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Date: July 25, 2012

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Subject: NE 93rd Culvert Condition Assessment – Technical Memorandum

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Site Location and Background

Based on documents from King County Assessor Records and aerial photographs dated 1936, the Thornton Creek culvert is believed to have been constructed in early 1930s. It is located on NE 93rd Street approximately 150-feet east of SandPoint Way NE and adjacent to Matthews Beach Park, approximately 1000-feet upstream of the confluence with Lake Washington. Seattle Public Utilities (SPU) has requested that Osborn Consulting, Inc. (OCI), along with structural engineer, CivilTech Engineering (CTE), investigate the existing culvert condition and identify structural repair alternatives. Previous studies looked at comprehensive solutions, whereas this assessment focused strictly on alternatives to protect public safety and health and potential repair options of the existing culvert structure. This memorandum summarizes the investigation process and the alternatives that were considered and developed.

Hydrology

Hydrology and hydraulics information was obtained from *Conceptual Design for NE 93rd Street Culvert Replacement*[1] prepared for Seattle Public Utilities by Pace Engineers, Inc. and Icicle Creek Engineers on December 31, 2010. The culvert is classified as having a Level of Service (LOS) of 25 years. Flows and return periods identified in the report include:

- 50-year flow in Thornton Creek is 395 cfs (December 3, 2007 storm)
- 100-year flow in Thornton Creek 420 cfs
- Existing culvert at or under capacity during December 11, 2010 storm (10 to 25 year flood event)

Assessment Approach and Results

The condition of the culvert was assessed using the Roads and Traffic Authority (RTA) Culvert Risk Assessment Guideline v3.02 as requested by SPU staff. The RTA guidelines include a four step process:

1. Identify Hazards (Site Visit Findings)
2. Estimate likelihood of failure
3. Estimate consequence of failure
4. Derive Assessed Risk Level (ARL)

By completing these steps the existing culvert deficiencies were identified and documented as summarized in the following sections.

Hazard Identification

On May 22, 2012, Tarelle Osborn (OCI), Dustin Ong (CTE), Mike Helminger (CTE) and Wan-Yee Kuo(SPU) performed a site inspection. The following was completed as part of the assessment:

[1] *Flood Insurance Study for Thornton Creek and its Tributaries; Lake Washington to Interstate 5,* Northwest Hydraulic Consultants, 5th July 2005

1. Information such as type, location, design data, and details was collected through the Culvert Inventory Collection process.
2. A Risk Assessment check list was completed (see **Appendix A** for Risk Assessment Checklist).
3. Relevant photographs and images were collected (see **Appendix B** for Photograph Log).

The following are the key observations and hazards identified at each area of the culvert. Please refer to **Appendix C** for a copy of the full memo on discussion of findings.

- Concrete Wingwall (running east-west)
    - Has a 3-degree outward lean
    - Soil loss at western end (16-inch gap between existing soil and cast-in-place edge)
    - Crack up to 1 inch at transition between wingwall and culvert, extends first horizontally then vertically. Using photographs taken in 2007, crack location and size remained unchanged
    - Overall structure of wingwall appears satisfactory, aside from cracks at transition
- Inlet
    - Footing at inlet wall shows signs of undermining
    - Both inlet walls exhibit a lean to the east up to 15 degrees
- Barrel
    - Barrel is a 3-sided box
    - Stream bottom extends below bottom of footings
    - Footings are approximately 2-feet deep
    - Footing at downstream end (last 5-feet) has been lost below east culvert wall
- Outlet Wall
    - Exhibit lean to east up to 15 degrees
    - Footings at outlet wall show signs of undermining
    - Eastern wall shows signs of buckling and soil backfill loss
    - Eastern wall also shows signs of exposed rebar, minor concrete spalling and general deterioration
- Bulkhead Walls
    - Downstream of the culvert, bulkhead walls include steel pipe struts to support walls at approximately mid height

Structural damage and shifting of the culvert wall appears to be caused by undermining of footings along the length of the culvert, and occur predominantly at the outlet and inlet locations on the eastern side of the culvert. The primary structural concern is undermined footings. Please see **Figures 1 and 2** for an illustration of the hydraulic forces and locations of undermining in plan and section view.

Below is a summary of the four hazards (structural collapse, slope instability, piping, and hydraulic flow) and the associated rating factors for the culvert (likelihood, consequence, and risk).

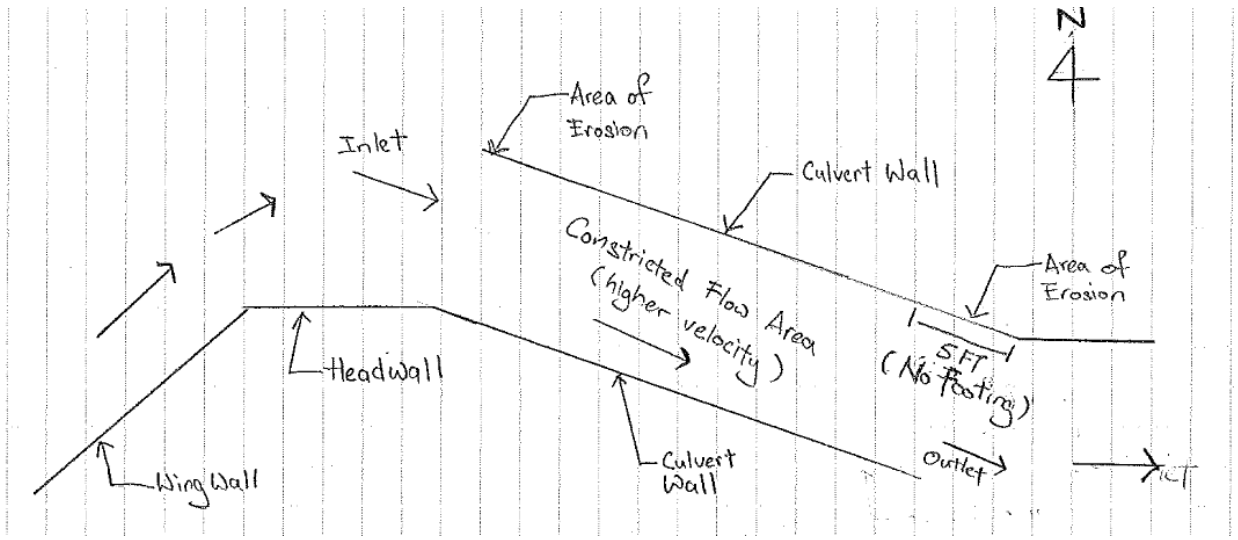
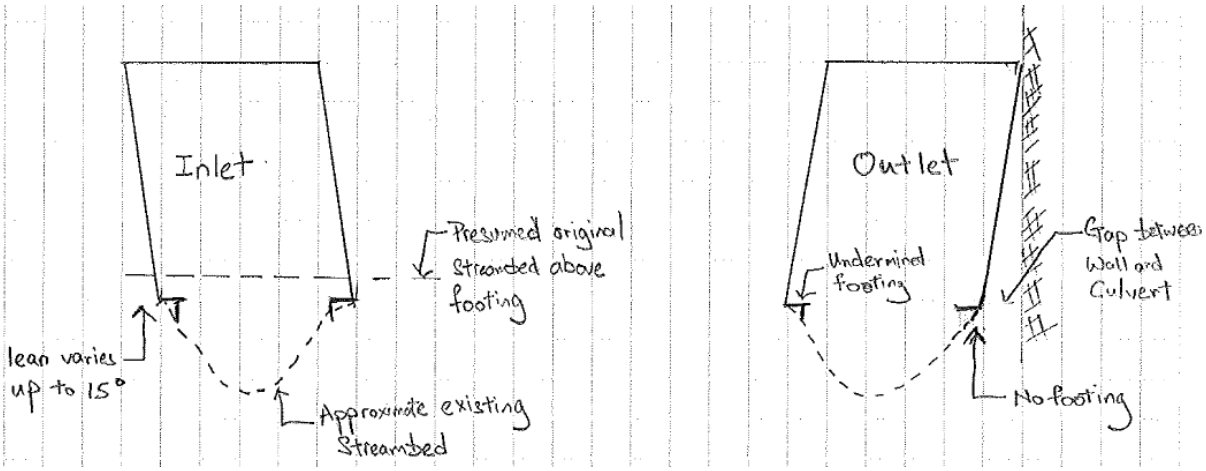


Figure 1. - Plan view



Inlet View - Looking Downstream

Outlet View - Looking Upstream

Figure 2. – Cross-Section View

Assessment Result

A brief introduction of factors and calculation method used in RTA Culvert Risk Assessment Guideline and the Risk Analysis form (**Table 1**) on NE 93rd Culvert is shown below. Please refer to *RTA Culvert Risk Assessment Guideline v3.02* for details and explanation on calculation methods and variable definitions.

M. Risk Analysis

Hazard/Failure Mechanism	SC-1	SI-1	SI-2	SI-3	SI-4	PI-1	PI-2	PI-3	HF-1	HF-2
Hazard Type	Structural Collapse	Slope Instability Afflux	Slope Instability Leakage Out of Barrel	Slope Instability Headwall Collapse	Slope Instability Under-mining	Piping Into Culvert	Piping Outside of Culvert due to Afflux	Piping Outside of Culvert due to Leaks out of Culvert	Hydraulic Flow Erosion by Over-topping Flows	Hydraulic Flow Cross Catch-ment Flooding
Likelihood Ratings										
Likelihood Factor 1	0.2	0.04	0	0	0.8	0	0	0	0.04	0.04
Likelihood Factor 2	0.9	0.10	0	0	0.5	0	0	0	0.01	0.1
Likelihood Factor 3		.20					0	0	0.01	0.05
Final Likelihood	.18	.02	0	0	.40	0	0	0	.004	0
Likelihood Rating (L1 - L6)	L2	L3	L6	L6	L2	L6	L6	L6	L3	L4
Consequence Class Ratings *										
Temporal Probability (T1 - T5)	PERSONS MAY SOMETIMES BE PRESENT AS PART OF THE NORMAL PATTERN OF USAGE. ROAD USERS ON MANY URBAN ARTERIAL ROADS & MOST MAJOR RURAL ARTERIAL ROADS									T3
Vulnerability (V1 - V5)	MOST PEOPLE ABLE TO EVADE DEBRIS (PEOPLE IN THE OPEN) BUILDING PENETRATED, NO COLLAPSE (PEOPLE IN BUILDINGS) LOST INTO A DEEP, NARROW VOID (VEHICLES CROSSING AREA)									V2
Consequence Class for Loss of Life (C1 - C5)	NO ADJUSTMENTS TO CONSEQUENCE RATING IS NECESSARY.									C2
Consequence Class for property damage (C1 - C5)	MODERATE INFRASTRUCTURE OR PROPERTY DAMAGE MODERATE DISRUPTION COSTS MODERATE REPAIR COSTS TOTAL DIRECT & INDIRECT COSTS $.5M - 2M									C3
* In general T, V and C ratings will be the same for all hazards, except for HF-2 which will have a different zone of influence (ie across other catchments) and different elements at risk.										
Risk Analysis Ratings										
Assessed Risk Level (ARL1 - ARL5)	ARL 1	ARL 2	ARL 5	ARL 5	ARL 1	ARL 5	ARL 5	ARL 5	ARL 2	ARL 3
Need for further investigation? (Y/N)	☒ Yes ○ No									
Comments: RECOMEND CULVERT INSPECTION @ 1 YEAR INTERVALS UNLESS STRUCTURAL MODIFICATIONS OR OTHER REPAIR WORK PERFORMED.										

