Advanced Programme - Planning, Design and Construction of Long Span Bridges

Considerations in Design of Bridges & Culverts

National Rural Infrastructure Development Agency

Ministry of Rural Development

Engineering Staff College of India (ESCI)

Hyderabad

Lecture 2

Considerations in Design of Bridges & Culverts

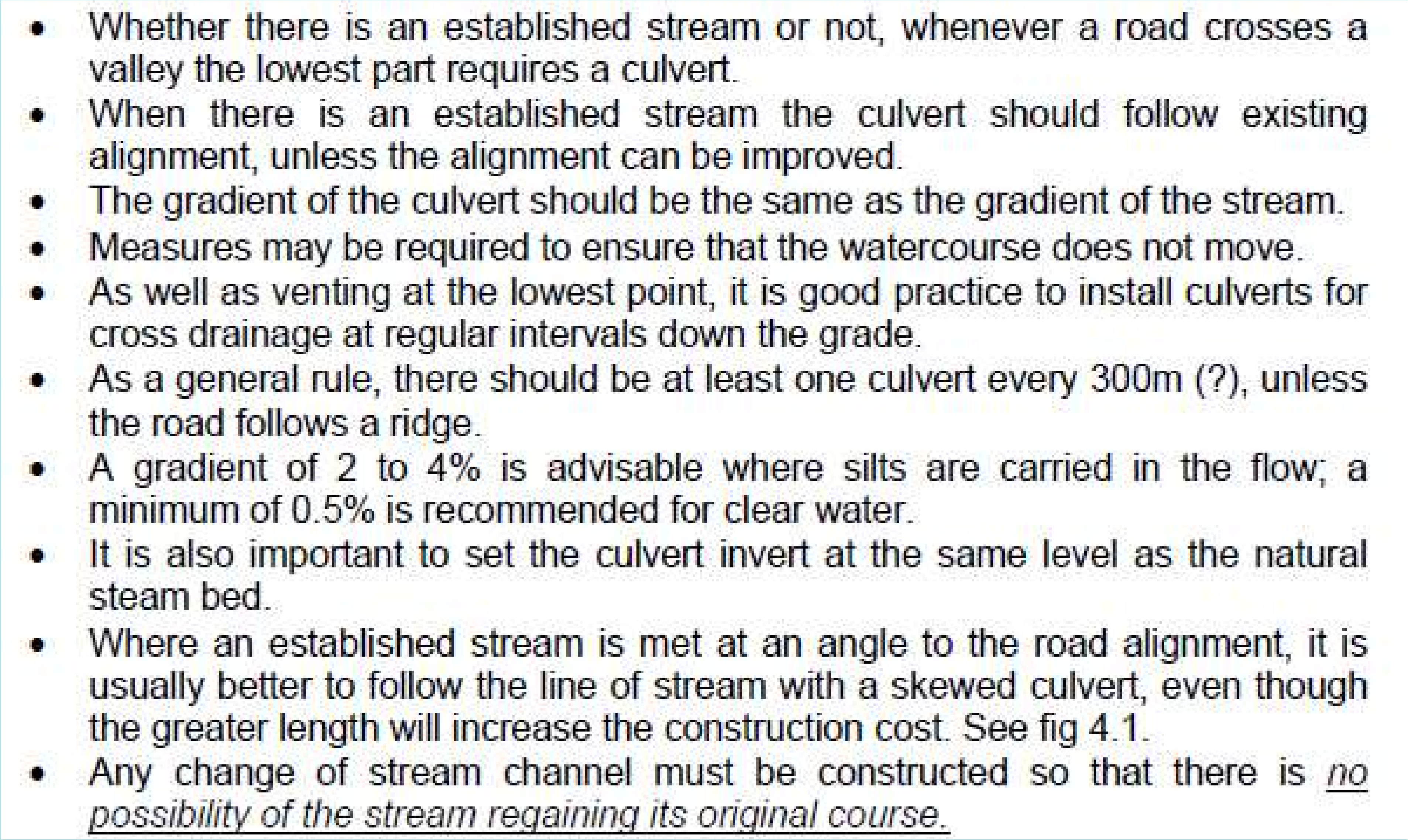
Classification

- Bridges
- Small: L < 30 m Span < 10 m
- Minor: L < 60 m
- Major: > 60 m
- Culvert: Cross Drainage Structure < 6 m in Length

Preliminary Design

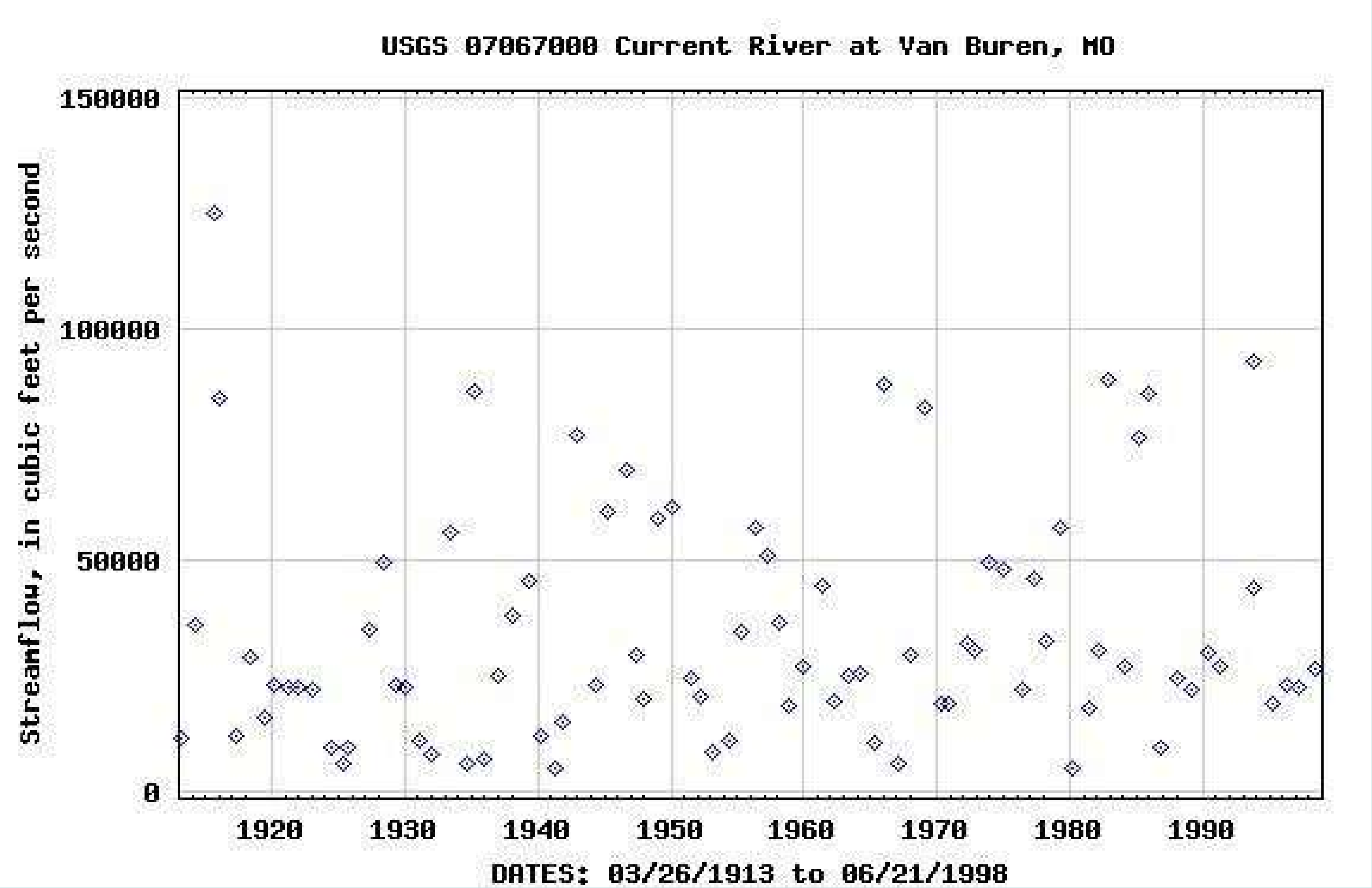
- Location
- Hydraulic design to determine required length and profile grade
- Type selection
- Geotechnical Design
- Structural Design

Location of Bridges & Culverts



- Whether there is an established stream or not, whenever a road crosses a valley the lowest part requires a culvert.
- When there is an established stream the culvert should follow existing alignment, unless the alignment can be improved.
- The gradient of the culvert should be the same as the gradient of the stream.
- Measures may be required to ensure that the watercourse does not move.
- As well as venting at the lowest point, it is good practice to install culverts for cross drainage at regular intervals down the grade.
- As a general rule, there should be at least one culvert every 300m (?), unless the road follows a ridge.
- A gradient of 2 to 4% is advisable where silts are carried in the flow; a minimum of 0.5% is recommended for clear water.
- It is also important to set the culvert invert at the same level as the natural steam bed.
- Where an established stream is met at an angle to the road alignment, it is usually better to follow the line of stream with a skewed culvert, even though the greater length will increase the construction cost. See fig 4.1.
- Any change of stream channel must be constructed so that there is *no possibility of the stream regaining its original course.*

Stream Gage Data



Flood-Frequency Rating Curve

Rational Method

$$Q = k_c \cdot C \cdot I \cdot A$$

Q = discharge (cfs or m^3/s)

