	28.14	23.9	28.74	0.000259	6.4	16372.42	685	0.21
REPAIR SITE 3-8 (US BOUNDARY)														
SOUTHrev PFP3	REACH # 3	360.504*	2yr	ExistCond	31746.62	-12.27	8.34	4.99	8.36	0.000227	0.91	35034.57	7023.39	0.07
SOUTHrev PFP3	REACH # 3	360.504*	2yr	2011Repairs	31762.79	-12.27	8.35	5	8.37	0.000226	0.91	35120.34	7027.05	0.07
SOUTHrev PFP3	REACH # 3	360.504*	25yr	ExistCond	86048.42	-12.27	11.76	7.69	11.79	0.00042	1.43	61178.55	7960.06	0.09
SOUTHrev PFP3	REACH # 3	360.504*	25yr	2011Repairs	86067.56	-12.27	11.77	7.7	11.8	0.000419	1.43	61265.82	7960.29	0.09
SOUTHrev PFP3	REACH # 3	360.504*	100yr	ExistCond	112698	-12.27	12.93	8.76	12.97	0.000484	1.62	70596.08	8058.84	0.1
SOUTHrev PFP3	REACH # 3	360.504*	100yr	2011Repairs	112718.3	-12.27	12.94	8.77	12.98	0.000482	1.62	70682.57	8058.84	0.1
REPAIR SITE 3-8														
SOUTHrev PFP3	REACH # 3	340	2yr	ExistCond	31746.62	-11.6	8.21	5.09	8.22	0.000164	0.82	39182.04	7695.35	0.06
SOUTHrev PFP3	REACH # 3	340	2yr	2011Repairs	31762.79	-11.6	8.22	5.09	8.23	0.000167	0.82	39173.59	7699.19	0.06
SOUTHrev PFP3	REACH # 3	340	25yr	ExistCond	86048.42	-11.6	11.5	7.62	11.53	0.000338	1.32	66278.34	8698.96	0.08
SOUTHrev PFP3	REACH # 3	340	25yr	2011Repairs	86067.56	-11.6	11.51	7.62	11.54	0.000341	1.32	66270.05	8701.99	0.08
SOUTHrev PFP3	REACH # 3	340	100yr	ExistCond	112698	-11.6	12.63	8.6	12.67	0.000396	1.5	76227.55	8864.16	0.09
SOUTHrev PFP3	REACH # 3	340	100yr	2011Repairs	112718.3	-11.6	12.64	8.6	12.68	0.0004	1.5	76219.23	8864.41	0.09
REPAIR SITE 3-5														
SOUTHrev PFP3	REACH # 3	325.*	2yr	ExistCond	31746.62	-12.43	8.03	4.75	8.04	0.000474	0.83	38331.86	8069.22	0.07
SOUTHrev PFP3	REACH # 3	325.*	2yr	2011Repairs	31762.79	-12.43	8.04	4.75	8.05	0.000476	0.83	38319.25	8070.57	0.07
SOUTHrev PFP3	REACH # 3	325.*	25yr	ExistCond	86048.42	-12.43	11.18	7.27	11.21	0.000687	1.33	65161.89	8968.68	0.09
SOUTHrev PFP3	REACH # 3	325.*	25yr	2011Repairs	86067.56	-12.43	11.19	7.26	11.21	0.000689	1.33	65145.06	8968.9	0.09
SOUTHrev PFP3	REACH # 3	325.*	100yr	ExistCond	112698	-12.43	12.26	8.24	12.3	0.000757	1.52	74921.57	9086.96	0.09
SOUTHrev PFP3	REACH # 3	325.*	100yr	2011Repairs	112718.3	-12.43	12.27	8.24	12.3	0.00076	1.52	74904.55	9087	0.09
INTERMEDIATE XS BETWEEN 3-5 & 3-6														
SOUTHrev PFP3	REACH # 3	310.*	2yr	ExistCond	31746.62	-13.27	7.65	4.37	7.67	0.00061	0.89	35986.5	8236.27	0.07
SOUTHrev PFP3	REACH # 3	310.*	2yr	2011Repairs	31762.79	-13.27	7.66	4.37	7.67	0.000613	0.89	35975.03	8236.88	0.07
SOUTHrev PFP3	REACH # 3	310.*	25yr	ExistCond	86048.42	-13.27	10.65	6.83	10.68	0.000836	1.39	62127.45	9089.94	0.09
SOUTHrev PFP3	REACH # 3	310.*	25yr	2011Repairs	86067.56	-13.27	10.65	6.83	10.68	0.000839	1.39	62108.7	9090.18	0.09
SOUTHrev PFP3	REACH # 3	310.*	100yr	ExistCond	112698	-13.27	11.68	7.82	11.72	0.0009	1.58	71555.42	9148.97	0.1
SOUTHrev PFP3	REACH # 3	310.*	100yr	2011Repairs	112718.3	-13.27	11.69	7.82	11.73	0.000903	1.58	71535.59	9149.26	0.1
REPAIR SITE 3-6														
SOUTHrev PFP3	REACH # 3	295.*	2yr	ExistCond	31746.62	-14.1	7.13	3.82	7.14	0.000938	0.99	32006.33	8389.24	0.09
SOUTHrev PFP3	REACH # 3	295.*	2yr	2011Repairs	31762.79	-14.1	7.13	3.81	7.15	0.000942	0.99	31990.07	8389.73	0.09
SOUTHrev PFP3	REACH # 3	295.*	25yr	ExistCond	86048.42	-14.1	9.97	6.26	10.01	0.001111	1.49	57622.48	9210.25	0.11
SOUTHrev PFP3	REACH # 3	295.*	25yr	2011Repairs	86067.56	-14.1	9.98	6.25	10.01	0.001115	1.49	57596.29	9210.31	0.11
SOUTHrev PFP3	REACH # 3	295.*	100yr	ExistCond	112698	-14.1	10.96	7.24	11.01	0.001169	1.69	66742.77	9218.46	0.11
SOUTHrev PFP3	REACH # 3	295.*	100yr	2011Repairs	112718.3	-14.1	10.97	7.24	11.01	0.001173	1.69	66715.11	9218.47	0.11
REPAIR SITE 3-6 (DS BOUNDARY)														
SOUTHrev PFP3	REACH # 3	280.*	2yr	ExistCond	31746.62	-14.93	6.06	2.73	6.09	0.002827	1.35	23024.69	8428.93	0.15
SOUTHrev PFP3	REACH # 3	280.*	2yr	2011Repairs	31762.79	-14.93	6.06	2.73	6.09	0.002826	1.35	23036.96	8429.52	0.15
SOUTHrev PFP3	REACH # 3	280.*	25yr	ExistCond	86048.42	-14.93	8.97	5.31	9.02	0.001893	1.73	49515.92	9331.24	0.13
SOUTHrev PFP3	REACH # 3	280.*	25yr	2011Repairs	86067.56	-14.93	8.97	5.31	9.02	0.001893	1.73	49523.07	9331.26	0.13
SOUTHrev PFP3	REACH # 3	280.*	100yr	ExistCond	112698	-14.93	9.94	6.26	9.99	0.001863	1.92	58548.87	9348.37	0.14
SOUTHrev PFP3	REACH # 3	280.*	100yr	2011Repairs	112718.3	-14.93	9.94	6.26	9.99	0.001863	1.92	58555.45	9348.38	0.14