Table 1: RTA Risk Analysis of NE 93rd Culvert

- Likelihood of Failure SC-1 (Structural Collapse) = Likelihood of collapse of culvert barrel x Likelihood of void or settlement at road surface
- Likelihood of Failure SI-1 (Slope Instability-Afflux) = Likelihood of storm event exceeding capacity or Likelihood of culvert blockage or insufficient hydraulics capacity x Likelihood of void or settlement at road surface
- Likelihood of Failure SI-2 (Slope Instability-leakage out of barrel) = Likelihood of leakage out of culvert x Likelihood of embankment slope instability
- Likelihood of Failure SI-3 (Slope Instability-headwall collapse) = Likelihood of headwall collapse x Likelihood of pavement collapse given headwall collapse
- Likelihood of Failure SI-4 (Slope Instability-undermining at inlet or outlet) = Likelihood of excessive erosion at outlet or inlet x Likelihood of road or culvert collapse
- Likelihood of Failure PI-1 (Piping-into culvert) = Likelihood of erosion into culvert x Likelihood of void or settlement at road surface
- Likelihood of Failure PI-2 (Piping-outside of culvert due to afflux) = Likelihood of erosion storm event exceeding capacity or Likelihood of culvert blockage or insufficient hydraulic capacity x Likelihood of piping failure of road embankment
- Likelihood of Failure PI-3 (Piping-outside of culvert due to leakage out of culvert) = Likelihood of barrel defects causing piping x Likelihood of road or void collapse
- Likelihood of Failure HF-1 (Hydraulic Flow-erosion by overtopping flows) = Likelihood storm event exceeding capacity or Likelihood of overtopping of road embankment x Likelihood of overtopping causing excessive erosion
- Likelihood of Failure HF-2 (Hydraulic Flow-cross catchment flooding) = Likelihood storm event exceeding capacity or Likelihood of culvert blockage or insufficient hydraulic capacity x Likelihood of cross catchment flooding
- Vulnerability (V) estimate = probability of event causing death, assuming person is within zone of influence of the failure or that a vehicle impacts the debris or is lost into a void caused by the failure
- Temporal Probability (T) estimate = probability that a given failure mechanism interacts with an element at risk
- Consequence (C) class for Risk of Life = derivation from temporal probability and vulnerability rating, using matrix on page 69 of *RTA Culvert Risk Assessment Guideline v3.02*
- Consequence (C) class for Risk to Property = consequence with respect to property damage and other consequential effects of failure as assessed in page 70 of *RTA Culvert Risk Assessment Guideline v3.02*

Likelihood of Failure

Likelihood of failure, L, is the probability that a failure mechanism will occur. There are five L ratings, ranging from L1 through L6. A rating of L1 is equivalent to an event that has a probability occurrence above 0.5, while L6 has probability of less than 0.0005. Hence, a lower L corresponds to the possibility of an event happening within a shorter period of time. **Table 2** contains a detailed explanation of various levels of Likelihood Ratings. Please see **Appendix A** and **Table 1** for detailed documentation and calculation of L-values. For NE 93rd culvert, the ratings assessed by the consultant team are as follows:

- Structural Collapse – likelihood rating of L2
- Slope Instability – likelihood rating of L2
- Piping– likelihood rating of L6
- Hydraulic Flow– likelihood rating of L3

Likelihood to L Rating Conversion		
Likelihood	L Rating	Description
Above 0.5	**L1**	The event may, or is expected to, occur within a short period under average circumstances, or the mechanism is active at present (depending on circumstances the "short" period could be from days to no more than two to three years).
0.05 to < 0.5	**L2**	The event may, or is expected to, occur within a moderate period (from a few years to no more than about 30 years) or within the inspection period under slightly adverse circumstances.
0.005 to < 0.05	**L3**	The event could be expected to occur at some time over about a 100 year period in the normal course of events but would only occur within the next inspection period under adverse circumstances.
0.0005 to < 0.005	**L4**	The event would not be expected to occur within about a 100 year period under normal conditions and is unlikely to occur within the next inspection period except under very adverse circumstances.
0.00005 to < 0.0005	**L5**	The event would not be expected to occur within about a 100 year period and is unlikely to occur within the next inspection period even under very adverse circumstances.
< 0.00005	**L6**	The event is unlikely to occur even under extreme circumstances.

Table 2: Likelihood Rating

Consequence of Failure

Consequence ratings for risk of life and property are used in combination with hazard likelihood to determine risk ratings for each kind of hazard present at a culvert. A summary of Consequence Risk Rating levels for risk to property is shown in **Table 3**. C ratings range from C1 to C5. This site has a rating of consequence class C3 for property damage due to the possibility of moderate infrastructure or property damage (including the access and possible damages to ten homes in the vicinity), with total direct and indirect cost between $0.5 million and $2 million. For consequence for risk to life rating, the site has a consequence class of C2, since it is in an urban setting and is the only access for Matthews Beach Park and local residences. See **Appendix A** and **Table 1** for detailed documentation and calculation of C-values.

Consequence Risk for Property		
Rating	Description	Example
C1	Total closure of a Sub-Network Rank 5 or 6 (SN5-6) road for an extended period	Major infrastructure or property damage (other than road) Very high disruption cost (other than road users) Very high repair cost (Total direct and indirect costs > $10M)
C2	Total closure of one carriageway of an (SN5–6) road or total closure of an (SN3-4) road for an extended period	Substantial infrastructure or property damage Large disruption costs High repair cost (Total direct and indirect costs > $2M < $10M)
C3	Partial or total closure of an (SN3-4) road for a short period, longer period if reasonable alternatives are available	Moderate infrastructure or property damage Moderate disruption costs Moderate repair cost (Total direct and indirect costs : $0.5M < $2M)
C4	Partial or total closure of an (SN2) road for a short period	Minor infrastructure or property damage Minor disruption costs Low repair cost (Total direct and indirect costs > $0.1M < $0.5M)
C5	Partial or total closure of an (SN1) road for a short period	Negligible infrastructure or property damage Little or no disruption costs Very low – no repair cost (Total direct and indirect costs < $0.1M)

Table 3: Consequence for Risk to Property Rating

Assessed Risk Level

The Assessed Risk Level (ARL) of the culvert is determined by: a combination of consequence risk of life rating and consequence for risk to property; and their interaction with likelihood rating. Essentially, ARL is the combination of the various probabilities. Structures are ranked from ARL1 to ARL5. A higher ARL implies a higher probability of failure occurrence and greater associated damages and life losses. See **Table 4** for a matrix on how L and C are used to determine ARL. A full checklist with associated ratings can be found in **Appendix A** and **Table 1**. For NE 93rd culvert, the ARL is as follows:

- Structural Collapse – ARL1
- Slope Instability – ARL1
- Piping – ARL 5
- Hydraulic Flow – ARL2

Assessed Risk Level Matrix					
	Consequence Class				
Likelihood	C1	C2	C3	C4	C5
L1	ARL1	ARL1	ARL1	ARL2	ARL3
L2	ARL1	ARL1	ARL2	ARL3	ARL4
L3	ARL1	ARL2	ARL3	ARL4	ARL5
L4	ARL2	ARL3	ARL4	ARL5	ARL5
L5	ARL3	ARL4	ARL5	ARL5	ARL5
L6	ARL4	ARL5	ARL5	ARL5	ARL5

Table 4: Assessed Risk Level Matrix

Since the worst ARL is ARL1, the culvert is assigned an overall ARL of 1. As a result of the ARL1 assessment rating, repair or replacement of the culvert should be considered; which confirms SPU's current "High Priority" status of this culvert. It is also recommended that culvert inspection should be performed after every storm event greater than or equivalent to a 10-year event. In addition, annual inspections after rainy season should be performed, unless structural modifications or other repair work has been performed.

The primary failure risk is associated with the erosion below the footing, caused by high velocities through the barrel of the culvert. This is an active condition that is worsened during high flows. Since soil is continuously eroded or lost beneath the footing, it is difficult to determine or predict the exact rate of loss without continuous monitoring and sediment transportation study. Structural instability may occur if a significant amount of soil is lost during a large storm event.

Fish Passage & Permitting Considerations

Thornton Creek is a fish bearing stream and it is assumed that the current culvert configuration does not meet Washington State Department of Fish and Wildlife (WDFW) criteria for culvert flow velocities and potentially other criteria, such as maximum hydraulic drop height and minimum water depth. The Washington Administrative Code (WAC) 220-110-070, states that the highest fish passage flow for meeting applicable flow depth, velocity, and jump height criteria is defined as the flow that is not exceeded more than 10 percent of the time during the months of adult fish migration.

The critical criterion for the 93rd culvert is the velocity. The WDFW maximum velocity criteria for a culvert between 100 and 200 feet long ranges from 3.0 to 4.0 feet-per-second, depending on the targeted fish species, and is even lower for juvenile passage criteria. Based on OCI's design experience with other fish passage culverts, achieving velocity, jump height and minimum water depth at this location would require replacement of the culvert with a bridge structure or installing a high flow bypass to reduce the amount of flow through the culvert.

The intent of this current assessment and memo is to identify potential repair options not replacement or bypass options. Therefore, fish passage improvements or accommodations are not included in the repair options listed below. SPU should consult with permitting specialist to understand current laws and regulations related to culvert projects on fish bearing streams.

Summary of Repair Options

Based on CTE's observation, structural repairs may be possible to extend the life of the culvert. Three structural repair options, intended to extend the life of the culvert, are outlined below. In each option, the main function is to stabilize the footing from any additional settling and provide support to the culvert walls to prevent further shifting. For a detailed discussion on each of the structural repair options, along with the pros and cons of each option, please refer to **Appendix D** for full memo from CTE, and **Appendix E** for sketches on repair options. A Hydraulic Project Application (HPA) from Washington State Department of Fish and Wildlife (WDFW) is required for all projects that require in-water work.

Since the undermined footing is the main concern, all three options involve strengthening of footing support. Repair Option 1 proposes use of steel struts between sidewalls. Repair Option 2 proposes use of steel H-piles to serve as a footing replacement. In Repair Option 3, a deadman system is proposed. All three repair options have an expected repair life of ten to twenty years, assuming repairs are performed as intended.

Immediate Repairs

Understanding that SPU would like to reduce the risk of culvert failure as soon as possible, the first repair options considered were those that could be implemented quickly (2012 construction season) and would not require significant permitting. Since loss of the footing support material is the primary concern, an effective, immediate repair is not possible as in-water work, and consequently permitting, is required. Effective stopgap measures to prevent additional erosion are not apparent at this time.

Installing steel struts across the culvert only (portion of Repair Option 1 described below) may result in a more stable structure, but will not remedy the primary concern of erosion.

Repair Option 1: Steel Struts

Description:
With a diversion or bypass of Thornton Creek in place (for in-water work), WDFW approved material would be added under and adjacent to the existing footing in undermined areas (see **Figure 3**). Steel struts would be field cut for snug-tight fit between side walls, welded to steel plates, and bolted to walls. Since placement of struts is optimized for structural purposes, raising struts to lessen impact on maintenance and blockage concerns is not feasible. Wingwall stabilization would also be included with this option using soil nails.