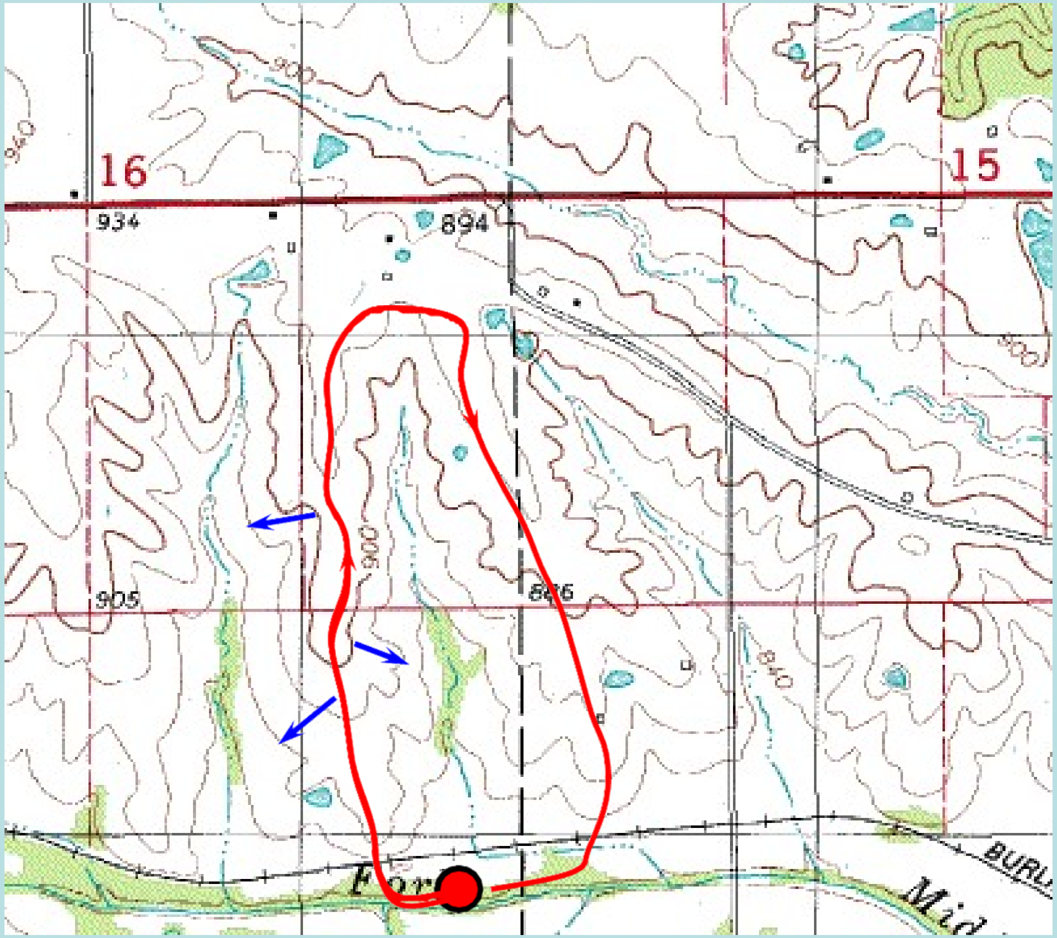
k_c = constant (1.0 for English units or 0.00278 for metric units)

C = Runoff Coefficient

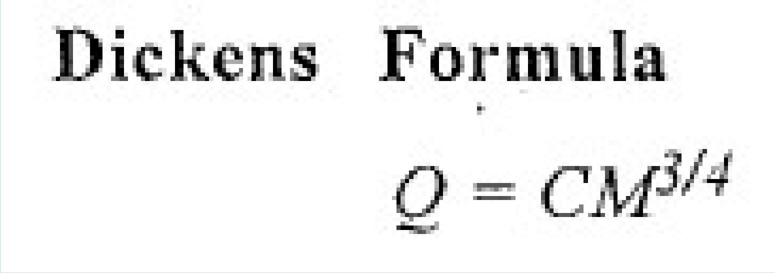
I = Rainfall Intensity (in/hr or mm/hr)

A = Drainage Area (acres or hectares)

Drainage Area Delineation

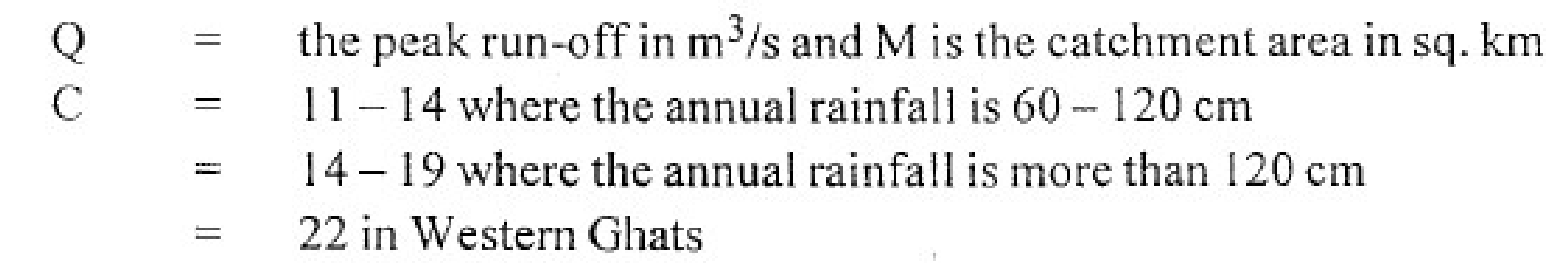


Peak Runn-off



Dickens Formula

$$Q = CM^{3/4}$$



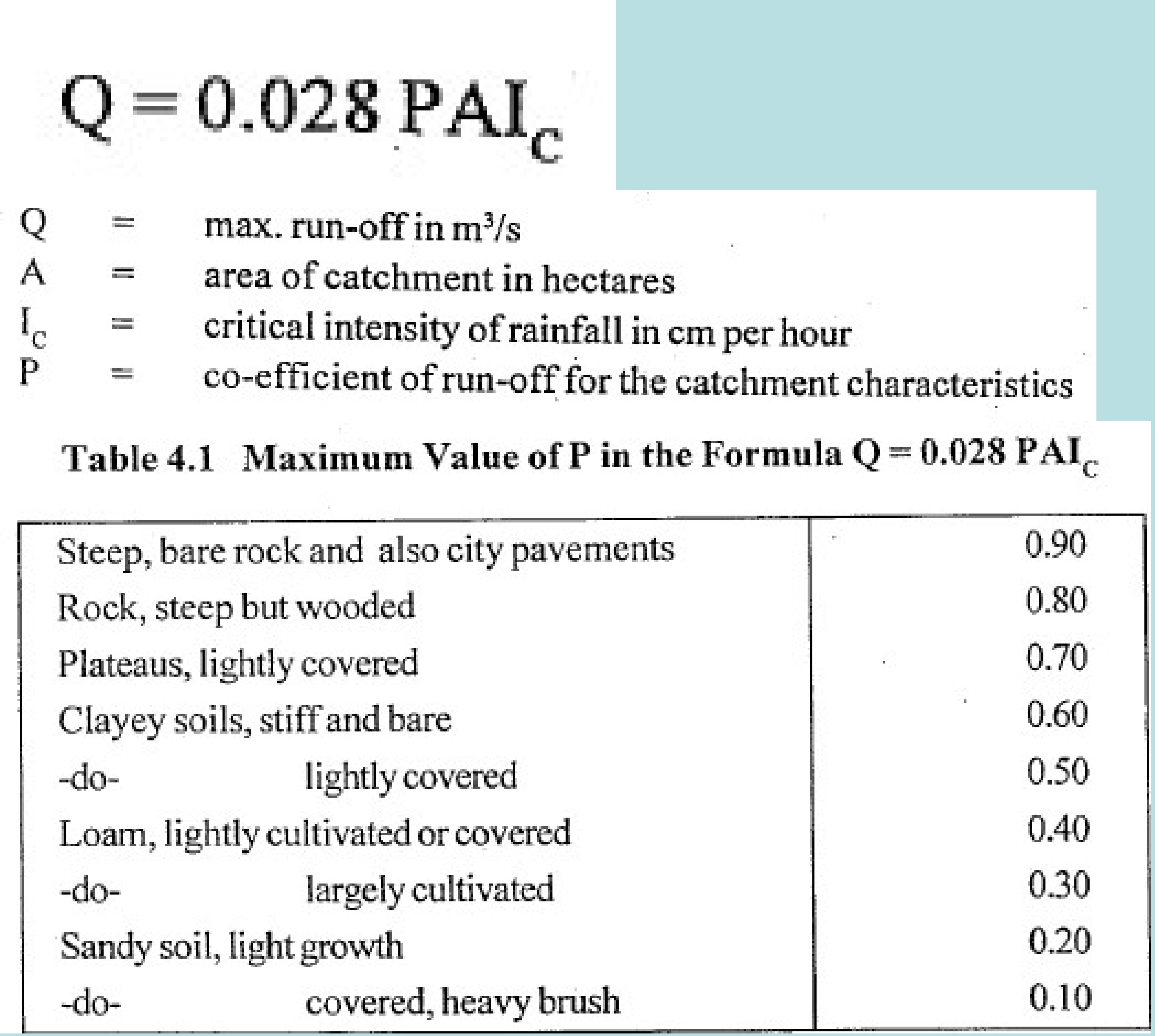
Q = the peak run-off in m^3/s and M is the catchment area in sq. km

