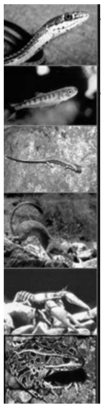


Stream Simulation Design Process

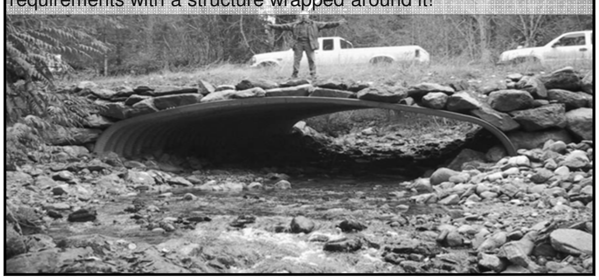
Assessment
Stream simulation feasibility
↓
Project alignment and profile
↓
Verify reference reach
↓
Bed shape and material
↓
Structure width, elevation, details
↓
Mobility / stability
↓
Design profile control →

- Profile range
- Sustainability
- Floodplain function, connectivity
- Safety factor

7. Structure Selection and Design Considerations

Kim Johansen – Siuslaw NF (Retired)
Bob Gubernick - Region 9 TST

As big as your reference reach channel plus stable banks and / or roughness elements, capable of handling the vertical changes, hydraulic capacity, debris, and floodplain conveyance requirements with a structure wrapped around it!



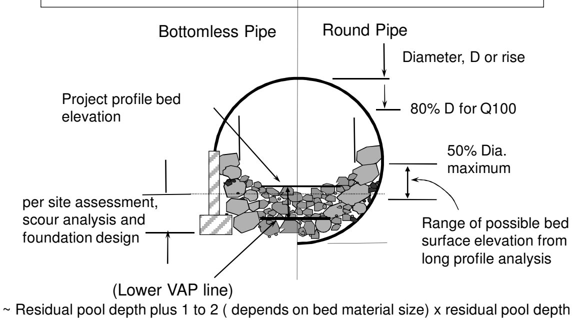
Culvert Size & Type Factors
1. Based on Project Objectives:

- ✓ Bankfull width minimum
- ✓ Hydraulic capacity for the Q100 plus debris
- ✓ Bed design self-sustainable with key piece (banks / steps/ etc. stable
- ✓ Minimize maintenance needs
- ✓ Passage of non-aquatic species
- ✓ Maintain floodplain processes

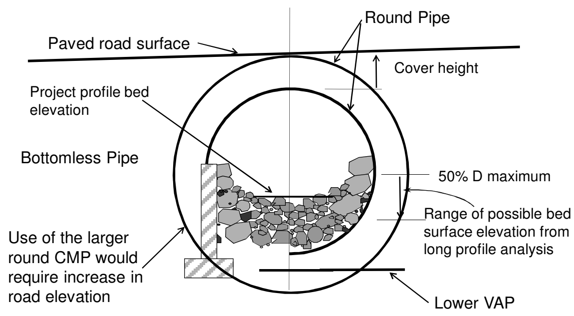
Culvert Size & Type Factors
2. Based on Site Conditions and Engineering Constraints:

- ✓ Channel to structure geometery is skewed
- ✓ Ice plugging in severe cold climate
- ✓ Large bed material diameter relative to culvert width
- ✓ High water level stage during floods or high tides.
- ✓ Soft foundations or shallow bedrock
- ✓ Approximate crossing structure dimensions and invert elevation
- ✓ Limited clearances due to pavement
- ✓ High conveyance across flood plain
- ✓ Utilities

Culvert Size and Elevations



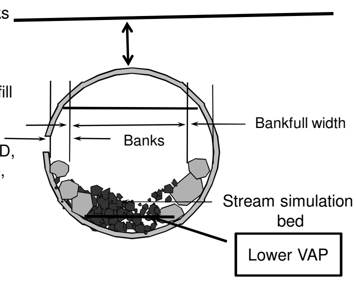
Depth of scour, proximity to bedrock, and feasibility of dewatering may determine the size and shape of the structure



Stream Simulation - gentle gradient First estimate of culvert width

Procedure:

1. Select a pipe type and size and fit pipe over cross section and banks
2. Check lower VAP requirements and bedrock issues
3. Check cover and max fill requirements
4. If OK proceed to final design and check HW/D, flood plain conveyance, and width against final key piece sizes and sediment mobility/stability . If not try another shape and size



Wildlife Passage at Road Crossings

Openness Ratio

The characteristic of a passage structure related to the ability of an animal to see through the structure and not feel confined while within the structure. The Openness Ratio is calculated as

For structures less than 100ft use 3.28*(height X width) /length > 1

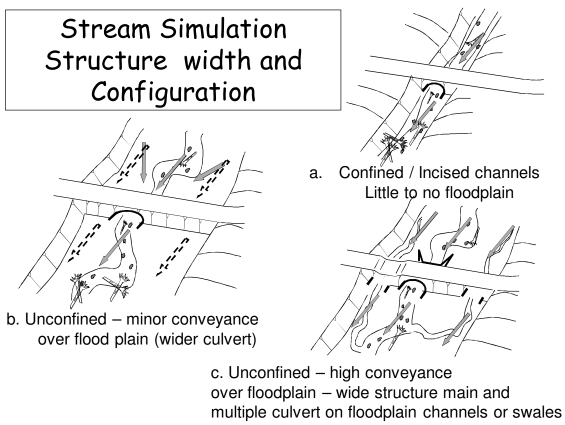
For longer structures contact Sandra Jacobson

Goat underpass

Wolf underpass

Elk Overpass

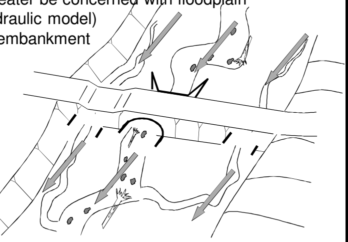
Stream Simulation Structure width and Configuration



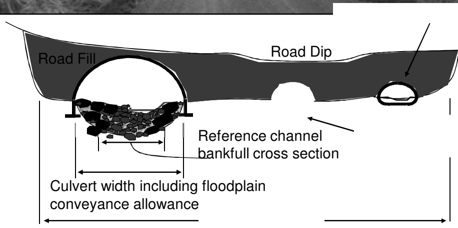
Unconfined channel - Requirements

- Hydraulic analysis to determine floodplain conveyance (high or low) Use common sense depending on site conditions and risk as to the level of analysis required
- Check mobility / stability against the reference reach main channel only!
- Add floodplain culverts in streams with high floodplain conveyance or with defined channels on floodplains (Rule of thumb is: when entrenchment ratio is 2 or greater be concerned with floodplain conveyance confirm with hydraulic model)
- Add road dips and armor embankment
- If channel is backwatered during high water, HW/D clearance may be an issue

!!!!GO TO THE SITE DURING FLOODING TO SEE CONVEYANCE ON THE FLOODPLAIN!!!!!

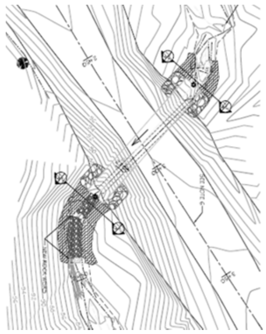


Design for sustainability, and maintenance of critical geomorphic processes based on the project objectives

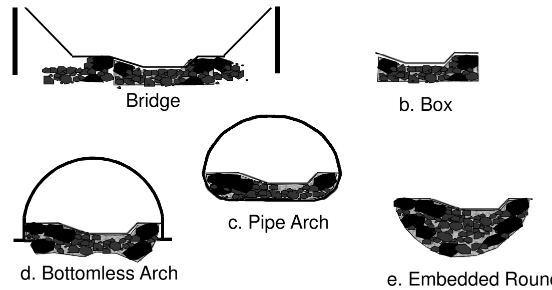


Structure Selection Considerations

- Fit
  - Around the constructed channel, banks, VAP, clearances (hyd. cap. + debris)
  - Site geometry
- Cost
  - Durability
  - Risk
- Construction complexity considerations
  - Traffic, ROW, Contractors
- Access
- Short-term impacts

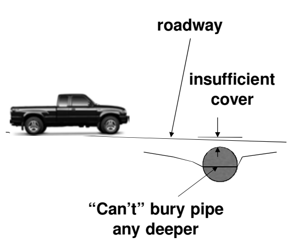


The same stream simulation can usually be constructed in any type of structure given enough embankment height;
Adequate embedment depth and constructability can be limitations.