Considerations:
This option is reliable, can be performed fairly quickly, and allows for ease of inspection after construction, while minimizing the unknowns. However, it is costly to divert the creek, and will require in-water work to repair the footing. Also, struts may require extensive maitenance and removal of debris as they will be in the watercourse at medium to high water levels. This option includes placement of fill below the ordinary high water and would require a permit from Army Corp of Engineers and Washington Department of Fish and Wildlife (WDFW). However, this should be investigated by the SPU Environmental process and discussed with permitting experts.

Constructability:
This option, excluding time to establish the bypass system, will take approximately a week for construction, assuming the materials are on site and a concrete pump truck is available. Roads will be able to remain open for the duration of construction. Maintenance of traffic will be required, and traffic across the culvert would likely be limited to local access only. Construction hours are estimated to be between 7a.m. to 7 p.m. on weekdays and 9 a.m. to 7 p.m. on weekends.

Cost Estimate:
The cost of construction for Option 1 is approximated to be $135,000. This includes a fifteen percent mobilization cost, and a forty percent contingency fee. An engineer's conceptual level construction cost estimate is included below. Please also see **Appendix F** for a more detailed conceptual cost estimate.

Repair Option 1 Engineer's Conceptual Construction Cost Estimate				
Item	**Unit**	**Unit Cost**	**Quantity**	**Cost**
Mobilization (15%)	LS	$ 9,000	1	$9,000
Stream Bypass	LS	$20,000	1	$20,000
Galvanized Steel Pipe Strut	EA	$ 2, 600	4	$10,400
Concrete/WDFW approved material	LS	$8,900	1	$8,900
Wingwall Stabilization	EA	$4,000	4	$16,000
Concrete Crack Sealing	LS	$2,000	1	$2,000
Total				$66,300
Contingency (40%)				$26,520
Sub-Total				$92,820
Survey, Permitting, Design and Engineering (45%)				$41,8769
Total Project Cost (rounded)				**$135,000**

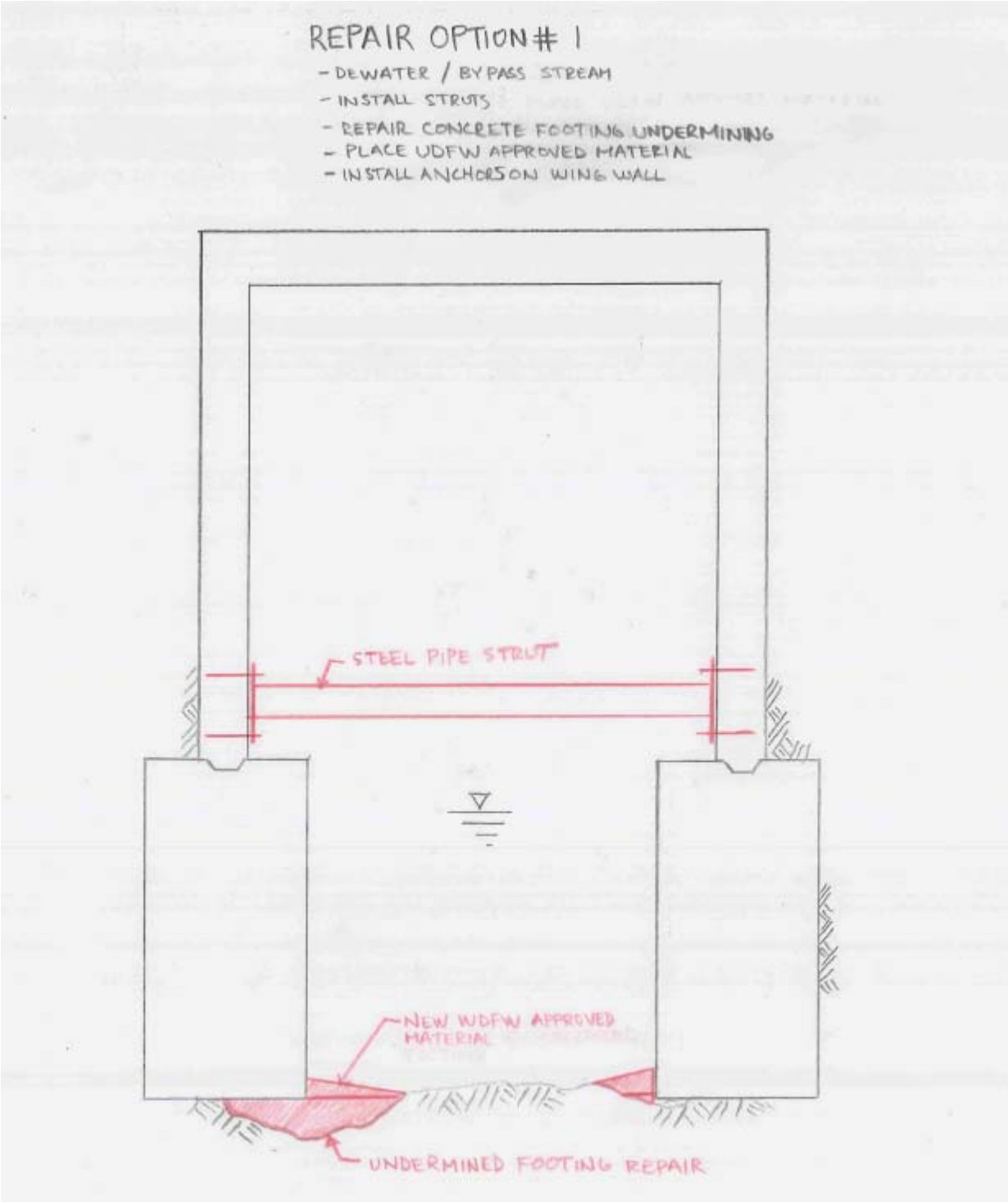


Figure 3. – Repair Option 1

Repair Option 2: Steel H-Piles

Description:
Steel H-pile soldier piles would be installed on the east side of the east culvert wall. Shafts would be drilled for the upper portion of the pile to allow installation of thru-bolts which would pass through the concrete side wall of the culvert. The shaft would then be backfilled with concrete and the H-pile would serve as a footing replacement. The new footing would prevent further settlement and walls from shifting inwards along the east side of the culvert. Wingwall stabilization would also be included with this option, using soil nails to prevent further deterioration. See **Figure 4** for a detail sketch of this option.

Considerations:
While it may be possible to avoid in-water work for this option, an in-water work permit may still be required. This needs to be evaluated via the Environmental process. Also, piles will be driven near fish-bearing stream, which can require special permitting for noise/vibration disturbance of endangered fish species. This option will be difficult to inspect after completion. Installing H-piles on both east and west sides of the culvert was considered. It was determined this would provide little additional benefit at significant additional costs.

Constructability:
In this option, the construction time will be approximately two weeks, with additional time required to repair the road. Traffic control will be required with a detour needed during construction hours. However, the road can be opened to local traffic during non-construction hours. Re-routing of traffic may be possible. The City of Seattle will need to coordinate with all appropriate agencies to determine alternative access options (see **Figure 5**). Construction hours are estimated to be between 7 a.m. to 7 p.m. on weekdays and 9 a.m. to 7 p.m. on weekends. This repair option will be relatively labor intensive compared to Repair Option 1. The cost of construction for Option 2 is approximated to be $279,000. This includes a fifteen percent mobilization cost, and a forty percent contingency fee. An engineer's conceptual level construction cost estimate is included below. Please also see **Appendix F** for a more detailed conceptual cost estimate.

Repair Option 2 Engineer's Conceptual Construction Cost Estimate				
Item	**Unit**	**Unit Cost**	**Quantity**	**Cost**
Mobilization (30%)	LS	$ 30,000	1	$30,000
Steel H-Pile	EA	$7,000	5	$35,000
Thru-bolt Anchors	EA	$8,100	5	$40,500
Excavation for Thru-bolt Anchors	LS	$10,000	1	$10,000
Roadway Repair	LS	$4,000	1	$4,000
Wingwall Stabilization	EA	$4,000	4	$16,000
Concrete Crack Sealing	LS	$2,000	1	$2,000
			Total	$137,500
			Contingency (40%)	$55,000
			Sub-Total	$192,500
			Survey, Permitting, Design and Engineering (45%)	$86,625
			Total Project Cost (rounded)	**$279,000**