C = 11 – 14 where the annual rainfall is 60 – 120 cm

= 14 – 19 where the annual rainfall is more than 120 cm

= 22 in Western Ghats

Peak Run-off



$$Q = 0.028\ PAI_C$$

Q = max. run-off in m^3/s

A = area of catchment in hectares

I_C = critical intensity of rainfall in cm per hour

P = co-efficient of run-off for the catchment characteristics

Table 4.1 Maximum Value of P in the Formula $Q = 0.028\ PAI_C$

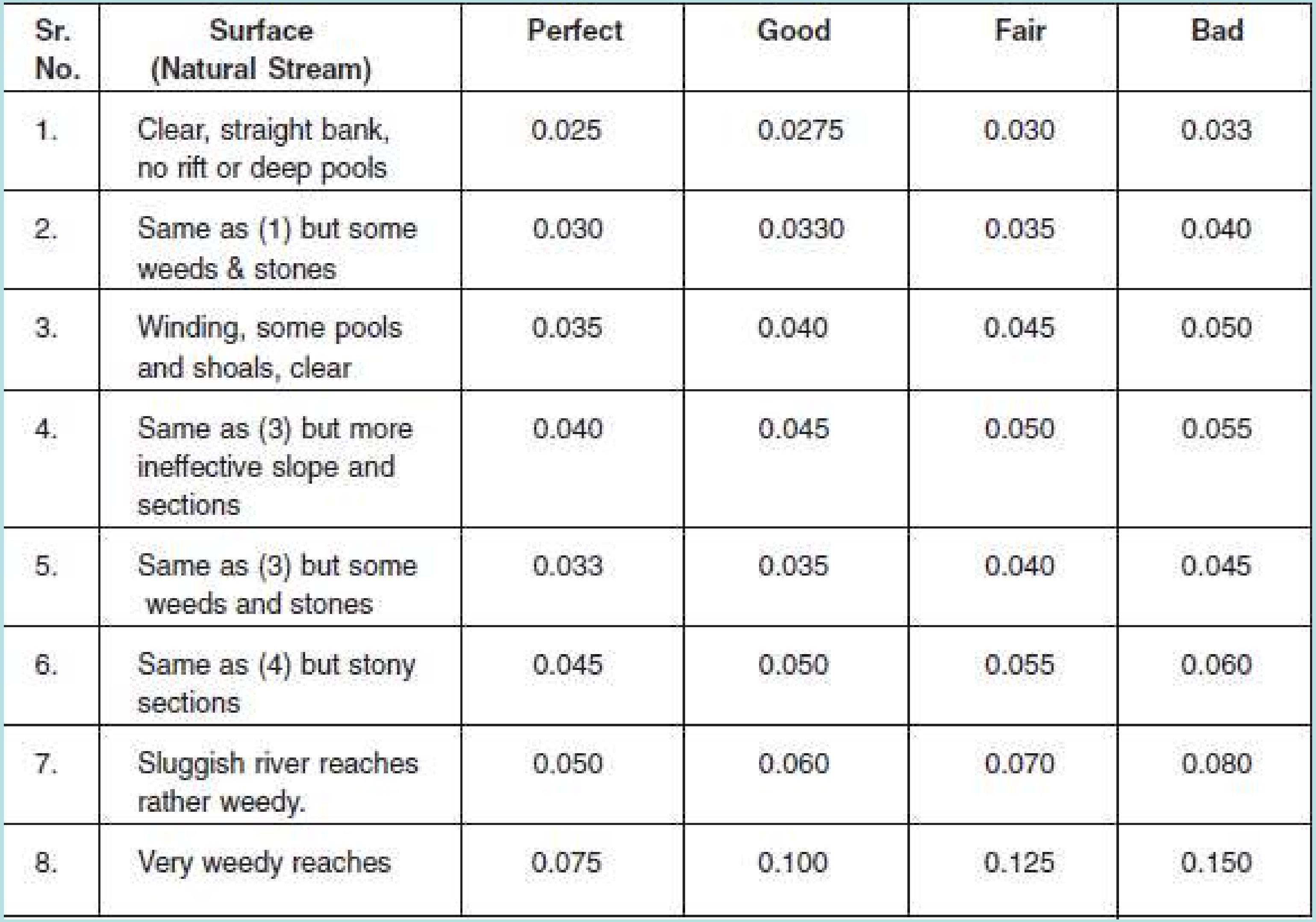
Steep, bare rock and also city pavements	0.90
Rock, steep but wooded	0.80
Plateaus, lightly covered	0.70
Clayey soils, stiff and bare	0.60
-do- lightly covered	0.50
Loam, lightly cultivated or covered	0.40
-do- largely cultivated	0.30
Sandy soil, light growth	0.20
-do- covered, heavy brush	0.10

Manning's Equation

$$Q = \frac{1.486}{n} \cdot A \cdot R^{2/3} \cdot \sqrt{S_0}$$

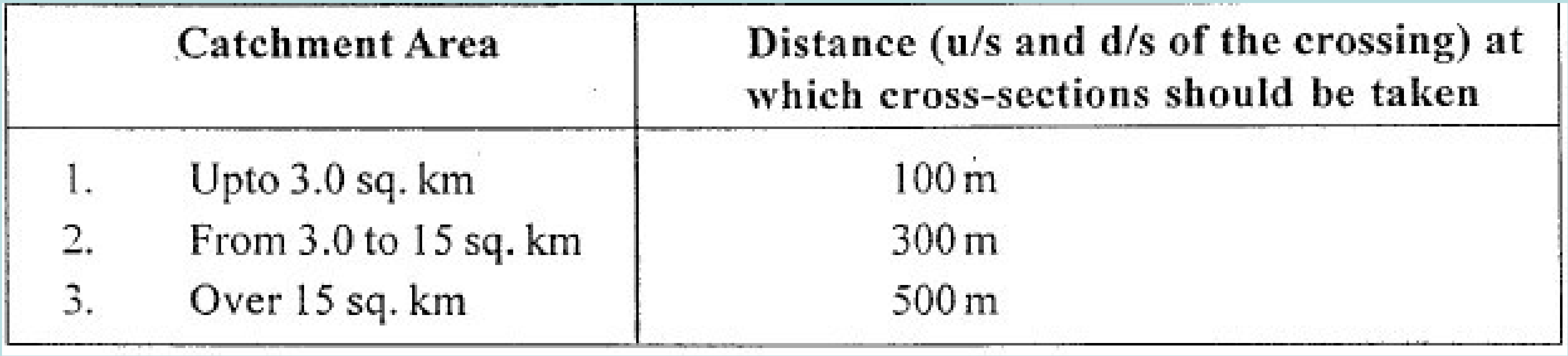
n = Roughness Coefficient
A = Area
R = Hydraulic Radius = A / P
P = Wetted Perimeter
S = Hydraulic Gradient (channel slope)

Coefficient of Rugosity



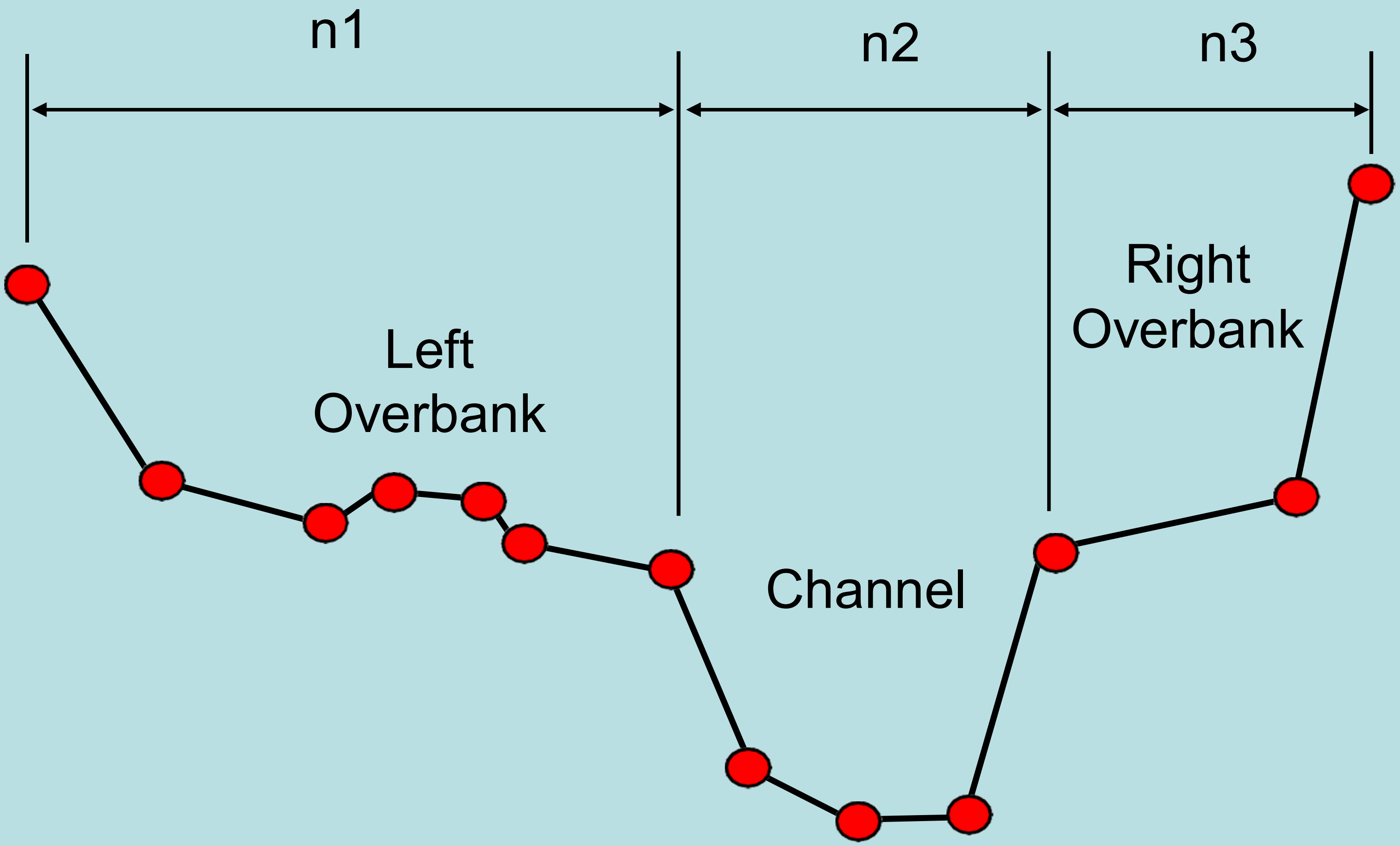
Sr. No.	Surface (Natural Stream)	Perfect	Good	Fair	Bad
1.	Clear, straight bank, no rift or deep pools	0.025	0.0275	0.030	0.033
2.	Same as (1) but some weeds & stones	0.030	0.0330	0.035	0.040
3.	Winding, some pools and shoals, clear	0.035	0.040	0.045	0.050
4.	Same as (3) but more ineffective slope and sections	0.040	0.045	0.050	0.055
5.	Same as (3) but some weeds and stones	0.033	0.035	0.040	0.045
6.	Same as (4) but stony sections	0.045	0.050	0.055	0.060
7.	Sluggish river reaches rather weedy.	0.050	0.060	0.070	0.080
8.	Very weedy reaches	0.075	0.100	0.125	0.150