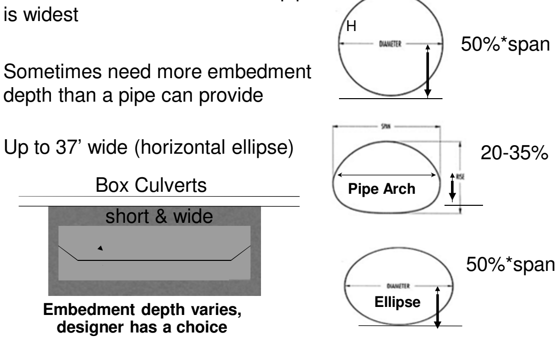
Structure Type and Cover Height

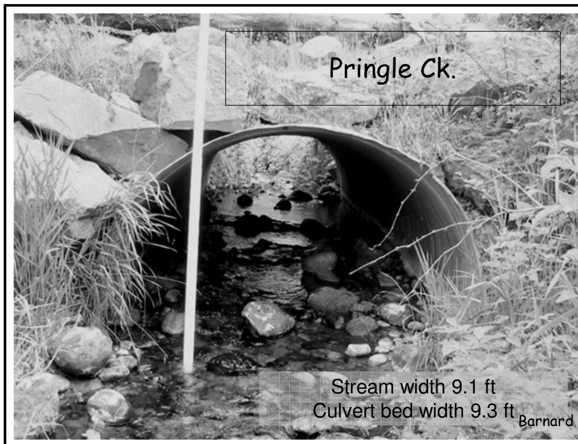
- Structure shapes are available to fit almost any site condition
- Each type has min & max fill heights limitations
- Some can be embedded deeper than others
- A low embankment height limits your options



Pipes

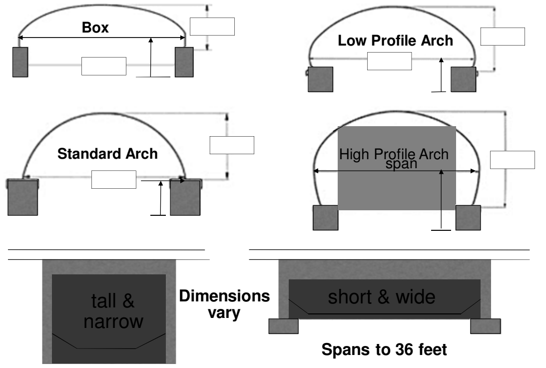
- Maximum embedment = where pipe is widest
- Sometimes need more embedment depth than a pipe can provide
- Up to 37' wide (horizontal ellipse)



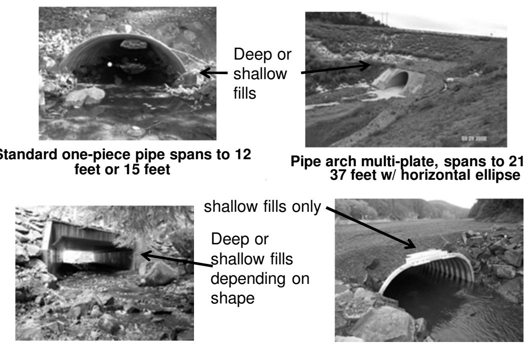


Arches

(embedment depth = footing depth +/- design bed elevation)



Structure Types--Examples



Standard one-piece pipe spans to 12 feet or 15 feet

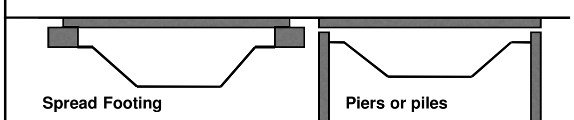
Pipe arch multi-plate, spans to 21 feet. 37 feet w/ horizontal ellipse

Concrete arch/bridge", spans to 36 feet, more for arched shapes

Box culvert multi-plate with metal footings, spans up to 40 feet

Bridges

- Foundation can sit on soil or rock foundations and usually consist of:
  - driven piles: good for soft soils, any soil, or when driven or bored and grouted into bedrock
  - piers – usually drilled to bedrock or founded to firm ground
  - retaining walls – shorten bridge but may cost more overall
  - spread footings – economical where channel is stable and soils can handle the load.