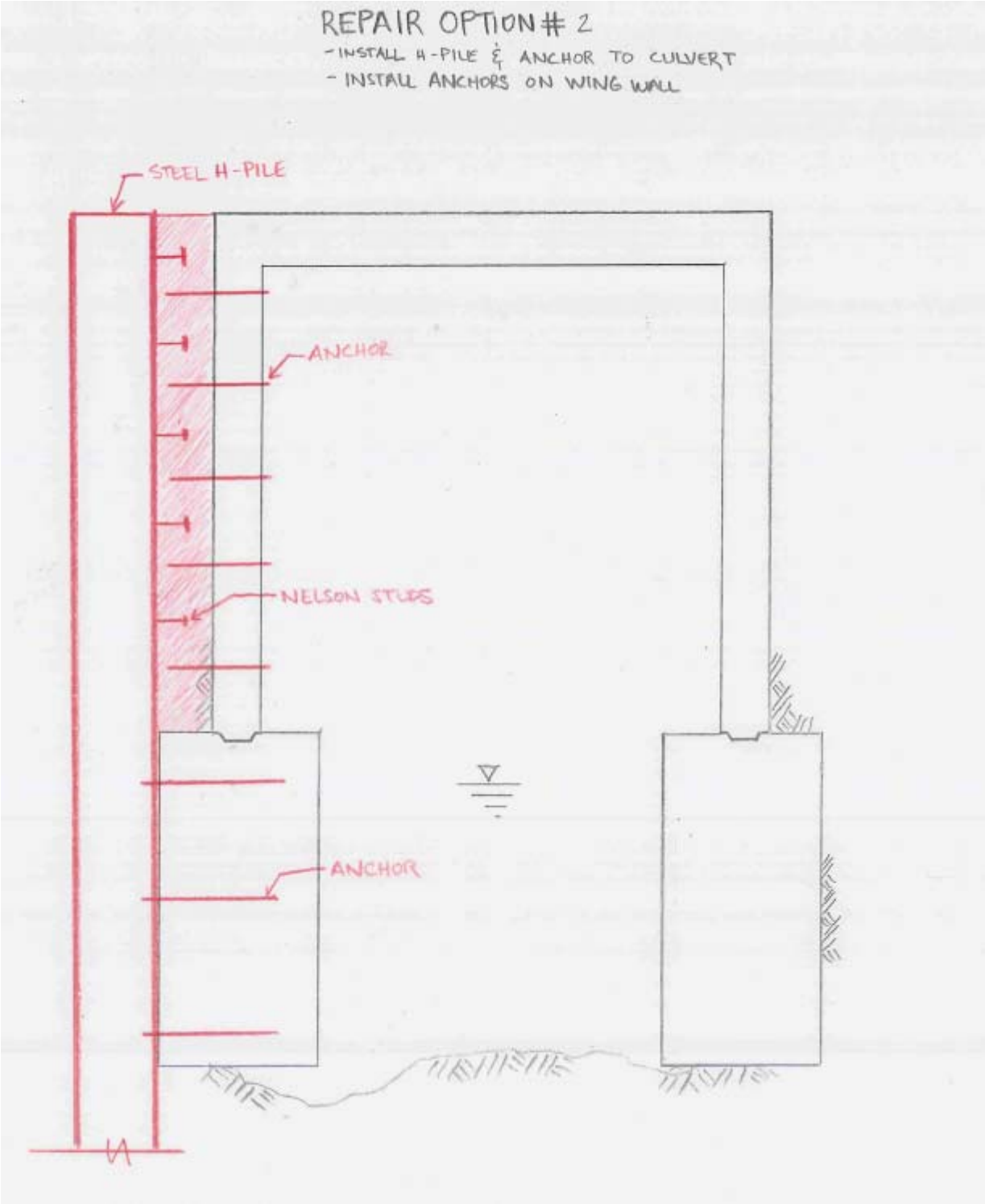


Figure 4. – Repair Option 2

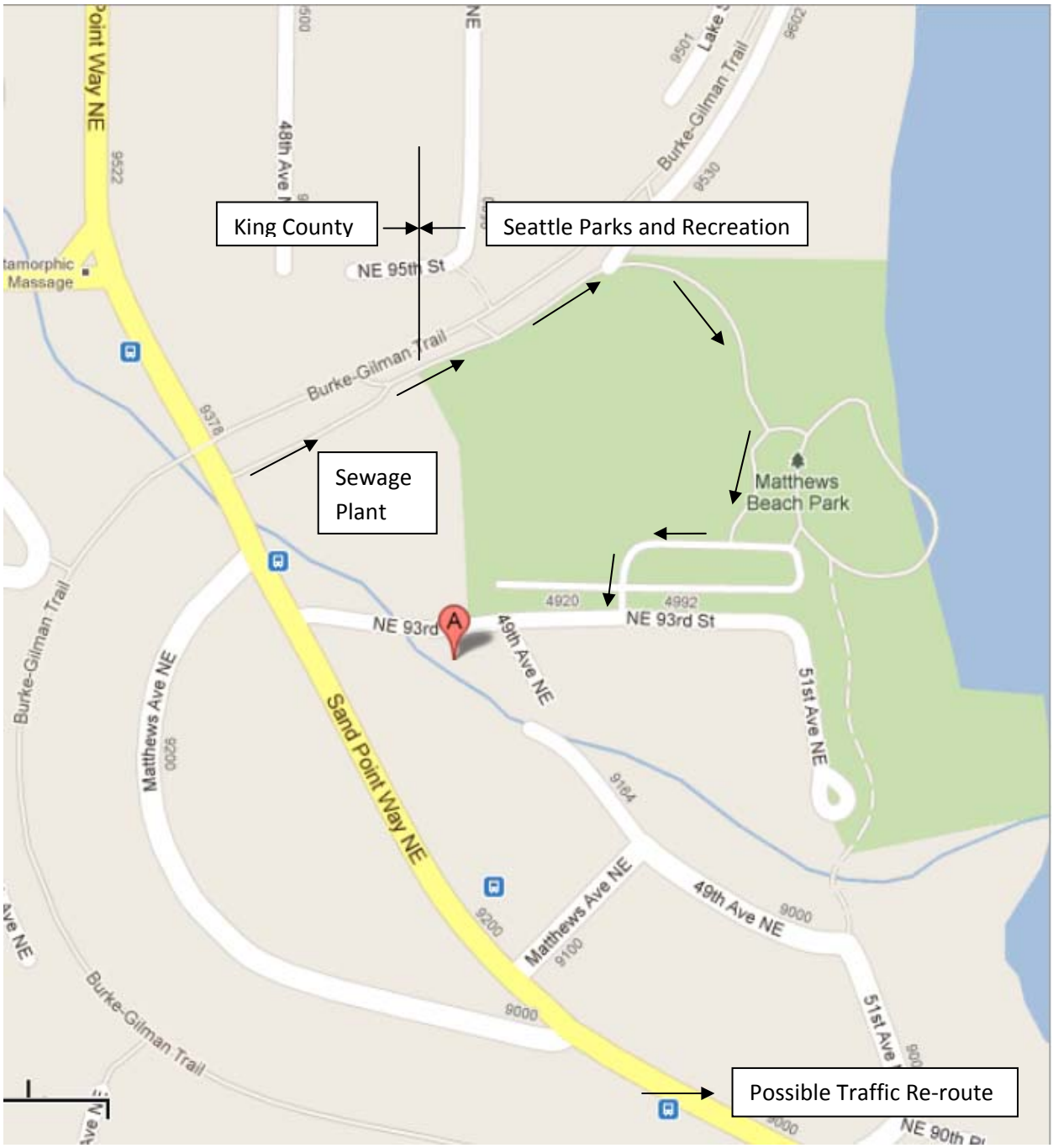


Figure 5. – Possible Traffic Re-route for Option 2 and 3

Repair Option 3: Deadman System

Description:
With a diversion or bypass of Thornton Creek in place (for in-water work), excavation would occur on the east side of the culvert wall to below the existing footing. The footing would be extended and a deadman anchor installed at three locations along the culvert. Existing streambed gravel or WDFW approved material would be used to fill in the excavated area within the channel. Wingwall stabilization would also be implemented, using soil nails, to stabilize structure (see **Figure 6**). Preliminary estimate indicates an approximate minimum setback distance of twenty feet for deadman system.

Considerations:
In-water work is required, and should be evaluated via the Environmental process. Similar to Option 2, this option is labor intensive and difficult to inspect after completion. Additionally, substantial excavation into the roadway prism and adjacent right-of-way is needed.

Constructability:
Similar to Option 2, this option will require approximately two weeks for construction. The road will be able to remain open during non-construction hours. Maintenance of traffic will be required, with access limited to local access only. Construction hours are estimated to be between 7a.m. to 7 p.m. on weekdays and 9 a.m. to 7 p.m. on weekends.

Cost Estimate:
The cost of construction for Option 3 is approximated to be $267,000. This includes a fifteen percent mobilization cost, and a forty percent contingency fee. An engineer's conceptual level construction cost estimate is included below. Please also see **Appendix F** for a more detailed conceptual cost estimate.

Repair Option 3 Engineer's Conceptual Construction Cost Estimate				
Item	**Unit**	**Unit Cost**	**Quantity**	**Cost**
Mobilization (30%)	LS	$ 26,000	1	$26,000
Stream Bypass	LS	$20,000	1	$20,000
Excavation	LS	$25,000	1	$25,000
Concrete/WDFW approved material	LS	$8,900	1	$8,900
Deadman	EA	$9,200	3	$27,600
Roadway Repair	LS	$6,000	1	$6,000
Wingwall Stabilization	EA	$4,000	4	$16,000
Concrete Crack Sealing	LS	$2,000	1	$2,000
			Total	$131,500
			Contingency (40%)	$52,600
			Sub-Total	$184,100
			Survey, Permitting, Design and Engineering (45%)	$82,845
			Total Project Cost	**$267,000**

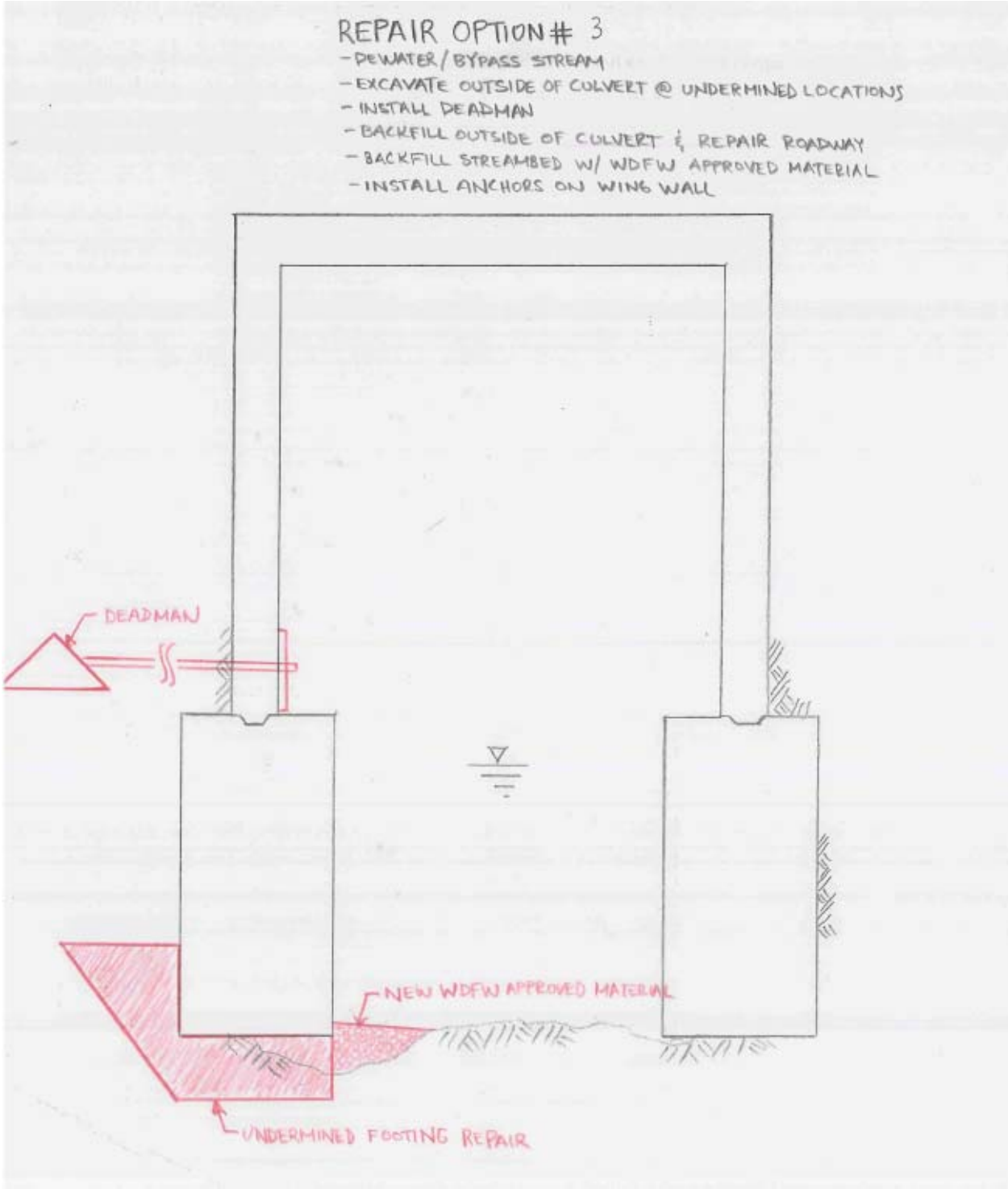


Figure 6. – Repair Option 3

Table 4 provides a summary of the various advantages and disadvantages of each option, along with its associated cost. Repair Option 1 has the lowest cost, while Repair Option 2 is most expensive.

Table 4: Options Comparison		
	Pros	**Cons**
Repair Option 1 Steel Struts	• Quick and reliable • Ease of inspection after repair • Fewer unknown variables • Takes approximately one week • Allows road to remain open	• Requires in-water work and permit • Struts maybe damaged by debris • Struts will be in the water course at high water levels
	Costs	**$135,000**
Repair Option 2 Steel H-pile	• Does not alter flow within culvert • Possibility of avoiding in-water work • Allows road to remain open during non-construction hours	• Pile driving near fish-bearing stream • Labor intensive • Difficult to inspect after completion • Remote possible problems with concrete from drill shaft escaping into creek • Maintenance of Traffic and re-routing required
	Costs	**$279,000**
Repair Option 3 Deadman System	• Does not alter flow within culvert • Allows road to remain open during non-construction hours	• Labor intensive • Requires in-water work and permit • Difficult to inspect after completion • Remote possible problems with concrete from drill shaft escaping into creek • Substantial excavation, but occur entirely within Right-of-Way • Maintenance of Traffic and re-routing required
	Costs	**$267,000**

Recommendation for Culvert Evaluation Approach and Standardization

The use of RTA Culvert Risk Assessment Guideline V3.02 encourages efficiency and uniformity on culvert condition assessments. The procedure reflects conditional probabilities that characterize a chain of events that occur for culvert failure, which can result in a risk to life and economic impact. This system enables systematic identification and assessment of culvert risks, allowing for appropriate prioritization of maintenance, repair and replacement. Also, it gives a consistent and accurate way of reporting and documenting culvert risk. Such information collected will allow SPU to improve its database on existing culverts, and allow for priority assessment of culvert repair and replacement.