Area of exposed groin

angle of riprap slope	2H:1V	
	26.6	degrees
	0.46	rad
Bench width (hyp)	10	ft
blanket thickness		
(tirangle base)	4.48	ft
Triangle Height	8.94	ft

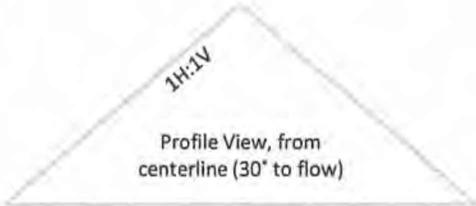


A rect

Hyp Length	38.01	ft
Rect length	29.07	ft
height	4.48	ft
Area	130.17	ft^2

A triangle

base	4.48	ft
height	8.94	ft
Area	20.02	ft^2
Sum of 2	40.04	ft^2
Area Total	170.21	ft^2



Drag force

Channel Velocity	5.88	ft/s	From HEC-RAS model at XS 13.1, 165kcfs (25 yr)
Bend Velocity	11.76	ft/s	= 2x mean velocity
Area Exposed	170.21	ft^2	
Cd	0.8	drag coefficient of a cylinder, L:D = 5:1, Cengal pg 574.	
Density of water	62.4	lb/ft3	
Gravity	32.2	lbm-ft/lbf-s2	
Fd	18246.6	lb	

Void Space rat 0.3

Section	Profile width (1:1 slopes on ramp)	Avg width (ft)	Area (ft^2)	Force (lb)	total vol (ft^3)	Rock vol (ft^3)	weight (lbs)	Submerged rock weight (lbs)	Stability Factor
Top thickness	0.0								
1/3 down	11.3	5.7	56.74	6082.20	321.50	96.45	15949.11	9930.58	1.6
2/3 down	22.7	17.0	56.74	6082.20	964.51	289.35	47847.33	29791.73	4.9
bottom	34.0	28.3	56.74	6082.20	1607.51	482.25	79745.55	49652.89	8.2