Bridge Structures

Pre-stressed concrete, pile foundation on bedrock is durable, economical

Wood: Glue laminated, trusses, sawn timber, logs, treated & untreated, economical

Steel: Permanent or temporary, some modular, painted or weathered steel for durability

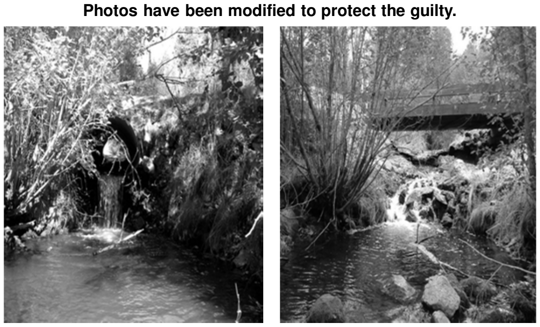
Not necessarily better just because it's a bridge.

Heavy Steel Modular Bridges can take failure and abuse from fires and debris flows. They can be reinstalled and still function proper with little to no repair.

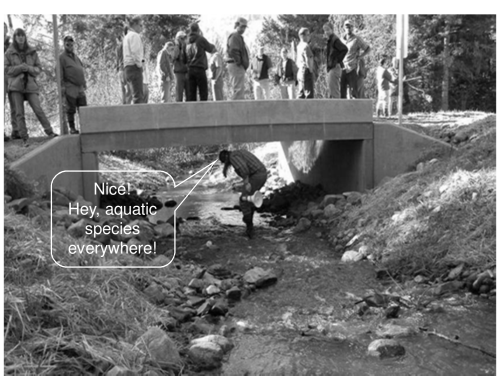
Modular Bridge Example - Townsend Brook Road, Pittsfield, VT

Bridges are beautiful, but don't forget about stream channel restoration

Photos have been modified to protect the guilty.



One year later, after head cut occurred, foundations are @ risk, riprap is undermined and unstable, footing has settled and rotated ~ failed.



Greater than bankfull

Geometry & Fit Considerations
You must address these questions!

- Can the road grade can be raised to improve structure fit?
- Can road alignment be varied for better structure to stream fit?
- Can a roadway dip be installed in debris prone areas?
- What is the proximity to bedrock in the bed and banks
- Are there any depth limitations due to utilities?

Structure shape versus channel shape
Embankment height above thalweg = BFW (12')

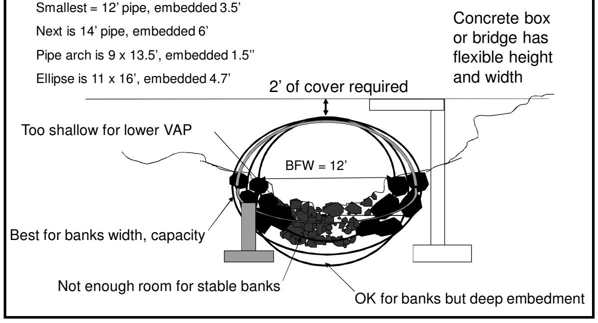
Example of fit solutions:

Smallest = 12' pipe, embedded 3.5'

Next is 14' pipe, embedded 6'

Pipe arch is 9 x 13.5', embedded 1.5''

Ellipse is 11 x 16', embedded 4.7'

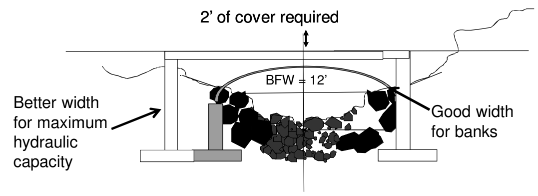


Structure shape versus channel shape
Embankment height above thalweg = 6'

Example of fit solutions:

Low Profile Arch, 16' wide, expensive due to shape and required thickness, Low hydraulic capacity.