While this is an excellent approach, it requires intensive training and documentation to ensure program integrity. Personnel involved must understand the RTA culvert management process; learn how to analyze inventory data, identify asset defects; and how to undertake risk assessments of culverts to derive the Assessed Risk Level. At the same time, it will require additional time in documentation of findings, and an increase in manpower. In addition, RTA analysis method is only for assessment. It does not provide recommendations or action items for the various ARL ratings. Hence, further consideration and discussion should be made before implementing RTA Culvert Assessment on SPU Level III culvert analysis.

OCI recommends that although the full RTA Culvert Risk Assessment Guideline is too complex, it can be used as a baseline to develop a similar but simplified approach to be used and adopted by SPU on Level III culverts analysis. For example, a simpler yet similar documentation process that includes photographs and notes can be used on field assessments. The various probabilities and risk levels can be utilized, but shall be streamlined and tailored for SPU. The streamlined assessment approach shall also include recommendations or actions for each category/rating. For example an ARL 1 rated culvert must be inspected after a specified storm event, and annually after every wet season. In addition, all ARL 1 culverts shall receive priority in repairs and modifications.

References

The following design manuals, technical memorandums and reports were reviewed to develop this report:

Memoranda prepared as part of this project

Discussion of Findings Memo, 2012, CivilTech Engineers. (Appendix C)

Discussion of Structural Repair Options Memo, CivilTech Engineers. (Appendix D)

Repair Options Sketches, CivilTech Engineers. (Appendix E)

Documents prepared by others

RTA Culvert Risk Assessment Guideline v. 3.02, 2010, Roads and Traffic Authority, NSW

Conceptual Design for NE 93rd Street Culvert Replacement, 2010, Pace Engineers, Inc. and Icicle Creek Engineers

Flood Insurance Study for Thornton Creek and its Tributaries; Lake Washington to Interstate 5, 2005, Northwest Hydraulic Consultants

SPU Culvert Detailed Visual Inspection Report, 2012, SPU

NE 93rd St. Culvert Information, 2012, SPU

Appendix A

RTA Risk Assessment Checklist

(CivilTech Engineering)

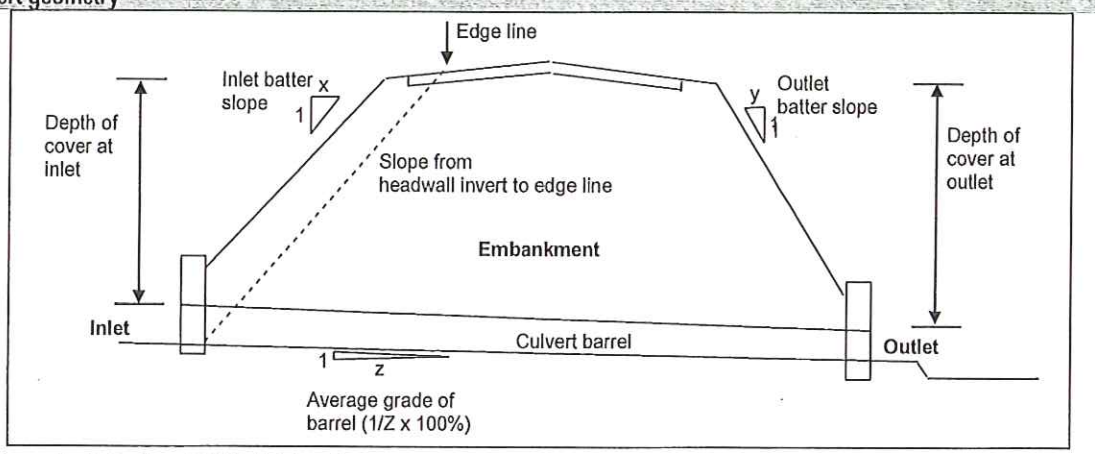
A Identification and Location (from RAMS database)

Culvert Number	THORNTON 01	Date	5/22/12 /	Assessor No	
Local Number		Region Code		Slope Number	
Culvert Comment eg access, location	CULVERT LOCATED ON NE 93RD ST BETWEEN SANDPOINT WAY & 49TH AVE NE, NEAR SW CORNER OF MATTHEWS BEACH WESTERN PARKING LOT. CULVERT FLOWS FROM NW TO SE. ACCESS VIA NE 93RD ST, OVER GUARDRAIL.				

	Latitude	Longitude	Road No (digits only)	C'way Code	Link	Offset along link (km)	Seg No	Seg Offset (km)	Speed limit
Inlet	47°41'45.19"N	122°16'31.61" W	93RD						
Outlet	47°41'44.94"N	122°16'31.10"W	93RD						

	Off-road Latitude	Off-road Longitude	Left or Right of C'way	Marked at roadside
Inlet			O Left O Right	O Yes O No
Outlet			O Left O Right	O Yes O No

B. Culvert geometry



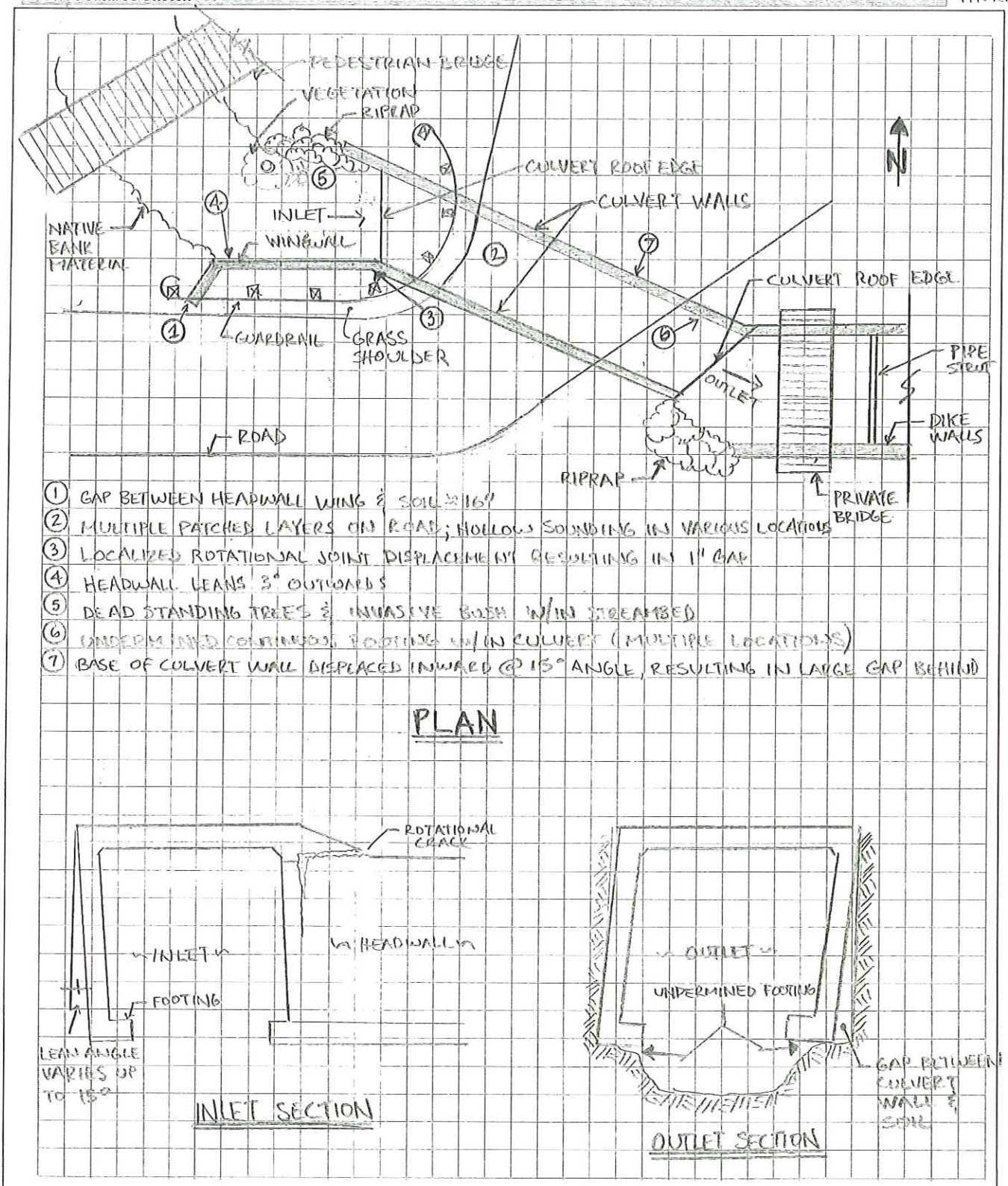
Culvert Geometry Data (from RAMS database)

Culvert length overall metres	Depth of cover at inlet metres	Depth of cover at outlet metres			Depth of Cover	Score	B1
11+/-	.6+/-	.6+/-			> 15m 10-15m 5-10m 3-5m < 3m	20 15 10 5 0	0

No. of pipes or boxes	Length of cell metres	Pipe diameter mm	Box/Cell width mm	Arch width mm	Batter Slope	Score	B2
1	11		2134		≥ 45° ≥ 35° ≥ 25° < 25°	20 15 10 5	5

Culvert Geometry Data (to be measured in field)

Average grade of barrel %	Inlet batter slope 1 in x	Outlet batter slope 1 in y	Slope from invert to edgeline	Culvert flow control	Average Grade of Barrel	B3
2	1:3 18.4°	1:3 18.4°	☐ > 60° ☐ 45° - 60° ☒ < 45°	☐ Inlet control ☒ Outlet control	≥ 25° 20 15-25° 15 10-15° 10 5-10° 5 < 5° 0	0



Notes:

1. Describe failure type and scale, mechanism if possible. Include any secondary failure mechanisms. Include any relevant features eg seepage, cracks, blockage, scour, etc.
2. Include the location of any structural features already in place, monitoring equipment, etc and the likely location of any proposed instrumentation/remedial works
3. Include details and distances of nearby features, eg building, services, slopes, bodies of water, etc. Include any decommissioned culverts or other such structures
4. Detail where possible the type of geology observed on the road embankment and adjacent geology which may affect the road.