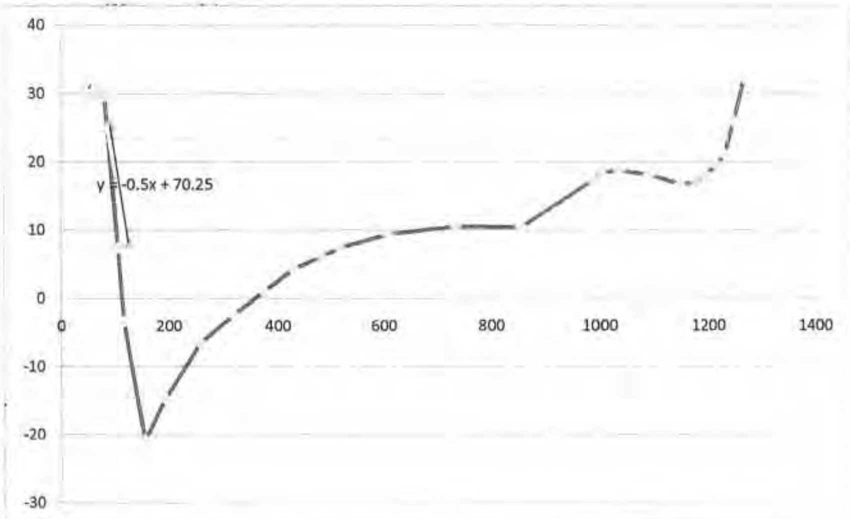
Force Balance

Mass of rock > force of water against rock at all sections of pyramid

Stability Factor >1 for all sections of pyramid

XS 13.1

Sta	Elev
50	32
57	30.1
61	30.1
69	30.2
75	30.9
80	29.7
104	7.4
116	-3.3
154	-20.8
192	-14.7
257	-6.6
317	-2.4
373	1
428	4.3



OHW	
87	23.25
1235	23.25

Current slope 1H:1V
Groin slope 2H:1V

Levee

Sta	Elev
85	25.25
119	8.25

Groin

Sta	Elev
90	25.25
124	8.25

Input into RAS as multiple block O

Width at OHW		1148
Horiz proj	10 ft	
Total widtł	44	3.83%
Sta start	84	
Sta End	129	
84	94	25.5
94	96	24.5
96	98	23.5
98	100	22.5
100	102	21.5
102	104	20.5
104	106	19.5
106	108	18.5
108	110	17.5
110	112	16.5
112	114	15.5
114	116	14.5
116	118	13.5
118	120	12.5
120	122	11.5
122	124	10.5
124	126	9.5
126	128	8.5
128	129	8

For sensitivity analysis, increase size of groin to 15% of XS width

Horiz proj	81 ft	
Total widtł	115	10.02%
Sta start	84	
Sta End	200	
84	165	25.5
165	167	24.5
167	169	23.5
169	171	22.5
171	173	21.5
173	175	20.5
175	177	19.5
177	179	18.5
179	181	17.5
181	183	16.5
183	185	15.5
185	187	14.5
187	189	13.5
189	191	12.5
191	193	11.5
193	195	10.5
195	197	9.5
197	199	8.5
199	200	8

Horiz proj	138 ft	
Total widtł	172	14.98%
Sta start	84	
Sta End	257	
84	222	25.5
222	224	24.5
224	226	23.5
226	228	22.5
228	230	21.5
230	232	20.5
232	234	19.5
234	236	18.5
236	238	17.5
238	240	16.5
240	242	15.5
242	244	14.5
244	246	13.5
246	248	12.5
248	250	11.5
250	252	10.5
252	254	9.5
254	256	8.5
256	257	8

	Reach		BakertoConcrete	BakertoConcrete					
	River Sta		13.1	16.6	14.6	NF 910.348	SF 340	SF 325	SF 295
	Site		1-3	12-9	17-6	22-7	3-8	3-5	3-6
	Profile		25 yr	25 yr	26 yr	25 yr	25 yr	25 yr	25 yr
	Q Total	(cfs)	165000	165000	165000	78932	86067	86067	86067
	Min Ch El	(ft)	-17.78	3.6	-6	-9.6	-11.6	-12.43	-14.1
	W.S. Elev	(ft)	33.58	39.75	36.89	25.34	11.51	11.19	9.98
	Vel Chnl	(ft/s)	6.18	7.55	6.95	5.77	1.43	1.33	1.49
	Froude # Chl		0.2	0.24	0.21	0.2	0.08	0.09	0.11
	Hydr Depth Chnl	(ft)	25.26	28.58	27.42	21.1	7.62	7.26	6.25
	Max Depth	(ft)	#NAME?	36.15	42.89	34.94	23.11	23.62	24.08
	Approach Depth	(ft)	47	28	28	30	15	15	15
	Momentum constricted		63629280	77734800	71557200	28419309	7679931	7142872	8002165
	Projection	(ft)	10	10	10	10	10	10	10
	Pier width	ft	30	30	30	30	30	30	30
	K1, Pier nose - Round		1	1	1	1	1	1	1
	K2, Pier flow angle - L/a=12, angle 15 deg		2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Kst - Abutment shape coef		0.55	0.55	0.55	0.55	0.55	0.55	0.55
	M - Discharge distribution factor		0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Factor of Safety		1	1	1	1	1	1	1
	Angle of attack	degree	15	10	10	25	10	10	10
	Angle of attack	radians	0.26	0.17	0.17	0.44	0.17	0.17	0.17
Type	Source								
Abutment	Froehlich 1989		58.3						
Longitudinal	Rice 1994		62.5	33.7	31.6	35.3	7.8	7.5	6.6
Pier	Richardson et al 1975		35.1						
	Scour potential	ft	5.0	5.7	3.6	5.3	-7.2	-7.5	-8.4
Launchable toe Calc									
Class II riprap Adequate					SITE REMOVED				
Blanket thickness required is 2 ft									
	Dry Placement	(factor)	1.25	1.25	1.25	1.25	1.25	1.25	1.25
	Thickness	ft	2	2	2	2	2	2	2
	Scour potential	ft	5.0	5.7	3.6	5.3	-7.2	-7.5	-8.4
	Per Method D (EM 1110-2-1601)								
	Launch Toe Vol Required	ft^3/ft	27.9	31.6	20.2	29.4	-40.3	-41.8	-46.8
	Less Design Surplus		21.4	25.1	13.7	22.9	No Add'l Roc	No Add'l R	No Add'l Rock req'd