Cross Sections

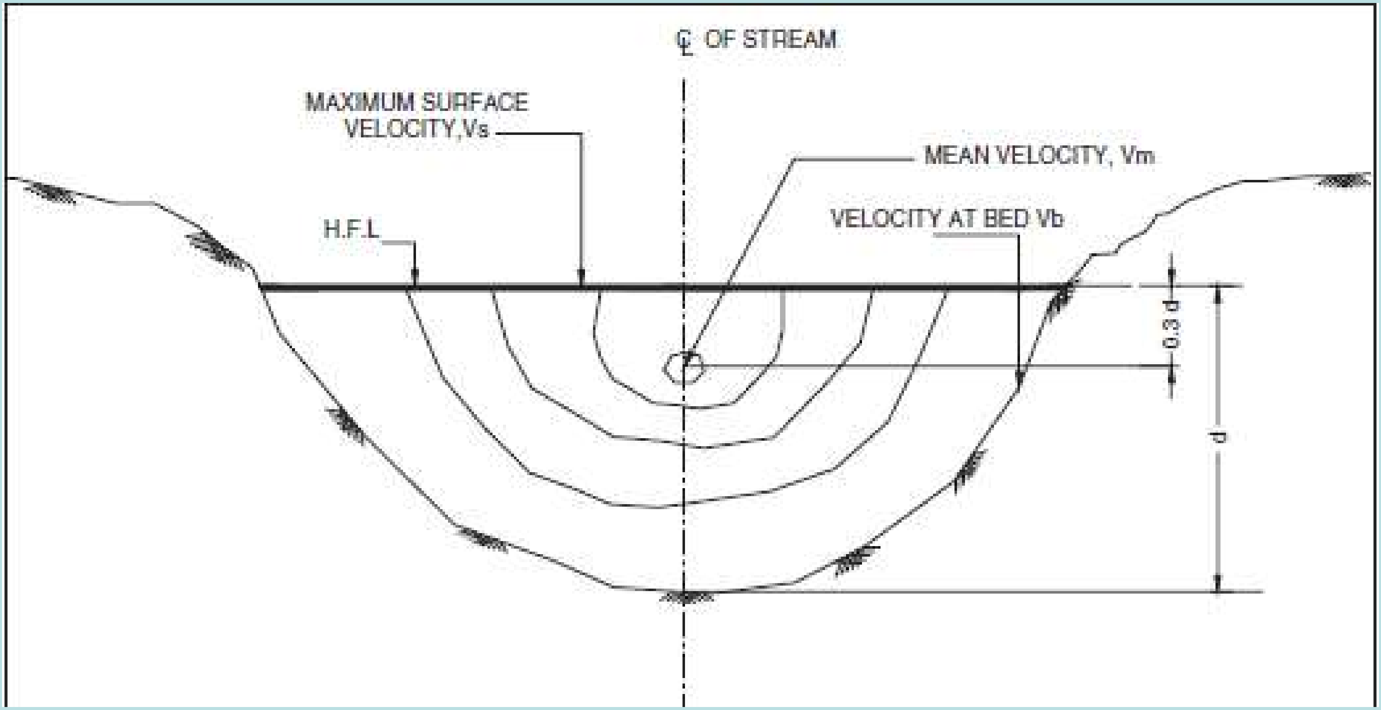


Catchment Area	Distance (u/s and d/s of the crossing) at which cross-sections should be taken
1. Upto 3.0 sq. km	100 m
2. From 3.0 to 15 sq. km	300 m
3. Over 15 sq. km	500 m