D. Culvert barrel adverse conditions

THORNTON OR

Method of Inspection of Culvert Barrel:	
☐	Inspection from ends of culvert (non-entry)
☒	Manned entry inspection
☐	Video inspection

D.1 General condition (deterioration & cracking)			*General Condition*		D1 10
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☒	SIGNIFICANT LATERAL TRANSLATION	Serious	10	
Poor	☐		Poor	5	

D.2 Shape (for flexible culverts only)			*Shape Condition*		D2 0
Imminent Failure	☐		Imminent Failure	20	
Critical	☐	N/A	Critical	15	
Serious	☐		Serious	10	
Poor	☐		Poor	5	

D.3 Seams or Joints			*Seams or Joints Conditions*		D3 0
Imminent Failure	☐		Imminent Failure	20	
Critical	☐	MATERIAL LOSS UNDER ROADWAY, BUT ZERO	Critical	15	
Serious	☐	EVIDENCE OF SEEM OR JOINT FAILURE	Serious	10	
Poor	☐		Poor	5	

E. Inlet/Outlet adverse conditions

E.1 Headwalls			*Headwall Condition*		E1 10
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☒	SEVERE HORIZONTAL & DIAGONAL CRACKS > 6mm	Serious	10	
Poor	☐	SEVERE DIFFERENTIAL OR ROTATIONAL SETTLEMENT	Poor	5	

E.2 Inlet Channel			*Inlet Channel*		E2 5
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☐		Serious	10	
Poor	☒	UNDERMINING OF FOOTING; DEBRIS IN CHANNEL	Poor	5	

E.3 Outlet Scour			*Outlet Scour*		E3 10
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☒	MAJOR SCOUR HAS UNDERMINED FOOTING TO	Serious	10	
Poor	☐	THE POINT OF TILTING WALLS & CRACKING CONC.	Poor	5	

F. Roadway and embankment adverse conditions

F.1 Pavement			*Pavement*		F1 5
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☐	BROKEN PAVEMENT W/SETTLEMENT & MISALIGNMENT,	Serious	10	
Poor	☒	MULTIPLE PATCHES, NEWLY FORME CRACKS ON NEW REPAIR	Poor	5	

F.2 Embankment			*Embankment*		F2 5
Imminent Failure	☐		Imminent Failure	20	
Critical	☐		Critical	15	
Serious	☐	GUARDRAIL SHOWS SIGNS OF SETTLEMENT. LOSS OF	Serious	10	
Poor	☒	SOIL @ W END OF WINGWALL (≈ 16"-20" GAP)	Poor	5	

G. Potentially affected development or features

General Nature of Adjacent Development:			
☒ Residential	☐ Industrial/ Commercial	☐ Open Space	☐ National Park /Wildlife Reserve Drainage/ Water Storage Catchment

Specific Developments/Features	Distance from road (m)
Regularly occupied buildings	
X Domestic/residential	
Commercial/residential	
Educational	
Offices	
Industrial	
Other:	
Normally unoccupied buildings	
Roads	0
Railways	—
Power distribution	20
Water Supply (PUMP STATION)	45
Gas supply	
Telecommunications	20
Open space (PARKING LOT)	20
Other	

Typical Scoring

Development Type	*Score**
- Occupied buildings	*10*
- Unoccupied buildings	*5*
- Other roads	*10*
- Railways	*10*
- Open spaces	*5*
- Services	*5*
- None	*0*

G 20

H. Culvert attribute score	B1	B2	B3	D1	D2	D3	E1	E2	E3	F1	F2	G	Total Score
	0	5	0	10	0	0	10	5	10	5	5	20	70

I. Inspection Notes

Weather Conditions on day of inspection	LIGHT RAIN (.24"), 55° HIGH TEMP, 48° LOW TEMP, OVERCAST, 11 MPH S WIND
Weather Conditions on preceding days	MODERATE RAIN (.55"), 62° HIGH TEMP, 50° LOW TEMP, OVERCAST, 9 MPH S WIND
Ground Conditions (eg acid sulphate, saline soil, high pH, etc)	GROUND CONDITIONS NOT ANALYZED SOIL APPEARS TO BE SILTY SAND TO SANDY SILT
Decommissioned or culverts in vicinity	NONE
Age of culvert (years)	66

J. Recommended preventative maintenance measures

☐ Debris removal	☐ Scour hole repair	*Strategic Estimate*	Est. Cost of Full Repair
☐ Vegetation removal	☐ Stabilise channel	☐ < $50,000	$ 1,000,000
☐ Flush sediment	☒ Stabilise embankment	☐ < $100,000	
☒ Joint sealing/repair		☒ < $200,000	Comment INCLUDES WORK TO INSTALL DEADMAN STRUTS TO STABILIZE DISPLACED BARREL WALLS
☒ Concrete repair (patch cracks, spalls)		☐ < $500,000	
		☐ >$500,000	

K. Possible remedial measures

Inlet/Outlet	*Barrel*	*Strategic Estimate for remedial measures*	Comment
☐ Add wing wall	☐ Invert repair (pave, armour, coat)	☒ < $100,000	INCLUDES WORK TO INSTALL PIPE SKIRTS & BRACES TO STABILIZE DISPLACED BARREL WALLS
☐ Add energy dissipater	☐ Replace a section/cell	☐ < $200,000	
☐ Add debris protection	☐ Culvert barrel lining	☐ < $500,000	
	☐ Replace	☐ <$1,000,000	
		☐ >$1,000,000	

L. Photo and image files

File Name	Caption
SITE (01)	GENERAL SITE CONDITIONS (UPSTREAM)
ROAD (01)	GENERAL ROAD CONDITIONS (LOOKING EAST)
ROAD (02)	ROAD PAVEMENT PATCHES & CRACKS (LOOKING SOUTH)
ROAD (03)	GUARDRAIL LEANING INWARD (LOOKING SOUTHWEST)
WINGWALL (01)	WINGWALL TILTING OUT & LOSS OF SOIL (LOOKING EAST)
WINGWALL (02)	WINGWALL TILTING OUT (LOOKING EAST)
WINGWALL (03)	SOIL LOSS AT WINGWALL (LOOKING WEST)
WINGWALL (04)	WINGWALL & FOOTING (LOOKING SOUTHWEST)
INLET (01)	SETTLEMENT CRACKING (21") @ INLET/WINGWALL (LOOKING SOUTH)
INLET (02)	INLET (LOOKING SOUTH)
INLET (03)	INLET (LOOKING EAST)
OUTLET (01)	OUTLET (LOOKING NORTH)
OUTLET (02)	BULKHEAD STRUT NEAR OUTLET (LOOKING SOUTH)
OUTLET (03)	CRACKING & BUCKLING OF BARREL WALL @ OUTLET (LOOKING EAST)
OUTLET (04)	LATERAL DISPLACEMENT OF BARREL WALL @ OUTLET (LOOKING EAST)
OUTLET (05)	SOIL LOSS BEHIND BARREL WALL @ OUTLET (LOOKING NORTH)

Notes for data entry Some fields can be filled in at the office before taking the form into the field.

A. Identification	• Enter the date of assessment and your assessor number • If any location data already entered is wrong, please correct it. Add any missing data. • Please write the culvert number at the top of all pages, in case they get separated.
B. Geometry	• If any location data already entered is wrong, please correct it. Add any missing data.
C. Site features sketch	• Complete the sketch on site. If required, draw separate additional sketches of specific features. • Indicate the points where photographs were taken.
D. Culvert Barrel Features	• Tick the appropriate items and write the scores.
E. Inlet Outlet Features	• Tick the appropriate items and write the scores.
F. Roadway and Embankment	• Tick the appropriate items and write the scores.
G Potentially affected devel.	• Tick the appropriate items and write the scores. Write distances from the culvert.
H Culvert Attribute Score	• Transcribe the previous scores and calculate the total score
I Inspection notes	• Enter brief notes as appropriate • Enter actual or estimated age of culvert structure
J Preventative maintenance	• Tick appropriate measures • Enter comment if other measures are suitable
K Remedial measures	• Tick appropriate measures • Enter comment if other measures are suitable
L. Photos and images	• List filenames and descritive captions.
M. Risk analysis	• Determine which hazards are present. For those that apply: o Calculate likelihoods (see *Guideline*) o Calculate temporal probability, vulnerability and consequence for life(see *Guideline*) o Calculate economic consequence(see *Guideline*) o Determine Assessed Risk Level rating(see *Guideline*)

M. Risk Analysis

Hazard/Failure Mechanism	SC-1	SI-1	SI-2	SI-3	SI-4	PI-1	PI-2	PI-3	HF-1	HF-2
Hazard Type	Structural Collapse	Slope Instability Afflux	Slope Instability Leakage Out of Barrel	Slope Instability Headwall Collapse	Slope Instability Under-mining	Piping Into Culvert	Piping Outside of Culvert due to Afflux	Piping Outside of Culvert due to Leaks out of Culvert	Hydraulic Flow Erosion by Over-topping Flows	Hydraulic Flow Cross Catch-ment Flooding
Likelihood Ratings										
Likelihood Factor 1	0.2	0.04	0	0	0.8	0	0	0	0.04	0.04
Likelihood Factor 2	0.9	0.10	0	0	0.5	0	0	0	0.01	0.1
Likelihood Factor 3		.20					0	0	0.01	0.05
Final Likelihood	.18	.02	0	0	.40	0	0	0	.004	0
Likelihood Rating (L1 - L6)	L2	L3	L6	L6	L2	L6	L6	L6	L3	L4
Consequence Class Ratings *										
Temporal Probability (T1 - T5)	PERSONS MAY SOMETIMES BE PRESENT AS PART OF THE NORMAL PATTERN OF USAGE. ROAD USERS ON MANY URBAN ARTERIAL ROADS & MOST MAJOR RURAL ARTERIAL ROADS									T3
Vulnerability (V1 - V5)	MOST PEOPLE ABLE TO EVADE DEBRIS (PEOPLE IN THE OPEN) BUILDING PENETRATED, NO COLLAPSE (PEOPLE IN BUILDINGS) LOST INTO A DEEP, NARROW VOID (VEHICLES CROSSING AREA)									V2
Consequence Class for Loss of Life (C1 - C5)	NO ADJUSTMENTS TO CONSEQUENCE RATING IS NECESSARY.									C2
Consequence Class for property damage (C1 - C5)	MODERATE INFRASTRUCTURE OR PROPERTY DAMAGE MODERATE DISRUPTION COSTS MODERATE REPAIR COSTS TOTAL DIRECT & INDIRECT COSTS $.5M - 2M									C3

* In general T, V and C ratings will be the same for all hazards, except for HF-2 which will have a different zone of influence (ie across other catchments) and different elements at risk.

Risk Analysis Ratings										
Assessed Risk Level (ARL1 - ARL5)	ARL 1	ARL 2	ARL 5	ARL 5	ARL 1	ARL 5	ARL 5	ARL 5	ARL 2	ARL 3

Need for further investigation? (Y/N)	☒ Yes ○ No	

Comments: RECCOMEND CULVERT INSPECTION @ 1 YEAR INTERVALS UNLESS STRUCTURAL MODIFICATIONS OR OTHER REPAIR WORK PERFORMED.