minimum required class II blanket thickness is 2 feet. Design is for class V with 4' blanket, 50% of this volume can be considered launchable toe volume

	Thickness	Slope (H:1)	Slope (H:1)	Length	Hyp 1	Hyp 2	Vol	Vol Surplus
Class II Vol	2	2	2	10	11.2	7.3	18.5	0.0
Design Vol	4	2	2	10	11.2	NA	25.0	6.5
	6	2	2	10	11.2	NA	25.0	6.5
	8	2	2	10	11.2	NA	25.0	6.5

Design Surplus

	K	a	a	b	c	W	D50	Scour
Straight Reach Lacey	0.097	0.3333	0.3333	0	-0.1666667	1118	2	4.737917
Blench	0.53	0.666666667	0.666666667	-0.6666667	-0.1092	1118	2	13.72244
Lacey Mod bend	0.195	0.333333333	0.333333333	0	-0.1666667	1118	2	9.528494

$$D_{30} = S_f C_s C_V C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}$$

RipRap sizing from EM 1110-2-1601
Equation 3-3

Cs	0.32	stability coefficient for mixed angular / rounded rock (angular = 0.3, rounded = .375)
Cv	1.25	vertical velocity distribution coef = 1.25 outer bend
Ct	1	thickness coefficeint - minimum thickness = D100 thickness
Water unit weight	62.4	lb/ft3
Stone unit weight	165	lb/ft3
K1	0.72	side slope correction factor using 2H:1V
g	32.2	ft/s^2
d	28	ft — maximum channel flow depth
Mean Velocity	8	Mean channel velocity
Design Velocity	10	ft/s — 1.25x mean channel velocity

Minimum Required Gradations (ft) (uses COE 1991 relationships- see below)

D_{15}	0.43	ft	D_{50}	**0.71**	ft
D_{30}	0.58	ft	D_{85}	0.81	ft

Deisgn Gradations

Class	D_{50} (ft)	Safety Factor	Recommendation
Class I	0.5	0.70	**Not Adequate**
Class II	1.32	1.85	**Adequate**
Class III	1.5	2.11	**Adequate**
Class IV	1.675	2.35	**Adequate**
Class V	2.05	2.88	**Adequate**
Toe	3.25	4.57	**Adequate**

RipRap Gradations

D_{50} (ft)	R (ft)	A (ft2)	Vol (ft3)	W (lbs)	Ton	Man size	Class	Velocity range
0.5	0.3	0.2	0.1	11	0.0	1/2 man	I	6-10
1	0.5	0.8	0.5	86	0.0	1 man		
1.32	0.7	1.4	1.2	199	0.1	1 man	II	10-14
1.5	0.8	1.8	1.8	292	0.1		III	14-16
1.675	0.8	2.2	2.5	406	0.2		IV	17
2	1.0	3.1	4.2	691	0.3			
2.05	1.0	3.3	4.5	744	0.4	2 man	V	18
2.5	1.3	4.9	8.2	1350	0.7	3 man		
3	1.5	7.1	14.1	2333	1.2			
3.5	1.8	9.6	22.4	3704	1.9	4 man		
4	2.0	12.6	33.5	5529	2.8	5 man		
4.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

Table C.4. Comparison of riprap gradations recommended by various agencies.[1]

Diameter	Relationship to D_{30} Diameter: USACOE (1991)	Relationship to D_{30} Diameter: Richardson et al. (1990)	Relationship to D_{50} Diameter: USACOE (1991)	Relationship to D_{50} Diameter: Richardson et al. (1990)	Relationship to D_{50} Diameter: Washington Dept. of Ecology (1992)
D_0	NS[2]	0.38	NS	0.25	0.25
D_{15}	0.75	0.66	0.64	0.43	NS
D_{30}	1.00	1.00	0.85	0.65	NS
D_{50}	1.17	1.54	1.00	1.00	1.00
D_{85}	1.40	2.70	1.20	1.75	NS
D_{100}	1.50	3.08	1.28	2.00	1.25 to 1.5

1 The values for these gradations have been adapted and interpreted from the cited references.
2 Not Specified

From King County Riprap Manual - http://your.kingcounty.gov/dnrp/library/archive-documents/wlr/biostabl/PDF/9305BnkStbApC.pdf