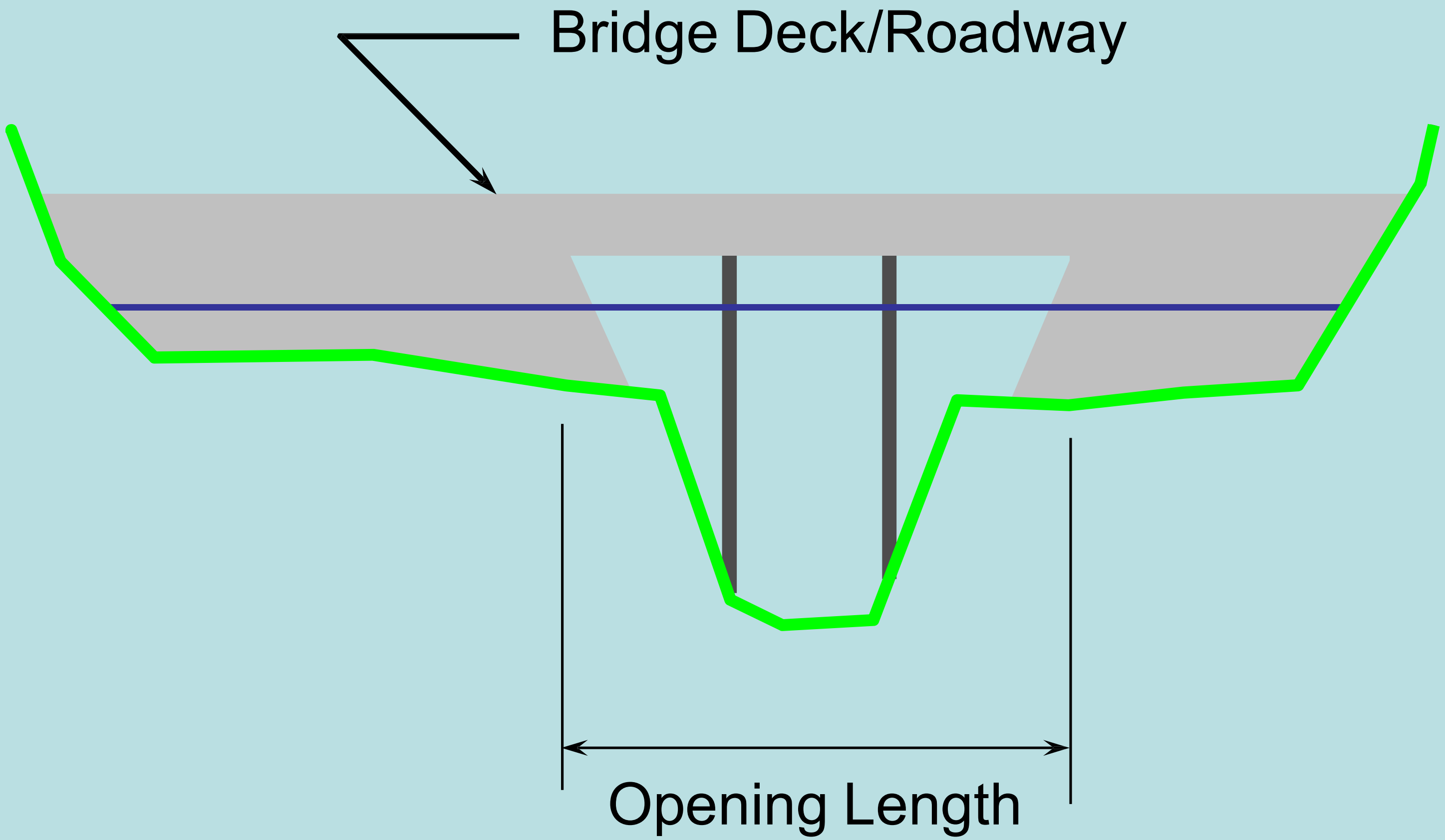
Stream Valley Cross-sections



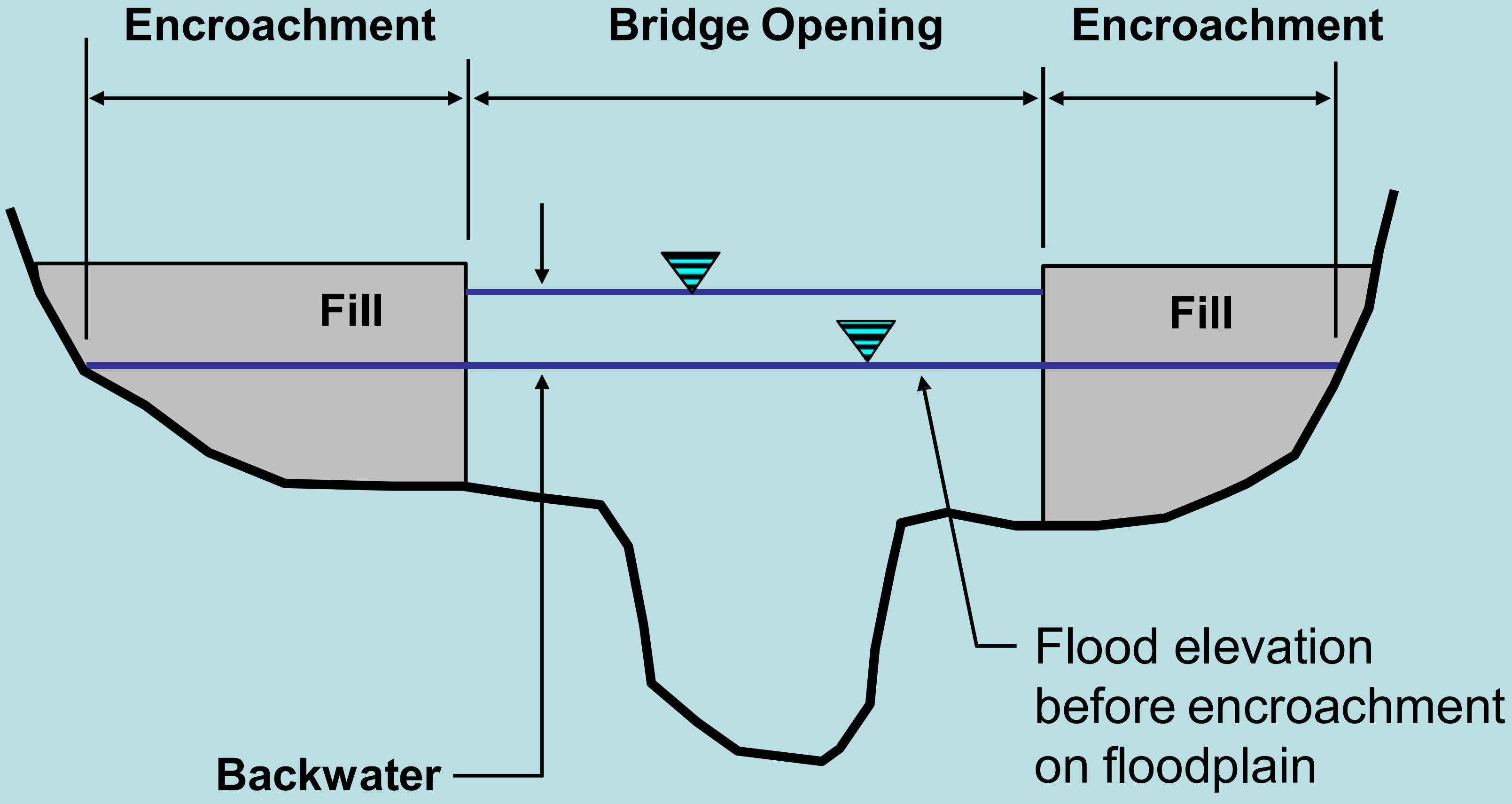
Velocity Distribution in a Stream



Constriction in a Valley



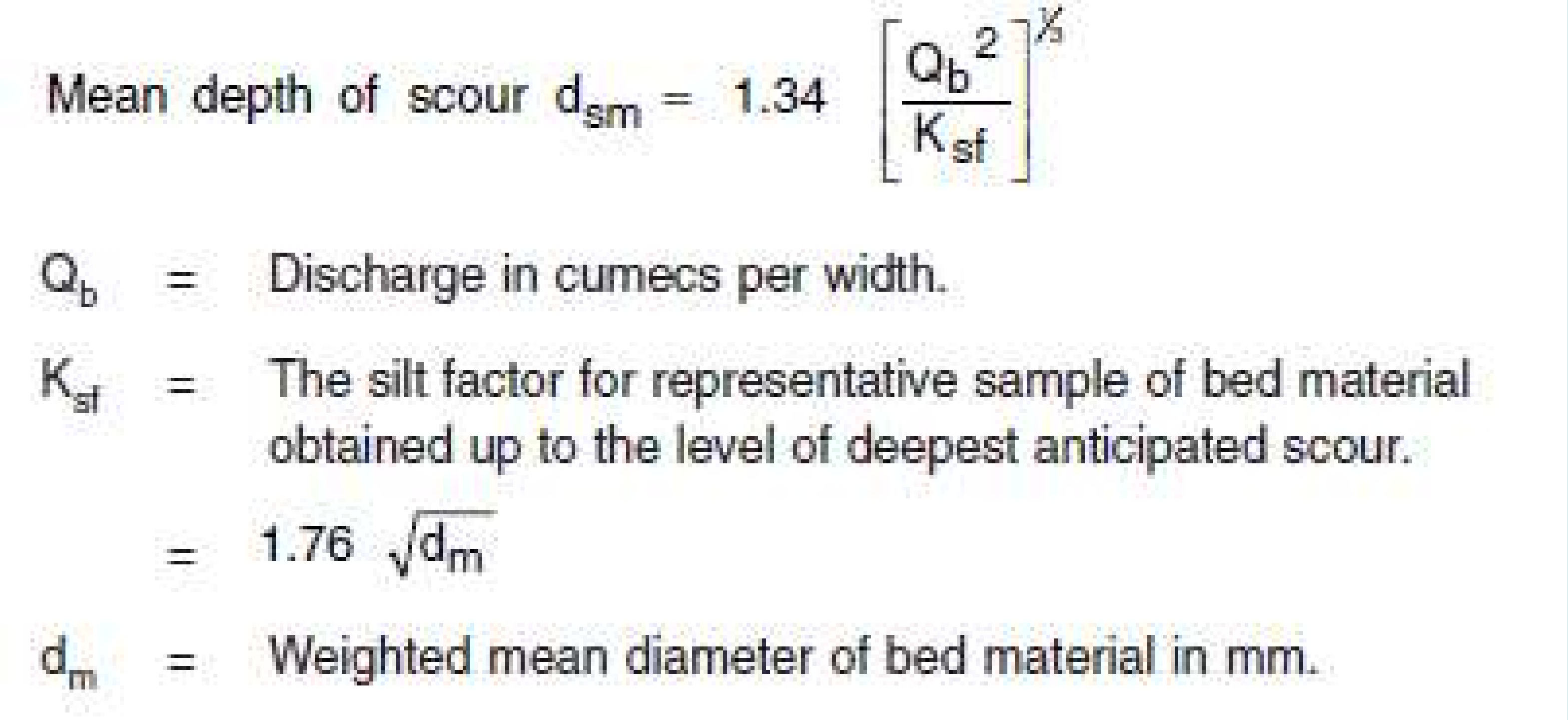
Encroachment by Roadway Fill



Backwater

Flood elevation before encroachment on floodplain

Scour Depth (IRC 78-2000)



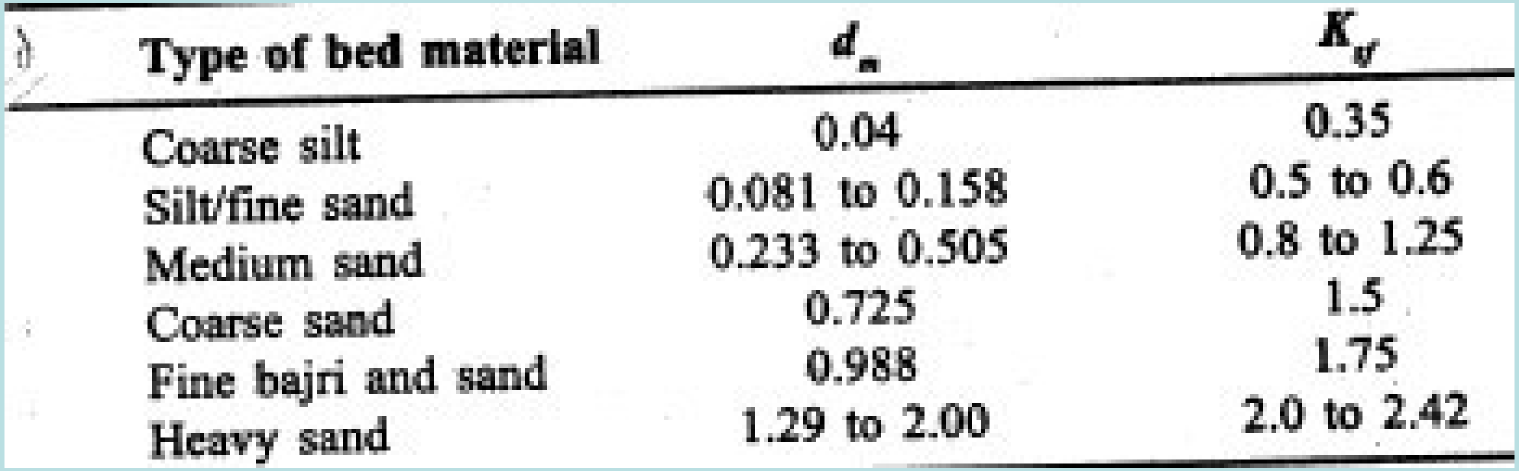
Mean depth of scour $d_{sm} = 1.34 \left[\frac{Q_b{}^2}{K_{sf}} \right]^{1/3}$

Q_b = Discharge in cumecs per width.

K_{sf} = The silt factor for representative sample of bed material obtained up to the level of deepest anticipated scour.

$= 1.76 \sqrt{d_m}$

d_m = Weighted mean diameter of bed material in mm.

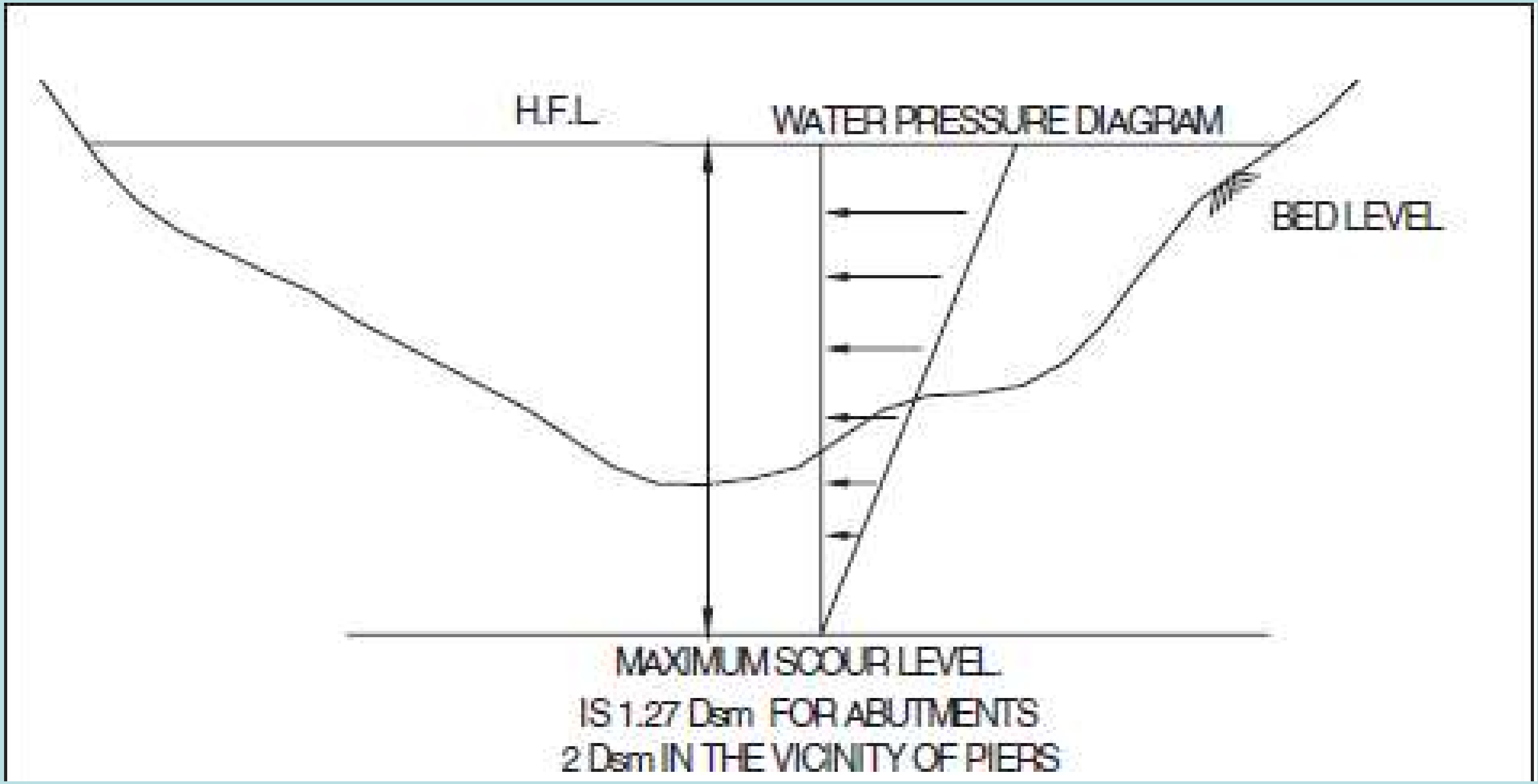


Type of bed material	d_m	K_{sf}
Coarse silt	0.04	0.35
Silt/fine sand	0.081 to 0.158	0.5 to 0.6
Medium sand	0.233 to 0.505	0.8 to 1.25
Coarse sand	0.725	1.5
Fine bajri and sand	0.988	1.75
Heavy sand	1.29 to 2.00	2.0 to 2.42