Appendix B

Photograph Log

(CivilTech Engineering)

CIVILTECH engineering

400 112th Ave NE
Suite 120
Bellevue, WA 98004

T: 425.453.6488
F: 425.453.5848

Site (01) – General site conditions (upstream)

Road (01) – General road conditions (looking east)

Road (02) – Road pavement patches & cracks (looking south)

Road (03) – Guardrail leaning inward (looking southwest)

Wingwall (01) – Wingwall tilting out and loss of soil (looking east)

Wingwall (02) – Wingwall tilting out (looking east)

Wingwall (03) – Soil loss at wingwall (looking west)

Wingwall (04) – Wingwall & footing (looking southwest)

Inlet (01) – Settlement cracking (~1”) @ inlet / wingwall (looking south)

Inlet (02) – Inlet (looking south)

Inlet (03) – Inlet (looking east)

Outlet (01) – Outlet (looking north)

Outlet (02) – Bulkhead strut near outlet (looking south)

Outlet (03) – Cracking & buckling of barrel wall @ outlet (looking east)

Outlet (04) – Lateral displacement of barrel wall @ outlet (looking east)

Outlet (05) – Soil loss behind barrel wall @ outlet (looking north)

Appendix C

Discussion of Findings Memo

(CivilTech Engineering)

Memo

To: Tarelle Osborn, PE

Cc: Dustin Ong, SE

From: Mike Helminger, PE

Date: May 31, 2012

RE: NE 93rd St Culvert Assessment

Technical Review Summary Memo

BACKGROUND

The objective of the project is to evaluate the condition of the box culvert on NE 93rd Street off of Sandpoint Way in Seattle and determine if the box culvert can be repaired or needs to be replaced due to its current structural integrity. The methodology used will generally follow the RTA Culvert Risk Assessment Guideline (version 3.02) as provided by the City of Seattle (City).

During City's risk screening process, this culvert was one of the top 10 culverts of concern. The culvert has visible signs of structural failure. The potential consequences have been estimated, but the likelihood of failure and need for repair vs. replacement has not been analyzed. The assumption is that the culvert can pass the 20 to 25-year flood event.

SITE INSPECTION

CivilTech Engineering (CTE), along with Tarelle Osborn (Osborn Consulting) and Wan-Yee (City), performed a site inspection on May 22, 2012. The weather at the time of inspection was overcast with light rain. The day prior to inspection experienced seasonally heavy rains, setting a record for that date of 0.55" precipitation. The flow in the culvert was approximately level with the top of the footing.

Site photographs were taken and the condition of the culvert was assessed using guidelines presented in the RTA Culvert Risk Assessment Guideline V3.02.

FINDINGS

Refer to the Site Features Sketch found in the RTA Culvert Risk Assessment form for the approximate configuration of the culvert, wingwall, and other site features.

Wingwall

A concrete wingwall runs in the east-west direction, leading to the inlet of the concrete culvert. The wingwall was observed to have a 3-degree outward lean. Evidence of soil loss at the western end of the wingwall was also noted as there was approximately a 16-inch gap between the existing soil and the cast-in-place edge of the wingwall. At the transition between wingwall and culvert, a crack, up to 1-inch, extends first horizontally and then vertically. Comparison between photos taken during the site inspection of May 22, 2012, and those previously taken in 2007 by others, indicate little change in the size or location of this crack. The overall structural condition of the wingwall, aside from the large crack at the transition, appears to be in satisfactory condition for a structure of this age.

Inlet

At the northern corner of the channel, where the culvert inlet begins, riprap lines the bank as it transitions into an extension wall from the culvert. Several dead trees, surrounded by a leafy, vine plant, are located within the stream at this corner. Both inlet walls exhibit a lean to the east up to 15 degrees. The footings at the inlet wall show signs of undermining.

Barrel

The overall structural condition of the barrel appears to be in satisfactory condition for a structure of this age. Footings along the length of the barrel show signs of undermining to various degrees. The base of the barrel is an open rock and gravel surface.

Outlet

Both outlet walls exhibit a lean to the east up to 15 degrees. The footings at the outlet wall show signs of undermining. One section of footing appears to have fractured off. The eastern wall exhibits signs of buckling as well as soil backfill loss. It also shows signs of exposed rebar, minor concrete spalling, and general deterioration. The outlet is surrounded by leafy vine plants that extend from the top of the culvert, down into the water and along the side walls. A large tree is located approximately 15-feet to the east.

Bulkhead Walls

Downstream of the culvert are bulkhead walls of similar character and age as the culvert. The width of the channel is slightly wider than that of the culvert. Steel pipe struts periodically support the walls at approximately mid-height.

CONCLUSIONS

Undermining of the footings along the length of the culvert, and predominantly at the outlet and inlet locations, and predominantly on the eastern side of the culvert, appears to be the root cause of the structural damage and shifting of the culvert walls. Structural repairs may be possible to extend the life of the culvert. Refer to the attached PDF for sketches of proposed structural repairs. Refer to the RTA Culvert Risk Assessment form for Assessed Risk Levels for the various Hazard/Failure Mechanisms.

Appendix D

Discussion of Structural Repair Options Memo

Memo

To: Tarelle Osborn, PE

Cc: Dustin Ong, SE

From: Mike Helminger, PE

Date: May 31, 2012

RE: NE 93rd St Culvert Assessment

Structural Repair Options Memo

BACKGROUND

Several structural repair options are available to possibly extend the life of the culvert. This memo will discuss the options and examine pros and cons of each option. The basic premise of the repairs is to stabilize the footings from settling any further and provide support to the culvert walls to prevent them from kicking inward. Quantity and locations of structural repair members are not discussed in this memo as repairs are presently at concept level.

REPAIR OPTION 1

This option would require the diversion of Thornton Creek to perform in-water work.

After the creek is diverted, cast-in-place concrete would be added underneath the existing footings in all undermined areas. Steel pipe struts would be field cut for a snug-tight fit between the side walls, welded to steel plates, and bolted to the walls.

Pros: Reliable; quick; easy to inspect following completion of repair work; less unknown variables
Cons: Costly to divert creek; requires in-water work; struts may be damaged by debris and will be in the watercourse at medium-to-high water levels

Rough cost estimate: $116,000

REPAIR OPTION 2

This option would not require the diversion of Thornton Creek to perform in-water work.

Steel H-pile soldier piles would be installed on the east side of the east culvert wall. Shafts would be drilled for the upper portion of the pile to allow installation of thru-bolts which will pass through the concrete side wall of the culvert. The shaft will then be backfilled with concrete and the H-pile will serve as a footing replacement and prevent further settlement and walls from kicking in along the east side of the culvert.

Pros: No in-water work required; does not alter flow within culvert
Cons: Pile driving near fish-bearing stream; labor intensive; difficult to inspect after completion; possible problems with concrete escaping drilled shaft into creek

Rough cost estimate: $240,000

REPAIR OPTION 3

This option would not require the diversion of Thornton Creek to perform in-water work.

Plastic sheathing would be installed along the edge of footings and covered with sandbags. Excavation from the outside of the culvert to just beneath the existing footing until reaching near the plastic sheathing would occur. Next, cast-in-place concrete would be poured into the excavated areas. Deadmen would be installed at a length sufficient to provide restraint to the culvert walls.

Pros: No in-water work required; does not alter flow within culvert
Cons: Labor intensive; difficult to inspect after completion; possible problems with concrete escaping into creek; substantial excavation into nearby property/roadway

Rough cost estimate: $229,000

Appendix E

Repair Options Sketches

(CivilTech Engineering)

CIVILTECH engineering

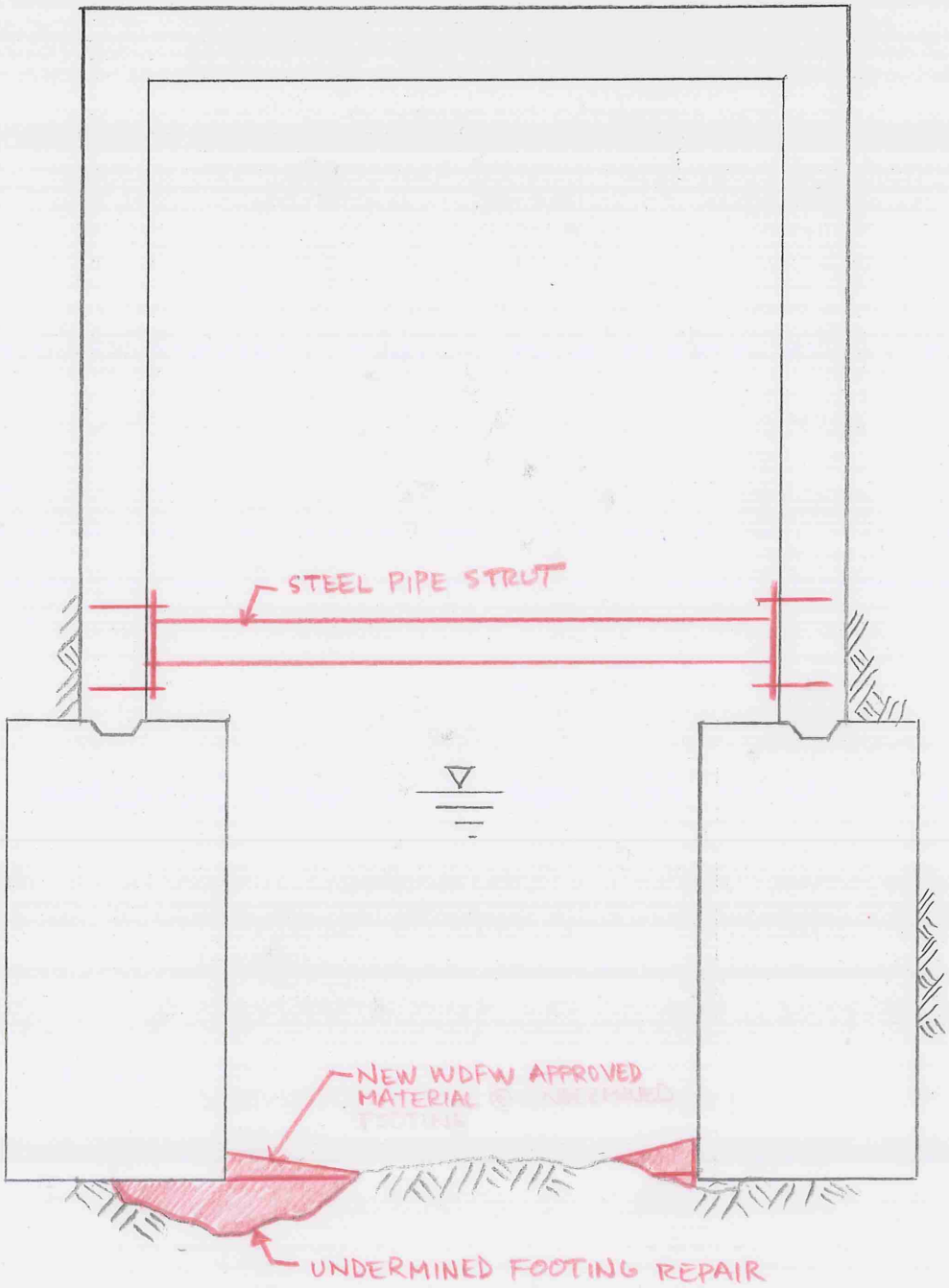
PROJECT NO. _____ SHEET NO. _____

PROJECT _____ COMPUTED BY _____ DATE _____

SUBJECT _____ CHECKED BY _____ DATE _____

REPAIR OPTION # 1

- DEWATER / BYPASS STREAM
- INSTALL STRUTS
- REPAIR CONCRETE FOOTING UNDERMINING
- PLACE WDFW APPROVED MATERIAL
- INSTALL ANCHORS ON WING WALL