S_f = safety factor (see *c* below)

C_s = stability coefficient for incipient failure, D_{85}/D_{15} = 1.7 to 5.2

= 0.30 for angular rock

= 0.375 for rounded rock

C_V = vertical velocity distribution coefficient

= 1.0 for straight channels, inside of bends

= 1.283 - 0.2 log (R/W), outside of bends (1 for (R/W) > 26)

= 1.25, downstream of concrete channels

= 1.25, ends of dikes

C_T = thickness coefficient (see *d*(1) below)

= 1.0 for thickness = $1D_{100}$(max) or 1.5 D_{50}(max), whichever is greater

d = local depth of flow, length (same location as V)

γ_w = unit weight of water, weight/volume

V = local depth-averaged velocity, V_{SS} for side slope riprap, length/time

K_1 = side slope correction factor (see *d*(1) below)

g = gravitational constant, length/time^2

Some designers prefer to use the traditional D_{50} in riprap design. The approximate relationship between D_{50} and D_{30} is $D_{50} = D_{30}\,(D_{85}/D_{15})^{1/3}$. Equation 3-3 can be used with either SI (metric) or non-SI units and should be limited to slopes less than 2 percent.

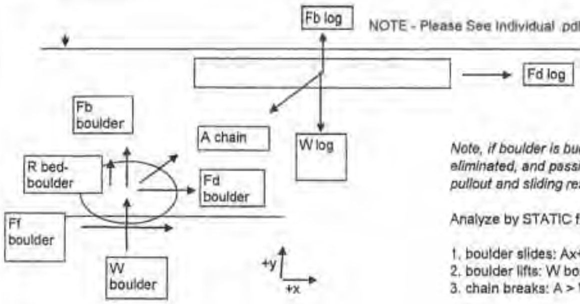
$$K_1 = \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}} \qquad (3\text{-}4)$$

where

θ = angle of side slope with horizontal

ϕ = angle of repose of riprap material (normally 40 deg)

=Input cell, Input variables



NOTE - Please See individual .pdf files for each specific LWD site

Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

Method
1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	1.5	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Boulder Parameters (assume spherical)	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
	4.85	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged: 100%
Design velocity: 8.8 — =mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.: 0.9 — Cd = short cylinder, L/D=2 to 4, Cengal p 574

Streambed material internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)

Applied forces	log	boulder	
Fb	[illegible]	[illegible]	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder
W	[illegible]	[illegible]
Ff		[illegible]
Ax	[illegible]	
Ay	[illegible]	
A	[illegible]	

Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax = Max Fd log
Ay = (Fb log - W log)
A = (Ax^2+Ay^2)^0.5

Static Force balance

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?
Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	1.52

Case 2. boulder lifts: W boulder - Fb boulder < Ay?
Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	2.11

Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes

Modified by KGW
Changes

Inserted capability for lateral Soil Capacity of buried boulders.
Modified volume of LWD calc to include frustrum volume
Inserted table of wood densities, User will still need to manually input values.
added QTY of boulders
Modified max area to include estiamted rootball cross section, defined as a rectangle H=3*DBH, Width = DBH
Modified chain WLL to 6900 - as spec'd by peerless chain for 1/2 long link marine mooring chain (www.peerless.com)
modified chain threshold to 1/2 A, as the LWD chain will have two attachment points into boulder.
added debris factor for LWD area. Added check box to ensure debris factor*RB area> log max area

Parameters

BOULDER ANCHOR STABILITY Moisture Content 80%

TABLE 1 Specific gravity of air-dried tim

Species	S_L	Density (lb/ft3)
Cedar	0.36	[illegible]
Spruce (Sitka, White and Englem	0.43	
Hemlock, Pine (Jack and Lodgep	0.48	
Pine (Ponderosa)	0.51	
Fir (Douglas)	0.54	

*Modified from Laminated Timber Institute of Canada (1980)

RB Diameter scale factor = 3.5 *DBH
RB Thickness/height scale factor= 1 *DBH

Esitmated Assembly Weight

Unit weight	LWD	Chain	Shackles	Boulders	Total	pick points	each anchor
1.5' DBH	2665	50	9	22000	24724	12362	6181
2' DBH	5205	75	9	16000	21289	10645	5322
2' DBH, DD3	5205	75	9	8000	13289	6645	3322

lift shackles	7/8"	13000	WLL
	Expected	12362	
		1.05	FS
Chain	1/2"	6900	WLL
	Expected	6181	
		1.12	FS

-6222

-11794.40 0.700207538 -8258.528896
0
-8258.528896

Table 3. Skagit River LWD Levee Repairs

Site	Length of repair	River Mile	Length of LWD	Qty LWD	HEC RAS info XS	River	Reach	Vel	Depth
1-3	75	13.1	75	8	13.1	Skagit	Baker2Concrete	6.5	58
3-6	150	SF 2.95	150	15	295	SOUTHrev PFP3	reach 3	1.52	24.6
3-8	225	SF 3.40	225	23	340	SOUTHrev PFP3	reach 3	1.52	24.6
12-9	1850	16.6	1575	158	16.71-16.49	Skagit	Baker2Concrete	8.1	40.4
17-16	250	13.1	GROIN	GROIN	13.1	Skagit	Baker2Concrete	6.5	58
22-7	350	NF 9.1	350	35	910.3	NORTHrev PFP3	Reach 2	6.4	37.9
Subtotals	2900		2375	239					