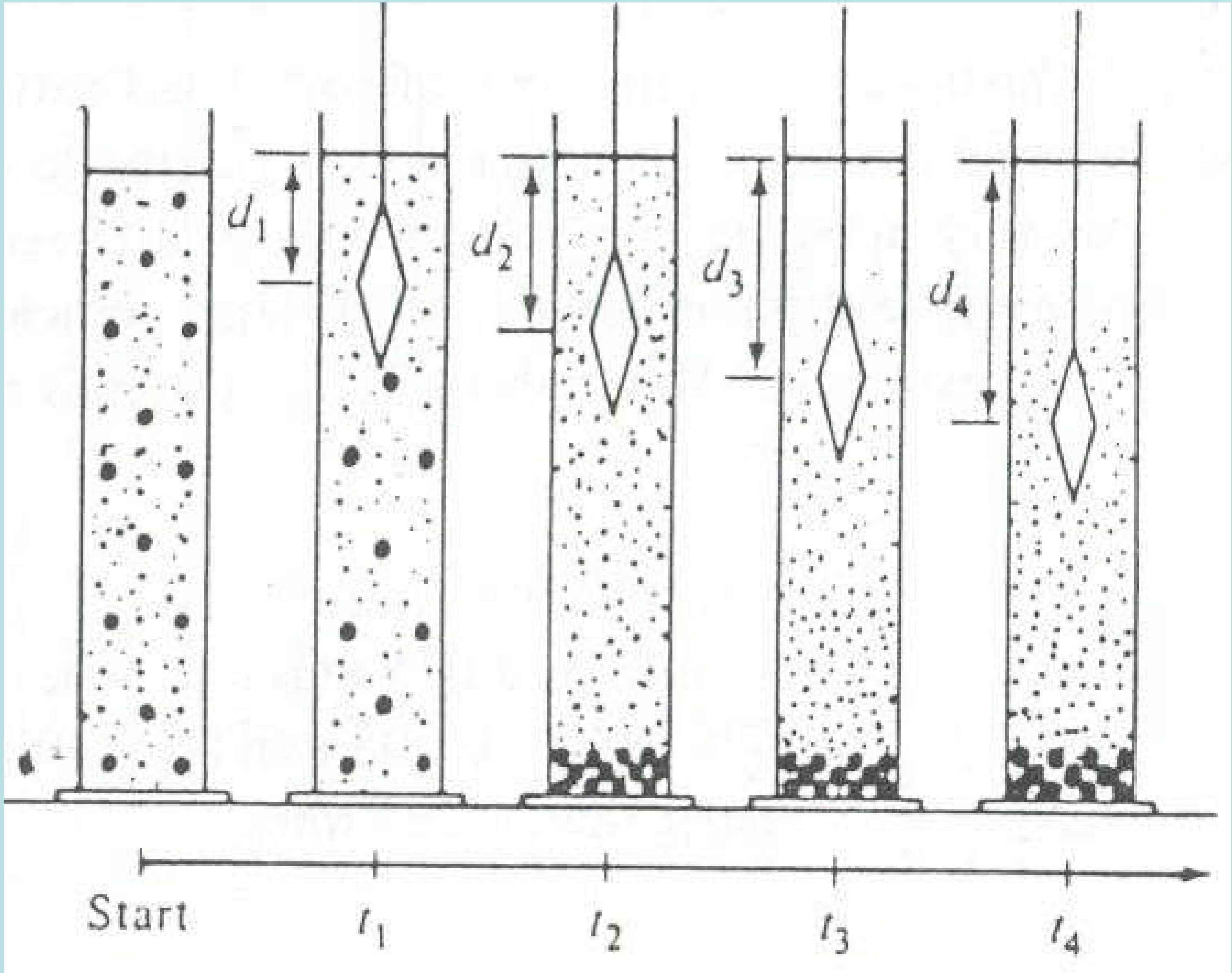
Value of silt factor (K_{sf}) for various bed materials.

Sr. No.	Bed Material	Grain size in mm	Silt factor(K_{sf})
1. Silt	Fine	0.081	0.50
	Fine	0.120	0.60
	Fine	0.158	0.70
	Medium	0.233	0.85
	Standard	0.323	1.00
2. Sand	Medium	0.505	1.25
	Coarse	0.725	1.50
	Mixed with fine bajri 0.988	1.75	
	Heavy	1.290	2.00

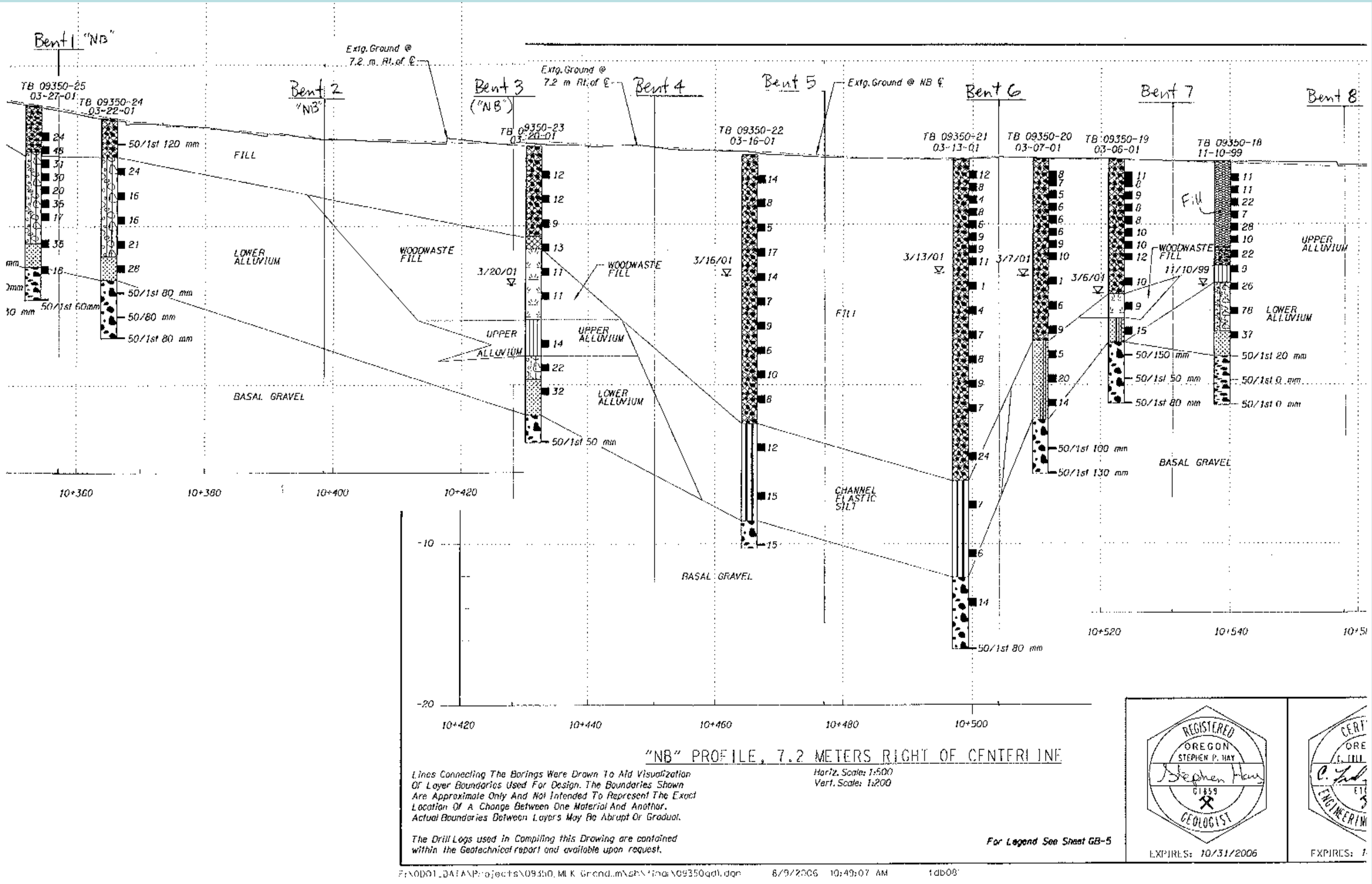
Max. Depth of Scour for Design of Foundations



Hydrometer Analysis



Subsurface Geologic Profile



"NB" PROFILE, 7.2 METERS RIGHT OF CENTERLINE

Horiz. Scale: 1:500
Vert. Scale: 1:200

Lines Connecting The Borings Were Drawn To Aid Visualization Of Layer Boundaries Used For Design. The Boundaries Shown Are Approximate Only And Not Intended To Represent The Exact Location Of A Change Between One Material And Another. Actual Boundaries Between Layers May Be Abrupt Or Gradual.

The Drill Logs used in Compiling this Drawing are contained within the Geotechnical report and available upon request.