CIVILTECH engineering

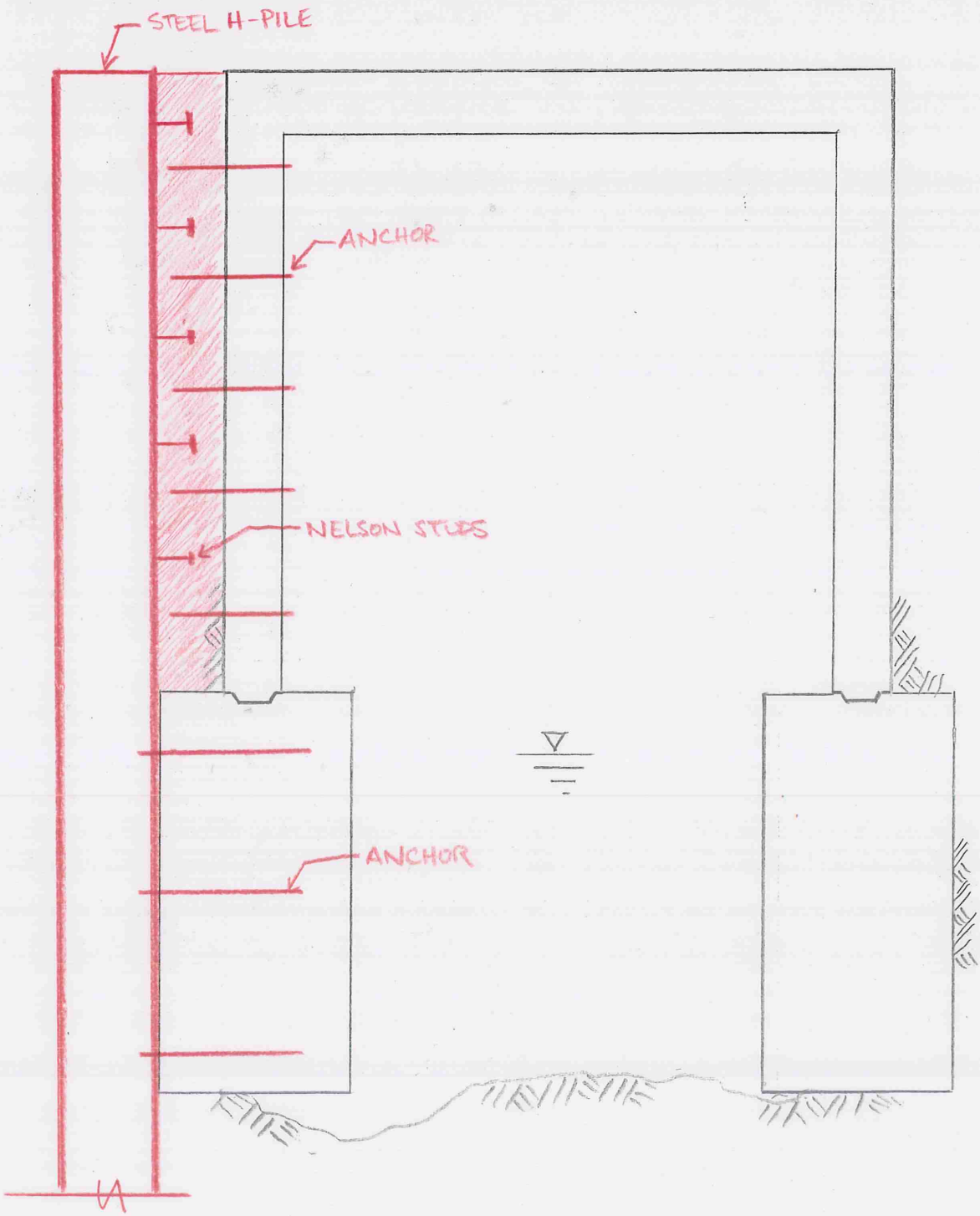
PROJECT NO. _____ SHEET NO. _____

PROJECT _____ COMPUTED BY _____ DATE _____

SUBJECT _____ CHECKED BY _____ DATE _____

REPAIR OPTION # 2

- INSTALL H-PILE & ANCHOR TO CULVERT
- INSTALL ANCHORS ON WING WALL



CIVILTECH engineering

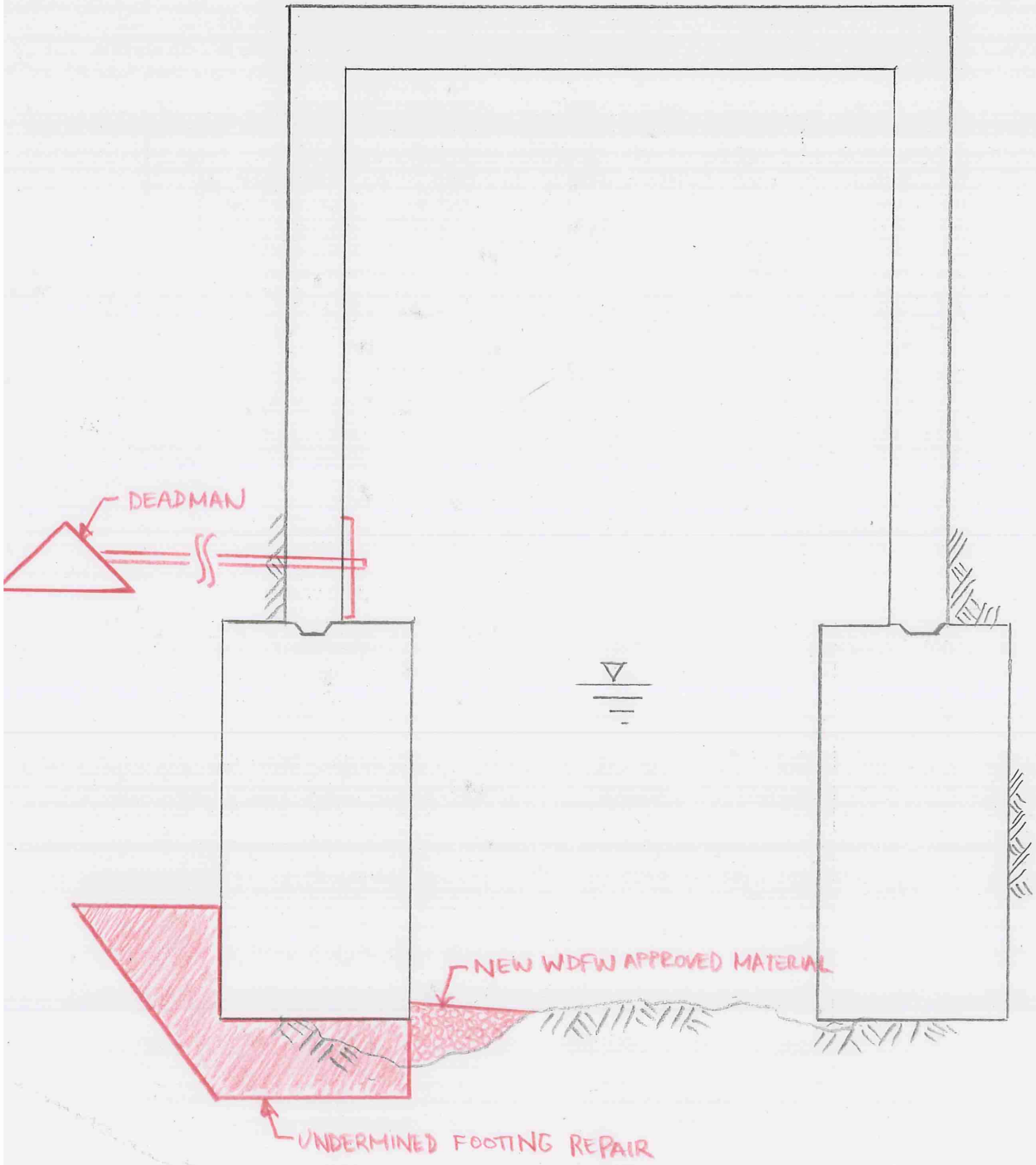
PROJECT NO. _____ SHEET NO. _____

PROJECT _____ COMPUTED BY _____ DATE _____

SUBJECT _____ CHECKED BY _____ DATE _____

REPAIR OPTION # 3

- DEWATER / BYPASS STREAM
- EXCAVATE OUTSIDE OF CULVERT @ UNDERMINED LOCATIONS
- INSTALL DEADMAN
- BACKFILL OUTSIDE OF CULVERT & REPAIR ROADWAY
- BACKFILL STREAMBED W/ WDFW APPROVED MATERIAL
- INSTALL ANCHORS ON WING WALL



Appendix F

Conceptual Cost Estimates

(CivilTech Engineering)

Option 1 - Steel Struts

Item	Quantity	Unit	Unit Cost	Cost
1. Mobilization (15%)	1	LS	15%	$ 9,000
2. Stream Bypass	1	LS	$ 20,000	$ 20,000
3. Galvanized Steel Pipe Strut - Furnish	4	EA	$ 600	$ 2,400
4. Galvanized Steel Pipe Strut - Install	4	EA	$ 2,000	$ 8,000
5. Concrete - Furnish	1	LS	$ 1,400	$ 1,400
6. Concrete - Install	1	LS	$ 7,500	$ 7,500
7. Wingwall Soilnail Tieback - Furnish	4	EA	$ 500	$ 2,000
8. Wingwall Soilnail Tieback - Install	4	EA	$ 3,500	$ 14,000
9. Concrete Crack Sealing	1	LS	$ 2,000	$ 2,000
			Total	$ 66,300
			Contingency (40%)	$26,520
			Sub-Total	$92,820
			Survey, Permitting, Design and Engineering (45%)	$41,769
			Total Project Cost	**$134,589**

Option 2 - H-Pile

Item	Quantity	Unit	Unit Cost	Cost
1. Mobilization (30%)	1	LS	30%	$ 30,000
2. Steel H-Pile - Furnish	5	EA	$ 2,000	$ 10,000
3. Steel H-Pile - Install	5	EA	$ 5,000	$ 25,000
4. Thru-bolt Anchors - Furnish	5	EA	$ 100	$ 500
5. Thru-bolt Anchors - Install	5	EA	$ 8,000	$ 40,000
6. Excavation for Thru-bolt Anchors - Install	1	LS	$ 10,000	$ 10,000
7. Roadway Repair	1	LS	$ 4,000	$ 4,000
8. Wingwall Soilnail Tieback - Furnish	4	EA	$ 500	$ 2,000
9. Wingwall Soilnail Tieback - Install	4	EA	$ 3,500	$ 14,000
10. Concrete Crack Sealing	1	LS	$ 2,000	$ 2,000
			Total	$ 137,500
			Contingency (40%)	$55,000
			Sub-Total	$192,500
			Survey, Permitting, Design and Engineering (45%)	$86,625
			Total Project Cost	**$279,125**

Option 3 - Deadman System

Item	Quantity	Unit	Unit Cost	Cost
1. Mobilization (30%)	1	LS	30%	$ 26,000
2. Stream Bypass	1	LS	$ 20,000	$ 20,000
3. Excavation for Concrete	1	LS	$ 25,000	$ 25,000
4. Concrete - Furnish	1	LS	$ 1,400	$ 1,400
5. Concrete - Install	1	LS	$ 7,500	$ 7,500
6. Deadman - Furnish	3	EA	$ 3,200	$ 9,600
7. Deadman - Install	3	EA	$ 6,000	$ 18,000
8. Roadway Repair	1	LS	$ 6,000	$ 6,000
9. Wingwall Soilnail Tieback - Furnish	4	EA	$ 500	$ 2,000
10. Wingwall Soilnail Tieback - Install	4	EA	$ 3,500	$ 14,000
11. Concrete Crack Sealing	1	LS	$ 2,000	$ 2,000
			Total	$ 131,500
			Contingency (40%)	$52,600
			Sub-Total	$184,100
			Survey, Permitting, Design and Engineering (45%)	$82,845
			Total Project Cost	**$266,945**