Concrete box 16' wide or 24' valley spanning, or similar thin structural bridge deck gives the most hydraulic capacity and may be comparable in cost to low profile arch.



Example of structure type hydraulic differences,

4% gradient 12' bank full width, 2' bank full height, Q2=12-cfs, Q100=300cfs
(shifts are more dramatic at lower gradients)

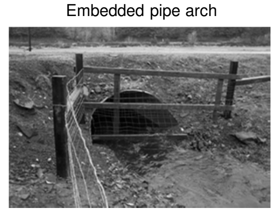
STRUCTURE SHAPE	DIMENSIONS	Q2 INLET DEPTH	Q100 INLET DEPTH
Rectangular Concrete box	12' wide x 6' high	2.2'	4.1'
1/2 round arch or embedded pipe	12' wide x 6' high	2.6'	5.1'
Low profile arch	12' wide x 4'-1/2" high	2.8'	6.7'

INLET DEPTH IS A FUNCTION OF AVAILABLE CROSS SECTIONAL AREA

High and Low Profile Structures

Low fill = low profile structure = ($)

Embedded pipe arch



Aluminum box with aluminum footings

Avoid multiple pipes across a channel for a number of reasons: debris catching, changes in depth, sediment accumulation in one of the structures, reduction in hydraulic capacity

Relative Costs

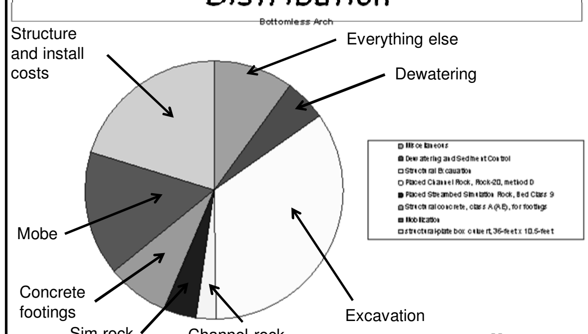
Culverts and Arches can cost much less than bridges on sites with tight horizontally or vertically curved roads.

The need for a guardrail raises the cost of a culvert 5-15k, while they are frequently a normal part of bridge construction costs.

- width < 15 feet
  - enclosed culverts & concrete box
  - bottomless arch
  - bridge
- widths 15-30 feet
  - site conditions determine suitability and actual cost
- widths >30 feet
  - bridges

Increasing cost ↓

Open Bottom Arch Cost Distribution



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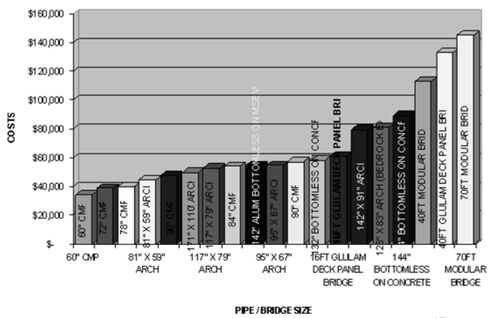
AVERAGE COST
TONGASS N.F.
2003



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Average Construction Costs
Green Mountain National Forest

Modular Bridge:
Avg. Structure Cost (incl. Abutments): $1,200/ft
Placement (incl. removal of existing): $28,000

Open Bottom Arch:
10' Span: $90,000
15' Span: $112,000
16' Span: $130,000
20' Span: $236,000
22' Span: $245,000

Changing from 12' open bottom arch to 18' OBA, 20' high road embankment, 80 feet long.