For Legend See Sheet GB-5

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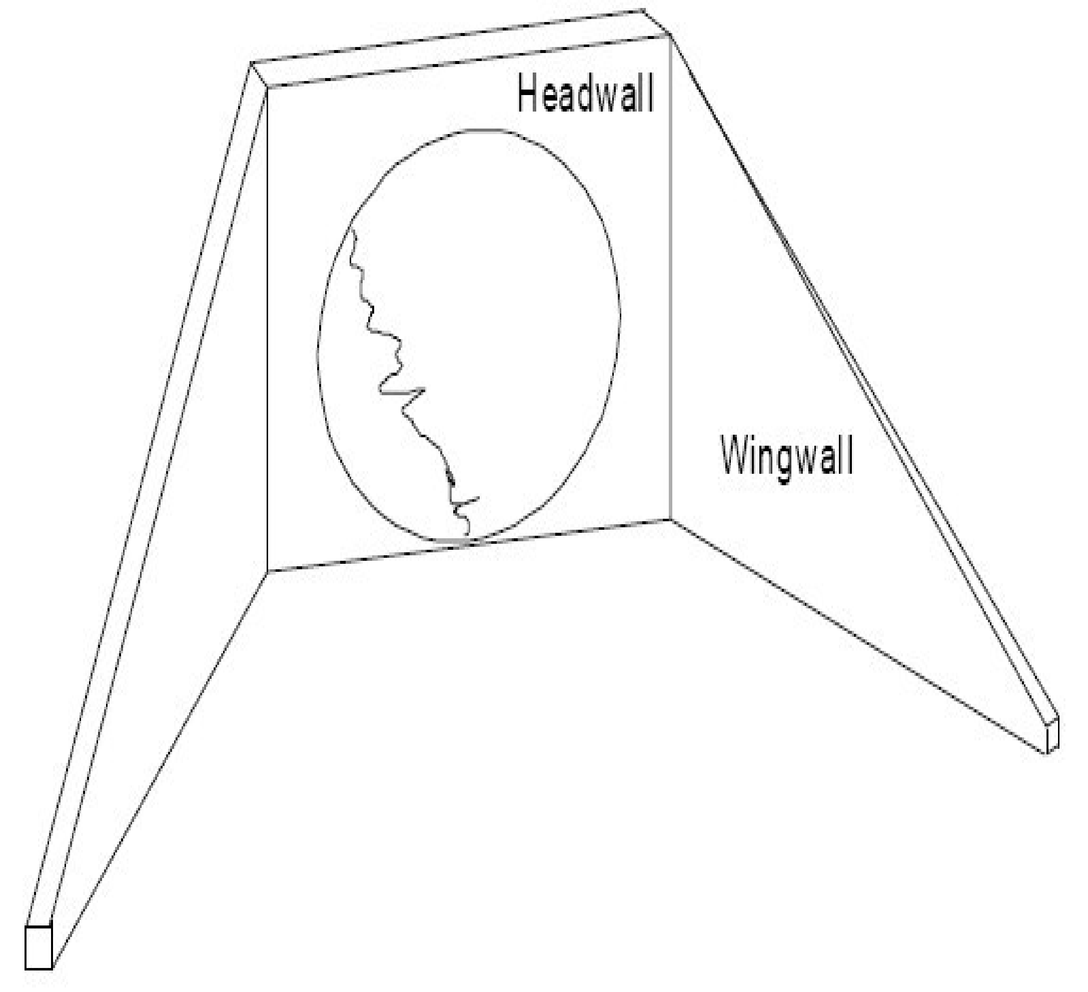
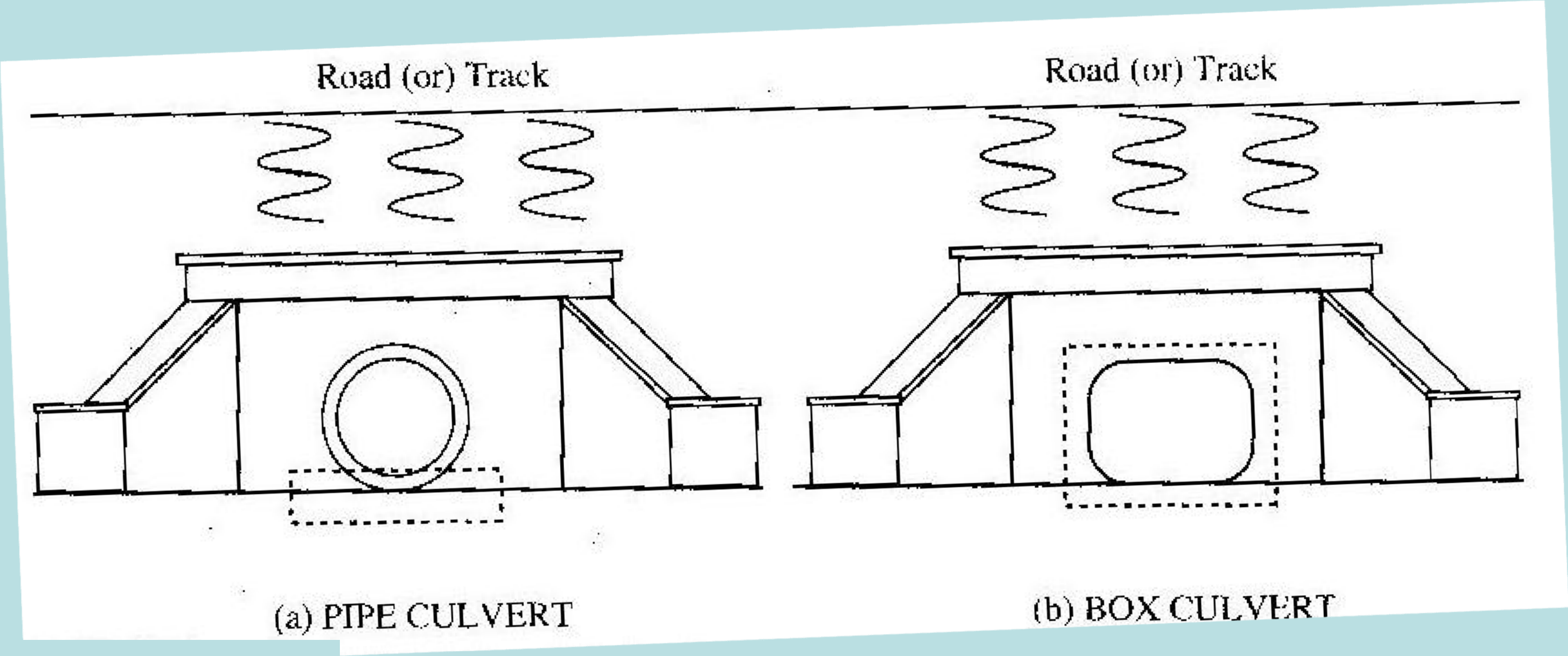
Culverts

- Definition - structure to convey surface runoff through embankments, near ground.
- Round pipe, rectangular box, arch, ellipse, bottomless, or other shapes.
- Concrete, steel, corrugated metal, polyethylene, fiberglass, or other materials.

Culverts

- End treatment includes projected, flared, & head and wing walls





(a) PIPE CULVERT

(b) BOX CULVERT

Culverts are smaller bridges, normally with one span built across small streams, drains or sewer carrying road on top

Concrete Box Culvert

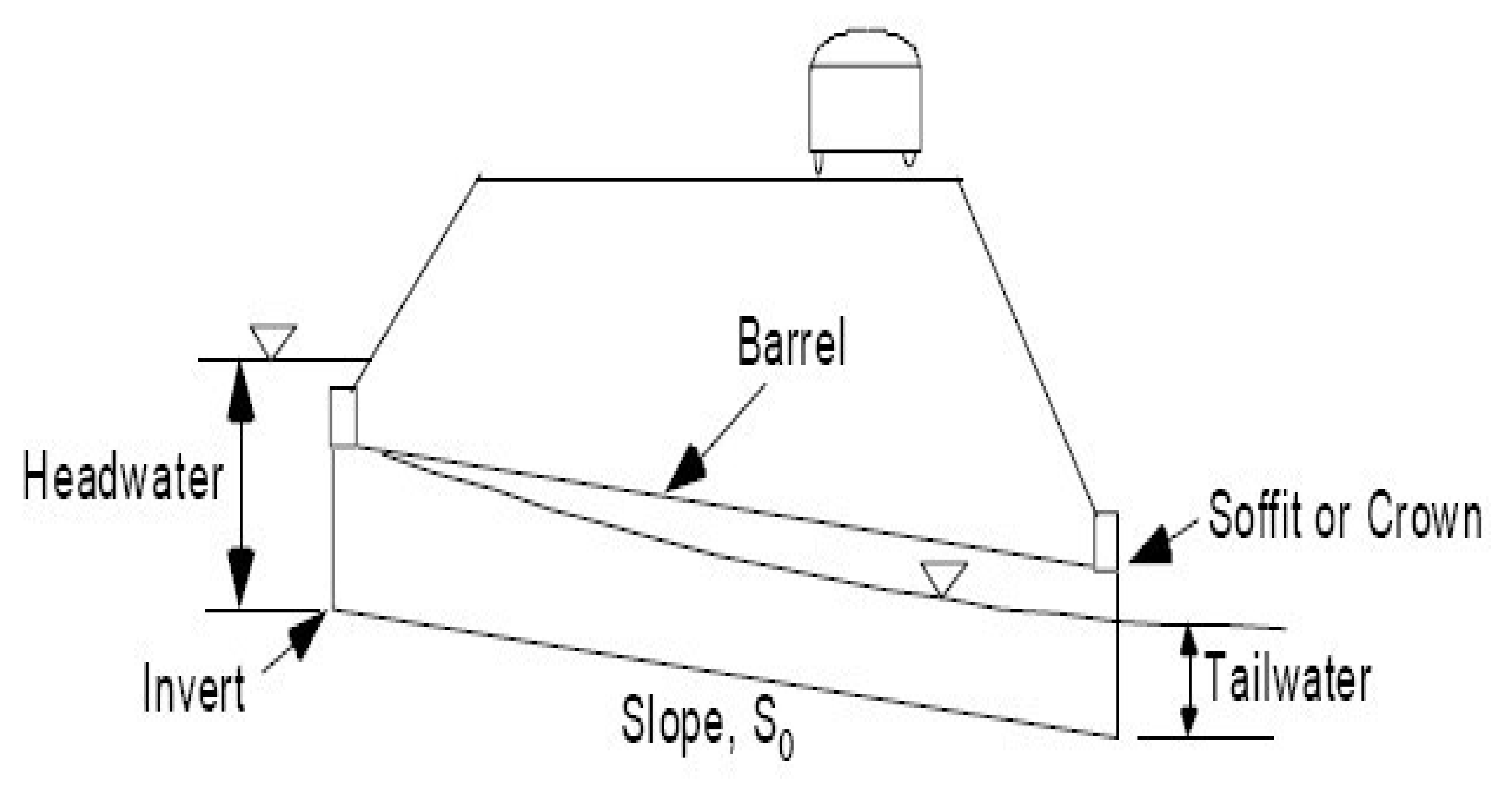
Box culvert with fish passage

Corrugated metal horseshoe culvert

Triple Box Culvert

Culvert or Bridge?