Table 4. Skagit River LWD Mitigation Sites

Site	Length of repair	River Mile	Length of LWD	Qty LWD	HEC RAS info XS	River	Reach	Vel	Depth
3-5 (2007)	460	SF 3.25	460	46	325	SOUTHrev PFP3	reach 3	1.77	26.2
3-6 (2007)	375	SF 2.95	375	38	295	SOUTHrev PFP3	reach 3	1.52	24.6
17-6 (2007)	400	14.6	400	40	14.6	Skagit	Baker2Concrete	7.7	47
22-7 (2007)	150	NF 9.1	150	15					
Subtotals	1385		1385	139					
TOTALS	4285		3760	378					

Item	QTY		Spec	Source
LWD	239	Ea	min 12" DBH with 3' diameter rootball, 20' stem length	http://www.peerlesschain.com/downloads/peerless-acco-2010.pdf#page=22
Chain	2679	ft	1/2" marine galvanized mooring chain (long link). WLL 6,900 lb or greater	http://www.peerlesschain.com/downloads/peerless-acco-2010.pdf#page=21
Shackles	956	Ea	3/4" marine galvanized screw pin anchor shackles. WLL 6,900 lb or greater	
Bolts	956	Ea	7/8" OD x 12" long, galvanized, threaded round eye bolt.	
Epoxy	0	fl oz.	Hilti RE 500 or equivalent	

Volume of epoxy

V hole (in3)	V bolt (in3)	Vol Epoxy	spill (in3)	total (in3)	Minimum fl oz.
3.5	2.5	1.1	2.0	2944.4	1631.5

Epoxy pull out resistance strength

Cracked concrete

5/8" threaded rod	Max	Dry Concrete
Uncracked Concrete	2142	1392.3
Cracked Concrete	1044	678.6
Rod Diameter	0.625	in
Embeded depth	8	in
Est area	19	in2
Min load strength	12791	lbs

http://www.us.hilti.com/fstore/holus/techlib/docs/4.2.6_HIT_RE_500_SD_%28221-260%29_r021.pdf

http://www.us.hilti.com/holus/page/module/techlib/teli_productreldocs.jsf;jsessionId=715E1D864A3362EAC6380B788E3BD8A9.node3?lang=en&selProdOid=434410&nodeId=-114925

Expected load	4600	lbs
% max	36%	max load of epoxy anchor

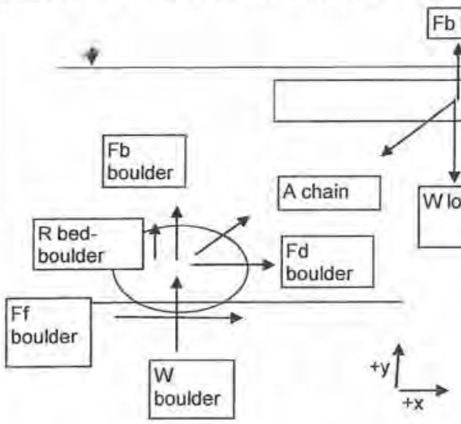
Threaded rod strength

3/4" threaded rod

Normal Strength (Nsa)	28249	lbs	ASTM A 193 B7 High Carbon steel
Shear Stregth (Vsa)	16950	lbs	ASTM A 193 B7 High Carbon steel
Tensile reduction	0.75		
Minimum Rod Strength	12712.5	lbs	

BOULDER ANCHOR STABILITY CALCULATOR

NOTE - Please See Individual .pdf files for each specific LWD site



Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

<u>Method</u>

1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	2	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Boulder Parameters (assume spherical)	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
	4.5	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged	100%	Streambed material Internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)
Design velocity	6.5	=mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.	0.9	Cd = short cylinder, L/D=2 to 4, Cengal p 574

Applied forces	log	boulder	
Fb	[illegible]	5354.57	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder	
W	[illegible]	[illegible]	Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff		[illegible]	Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax	[illegible]		Ax = Max Fd log
Ay	[illegible]		Ay = (Fb log - W log)
A	[illegible]		A = (Ax^2+Ay^2)^0.5

<u>Static Force balance</u>

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?
Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	1.55

Case 2. boulder lifts: W boulder - Fb boulder < Ay?
Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	1.74