Foundation Fill	$4,000	+2,000
Structural Excavation	$24,240	+4,440
Constructed Steps (2 inside pipe)	$1,280	+480
Stream Simulation Rock	$8,775	+4,350
"Filler Material"	$400	+200
Aggregate Surfacing	$1,480	+80
Concrete Footings	$22,500	+5,000
Reinforcing Steel	$2,200	+43
Mobilization	$9,794	+3,728
Open Btm Multi-plate Pipe 12', 18'	$33,060	+15,040
TOTAL CONTRACT	$107,729	+$35,361

50% width increase ~ 33% cost increase

Changing from 8' open bottom arch to 12' OBA, 20' high road embankment, 80 ft long.

Foundation Fill	$2,650	+1,350
Structural Excavation	$22,960	+2,960
Constructed Steps (2 inside pipe)	$1,280	+480
Stream Simulation Rock	$5,070	+1,300
"Filler Material"	$400	+100
Aggregate Surfacing	$1,480	+80
Mobilization	$7,350	+2,060
One-piece Round GALV Embedded Pipe	$15,200	+7,000
TOTAL CONTRACT	$56,390	+15,330

50% width increase ~ 27% cost increase

Durability

- Abrasion – Physical reaction
  - from sediment transport: rate, size, shape of particles
  - removes culvert surface protection, reduced thickness
- Corrosion – Chemical reaction
  - embedded pipe or pipe arch
  - rate increases after surface is abraded
  - rate: pH & resistivity
  - check for unusual corrosion rate at existing culvert
- Concrete Deterioration – can be a problem if mix quality is poor or If salts are used on the road, concrete deck will see shorter life spans

Durability - Abrasion

Abrasion rate depends on
- Sediment
  - size
  - density~ strength
  - shape (sharpness)
  - transport rate
- Flow characteristics

Material Abrasion Resistance (high → low)
- **Concrete**
  - **quality important**
  - **resistant to abrasion**
- **Aluminum culverts**
  - **more vulnerable to sand**
- **Aluminized-steel culverts**
  - **more vulnerable to cobble**
- **Galvanized steel culverts**
  - **more vulnerable to cobble**

Durability – Corrosion Resistance

- pre-stressed concrete
- reinforced concrete bridges and culverts
- weathering steel or painted bridges
- aluminum culverts
- aluminized steel culverts (no multi-plates)
- galvanized steel culverts
- treated timber bridges (varies with treatment)
- untreated timber or log bridges

Most resistant → **Least resistant**

"Normal" Corrosion & Abrasion in a Galvanized Steel Culvert

Abnormal Corrosion Galvanized Steel backfill/groundwater properties

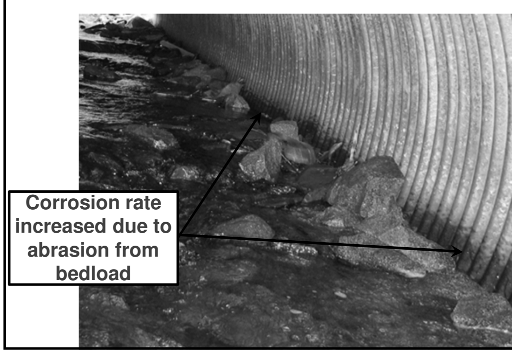
Oregon Department of Transportation Hydraulics Volume 1.
Table 6.1 PIPE MATERIAL SERVICE LIFE

Culverts, Storm Sewers, Under Drains
Average Years to Maintenance, Repair or Replacement
Due to Abrasion & Corrosion

Material	Location East or West of Cascades	Water & Soil pH	Soil Resistivity (ohm-cm)	Service Life
Galvanized Steel	East	4.5 – 6.0	1500-2000	30
	East	>6 – 7	1500-2000	35
	East	>7 – 10	1500-2000	40
Galvanized Steel	West	4.5 – 6.0	1500-2000	15
	West	>6 – 7	1500-2000	20
	West	>7 – 10	1500-2000	25
Aluminum	East or West	4.5 - 10	>1500	75
Aluminized Steel	East	5 – 9	>1500	65
	West	5 - 9	>1500	50
Concrete	All Locations	4.5 – 10	>1500	75+
Polyethylene	All Locations	4.5 – 10	>1500	75

Soil Resistivity measures changes in conductivity by passing electrical current through ground soils. **The higher the resistivity the less corrosive the soil**

Another good reason for full length and height banks!