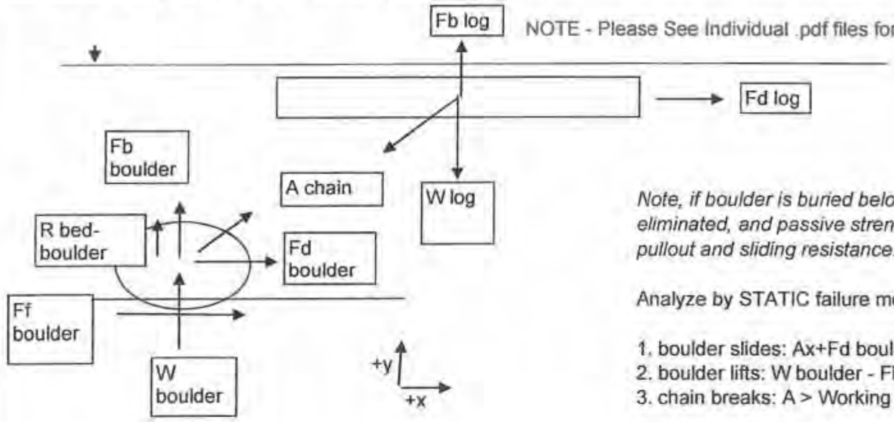
Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes

DD3 (all) Dual Rock

BOULDER ANCHOR STABILITY CALCULATOR

NOTE - Please See Individual .pdf files for each specific LWD site



Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

Method
1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	2	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
Boulder Parameters (assume spherical)	3.5	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged	100%	Streambed material Internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)
Design velocity	1.5	=mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.	0.9	Cd = short cylinder, L/D=2 to 4, Cengal p 574

Applied forces	log	boulder	
Fb	[illegible]	[illegible]	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder	
W	[illegible]	[illegible]	Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff		[illegible]	Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax	[illegible]		Ax = Max Fd log
Ay	[illegible]		Ay = (Fb log - W log)
A	[illegible]		A = (Ax^2+Ay^2)^0.5

Static Force balance

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?
Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	13.72

Case 2. boulder lifts: W boulder - Fb boulder < Ay?
Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

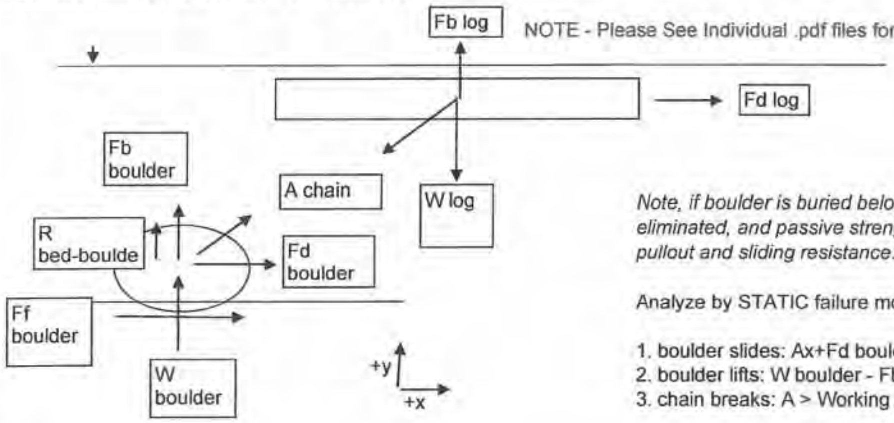
Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	1.42

Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes

DD 12-9

BOULDER ANCHOR STABILITY CALCULATOR



NOTE - Please See Individual .pdf files for each specific LWD site

Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

Method

1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	1.5	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
Boulder Parameters (assume spherical)	4.85	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged	100%	Streambed material Internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)
Design velocity	8.4	=mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.	0.9	Cd = short cylinder, L/D=2 to 4, Cengal p 574

Applied forces	log	boulder	
Fb	[illegible]	[illegible]	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder	
W	[illegible]	[illegible]	Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff		[illegible]	Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax	[illegible]		Ax = Max Fd log
Ay	[illegible]		Ay = (Fb log - W log)
A	[illegible]		A = (Ax^2+Ay^2)^0.5

Static Force balance

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?

Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	1.67

Case 2. boulder lifts: W boulder - Fb boulder < Ay?

Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	2.11

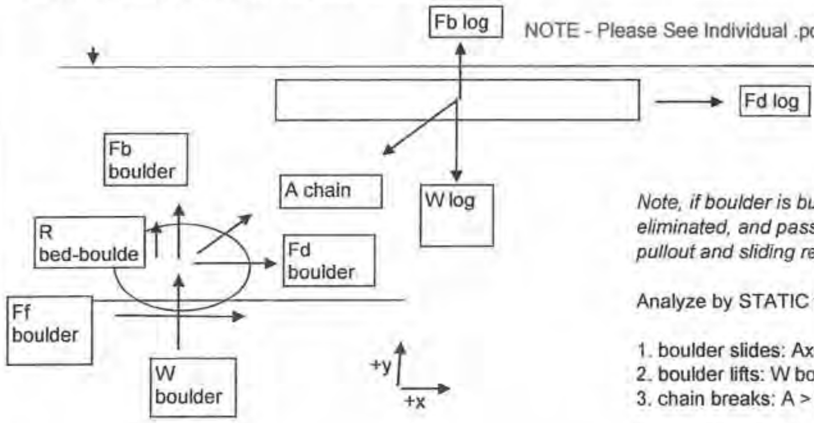
Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes

DD 17-6

BOULDER ANCHOR STABILITY CALCULATOR

NOTE - Please See Individual .pdf files for each specific LWD site



Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

Method

1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	1.5	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
Boulder Parameters (assume spherical)	4.85	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged	100%	Streambed material Internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)
Design velocity	7.7	=mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.	0.9	Cd = short cylinder, L/D=2 to 4, Cengal p 574

Applied forces	log	boulder	
Fb	[illegible]	[illegible]	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder	
W	[illegible]	[illegible]	Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff		[illegible]	Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax	[illegible]		Ax = Max Fd log
Ay	[illegible]		Ay = (Fb log - W log)
A	[illegible]		A = (Ax^2+Ay^2)^0.5

Static Force balance

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?

Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	1.99

Case 2. boulder lifts: W boulder - Fb boulder < Ay?

Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	2.11

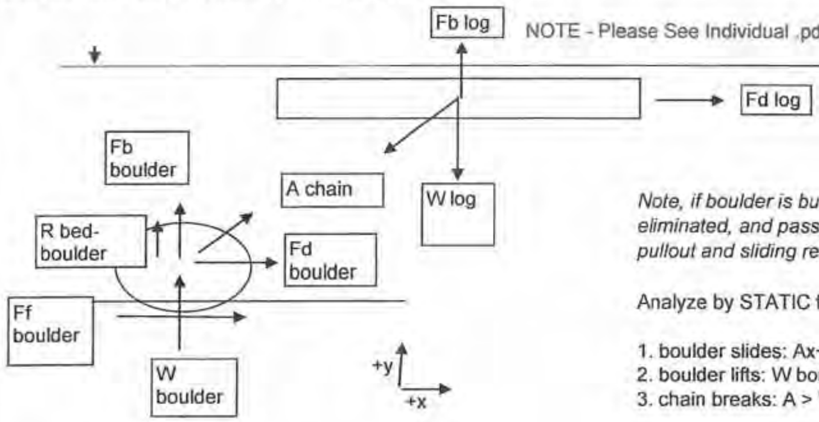
Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes

DD 22-7

BOULDER ANCHOR STABILITY CALCULATOR

NOTE - Please See Individual .pdf files for each specific LWD site



Note, if boulder is buried below bed, drag on boulder is eliminated, and passive strength will greatly increase pullout and sliding resistance.

Analyze by STATIC failure modes:

1. boulder slides: Ax+Fd boulder > Ff boulder
2. boulder lifts: W boulder - Fb boulder < Ay
3. chain breaks: A > Working Load Limit

Method

1. Compute applied loads: Fb, Fd
2. compute resisting loads, W, Ff
3. Use A chain to transfer loads, and analyze stability of either log or boulder seperately

	length	DBH	density	Debris Factor	min area	max area	volume	Weight	RB Area	RB Width
Log dimensions	20	1.5	53.2	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Boulder Parameters (assume spherical)	Diameter	Qty	% Buried	dry density	area	volume	Weight EA	Maximum Lateral soil capacity
	4.85	2	0%	165	[illegible]	[illegible]	[illegible]	[illegible]

LWD % submerged	100%	Streambed material Internal soil friction angle (the 35 range: 29 (loose) - 42 (dense)
Design velocity	9.5	=1.5*mean HEC-RAS channel velocity @ 25 yr event
Design drag coef.	0.9	Cd = short cylinder, L/D=2 to 4, Cengal p 574

Applied forces	log	boulder	
Fb	[illegible]	[illegible]	= % submerged*weight of displaced water
Fd max	[illegible]	[illegible]	= Design Area * % SUBMERGED * Cd * 1/2 *rho * V^2
Area assumption	OK		A_{Log} =Debris Factor * RB Area, $A_{Boulder}$ =Area sphere

Resisting forces	log	boulder	
W	[illegible]	[illegible]	Ff = net weight on bed*tan(theta) (if unburied) OR % buried * latreal soil capacity
Ff		[illegible]	Ff = (W boulder + Fb boulder + (Fb log + W log))*tan(theta) OR Qty*% buried*lateral soil capacity
Ax	[illegible]		Ax = Max Fd log
Ay	[illegible]		Ay = (Fb log - W log)
A	[illegible]		A = (Ax^2+Ay^2)^0.5

Static Force balance

Case 1. boulder slides: Ax+Fd boulder > Ff boulder?
Horiz. Fx = 0 = Ff boulder - Fd boulder - Fd log

Ax+Fd boulder	Ff	Delta	Stable?	Safety Factor
[illegible]	[illegible]	[illegible]	yes	1.31

Case 2. boulder lifts: W boulder - Fb boulder < Ay?
Vertical: Fy = 0 = W log + W boulder - Fb log - Fb boulder

Weight	Bouyant	Delta	Stable?	
[illegible]	[illegible]	[illegible]	yes	2.11

Case 3. chain breaks: A > Chain Working Load Limit?

A	chain WLL	Within Tolerance?
[illegible]	[illegible]	yes