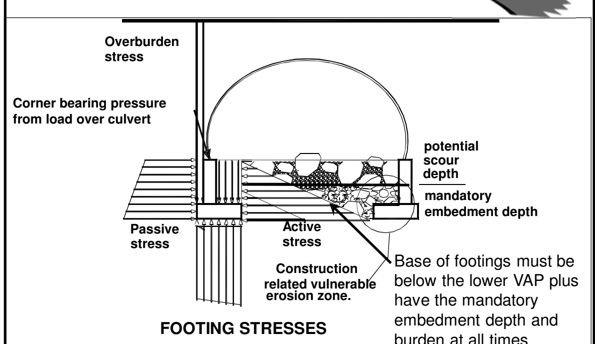


Know your traffic needs!

Bypass roads – adding later may require structure modification, $$$ So Plan Ahead, NEPA, fire access, recreation

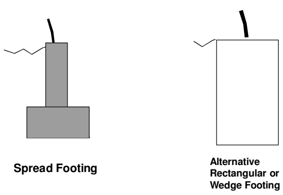
- By pass roads are most suitable for Forest roads or Country roads where land is available for temporary construction & public traffic use.
- Highway designs often require 24/7 traffic.
- No bypass road but maintaining traffic usually requires staged construction with a longer structure and possibly the use of temp retaining wall to separate construction elevation from traffic elevation.

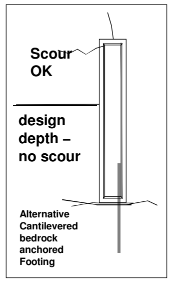
Foundation Design



Footing Shapes for Open Bottom Arches (OBA)

- To remain stable, OBA footings require burial to a specific depth. Thus, scour below this depth may cause foundation failure.
- Footing shape dependent on bearing material.

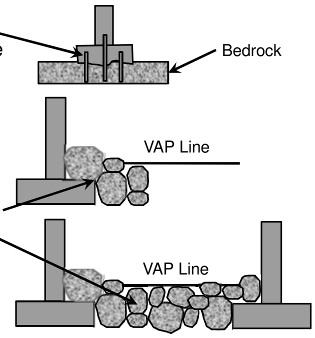




Bottomless Footing Scour Protection

Methods

- Attach / anchor in bedrock (cast in place or precast on a pourable fill base)
- Go well below scour (VAP) depth.
- Protect footings with Rip rap (along footing or full channel width immobile bed)

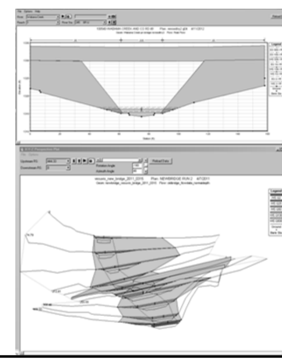


Stream Simulation Structure Selection Summary

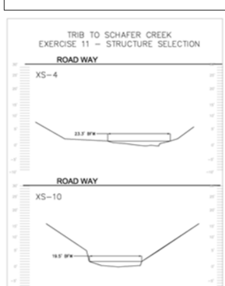
- Structure sized to fit over bankful channel, banks and lower VAP
- Debris passage is optimized. clearance based on what will pass
- Check floodplain conveyance and adjust size, shape and number of structures accordingly
- Check hydraulic capacity max 0.8:1 HW/D. No pressurized flow
- Does the structure size lie below the lower VAP
- Is there enough cover over pipe?
- Terrestrial wildlife passage? Openness ratio greater than 1
- Will the structure materials last in the envirnoment (abrasion & corrosion?
- What are the foundation issues
- Do you have access or constructability issues at the site
- Does the structure meet all of your project objectives?

Flood Conveyance and Hydraulic Modeling

- ✓ Use ineffective flow or obstruction function for blockage modeling
- ✓ Use lid function for modeling enclosed structures with channels thru them
- ✓ Use channel modification tool for easy adjustment of channels shapes / sizes
- ✓ Divide channel into logical sections (floodplain sides, main channels, and flood or side channels.
- ✓ Calibrate your model with real data.



Exercise 7 – Structure Type Selection



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