Definition Sketch



Culvert Design - Basics

- Top of culvert not used as pavement surface (unlike bridge), usually less than 6 m span
- > 6 m use a bridge
- Three locations
  - Bottom of Depression (no watercourse)
  - Natural stream intersection with roadway (Majority)
  - Locations where side ditch surface drainage must cross roadway

Hydrologic and Economic Considerations

- Alignment and grade of culvert (with respect to roadway) - important
- Similar to open channel
- Design flow rate based on storm with acceptable return period (frequency)

Culvert Design Steps

- Obtain site data and roadway cross section at culvert crossing location (with approximation of stream elevation) – best is natural stream location, alignment, and slope (may be expensive though)
- Establish inlet/outlet elevations, length, and slope of culvert

Culvert Design Steps

- Determine allowable headwater depth (and probable tailwater depth) during design flood – control on design size – f(topography and nearby land use)
- Select type and size of culvert
  - Examine need for energy dissipaters

Headwater Depth

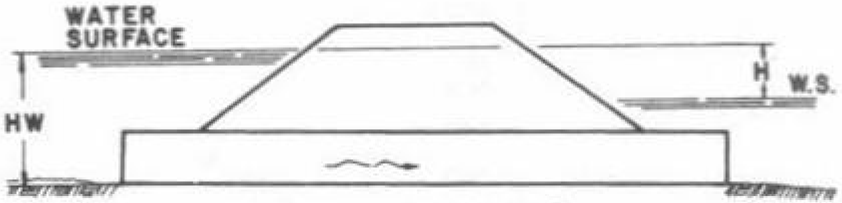
- Constriction due to culvert creates increase in depth of water just upstream
- Allowable level of headwater upstream usually controls culvert size and inlet geometry
- Allowable headwater depth depends on topography and land use in immediate vicinity

Types of culvert flow

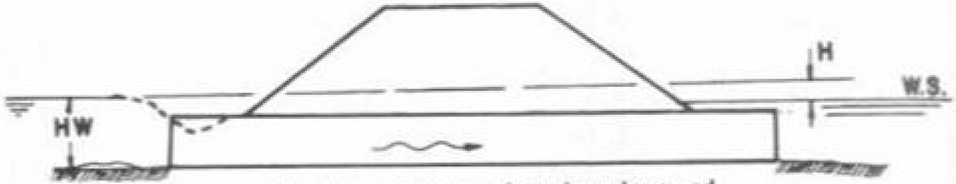
- Type of flow depends on total energy available between inlet and outlet
- Inlet control
  - Flow is controlled by headwater depth and inlet geometry
  - Usually occurs when slope of culvert is steep and outlet is not submerged
  - Supercritical, high v, low d
  - Most typical
  - Following methods ignore velocity head

Types of culvert flow

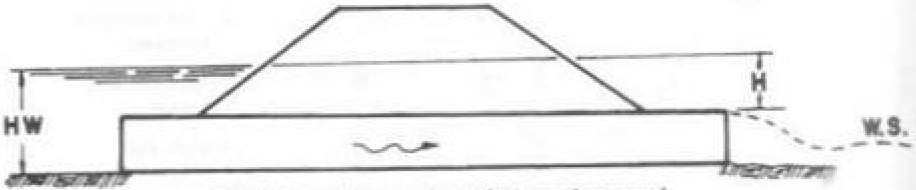
- Outlet control
  - When flow is governed by combination of headwater depth, entrance geometry, tailwater elevation, and slope, roughness, and length of culvert
  - Subcritical flow
  - Frequently occur on flat slopes
  - Concept is to find the required HW depth to sustain Q flow
  - Tail water depth often not known (need a model), so may not be able to estimate for outlet control conditions



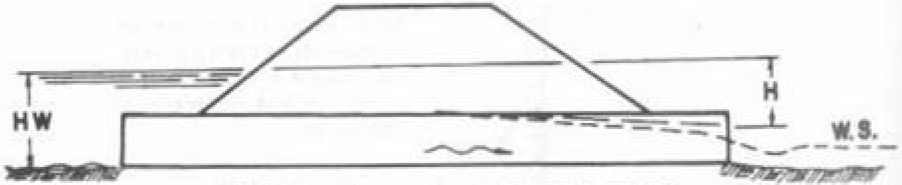
(a) Inlet and outlet submerged



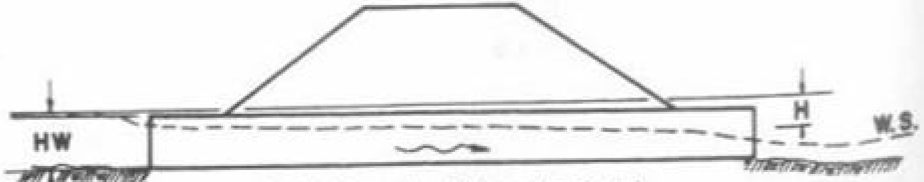
(b) Inlet unsubmerged, outlet submerged



(c) Inlet submerged, outlet unsubmerged



(d) Inlet submerged, outlet unsubmerged



(e) Inlet and outlet unsubmerged

Figure 17.18 Types of Outlet Control

Culvert Scour Prevention

Riprap

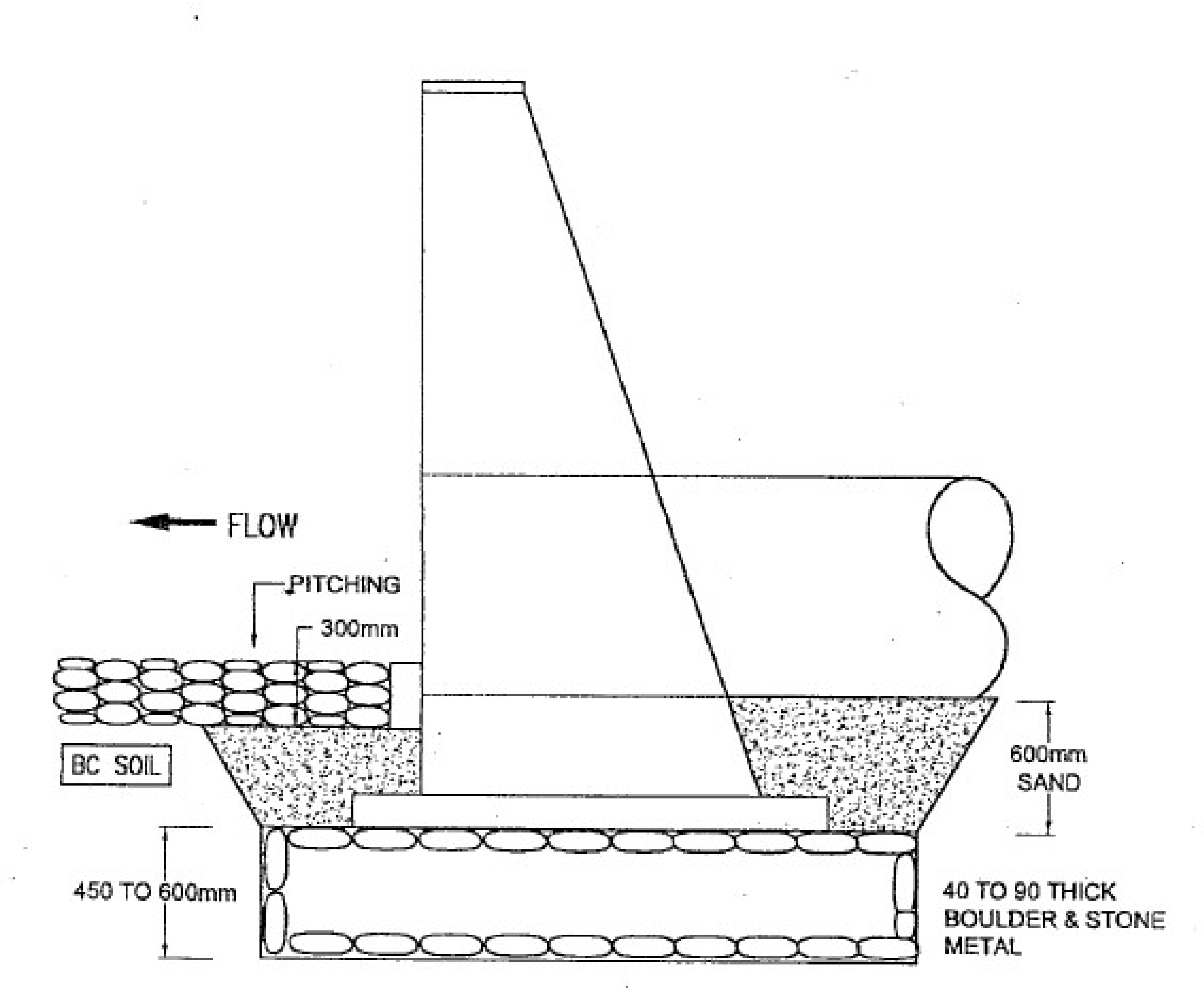
Gabions

Grade Control Scour Prevention

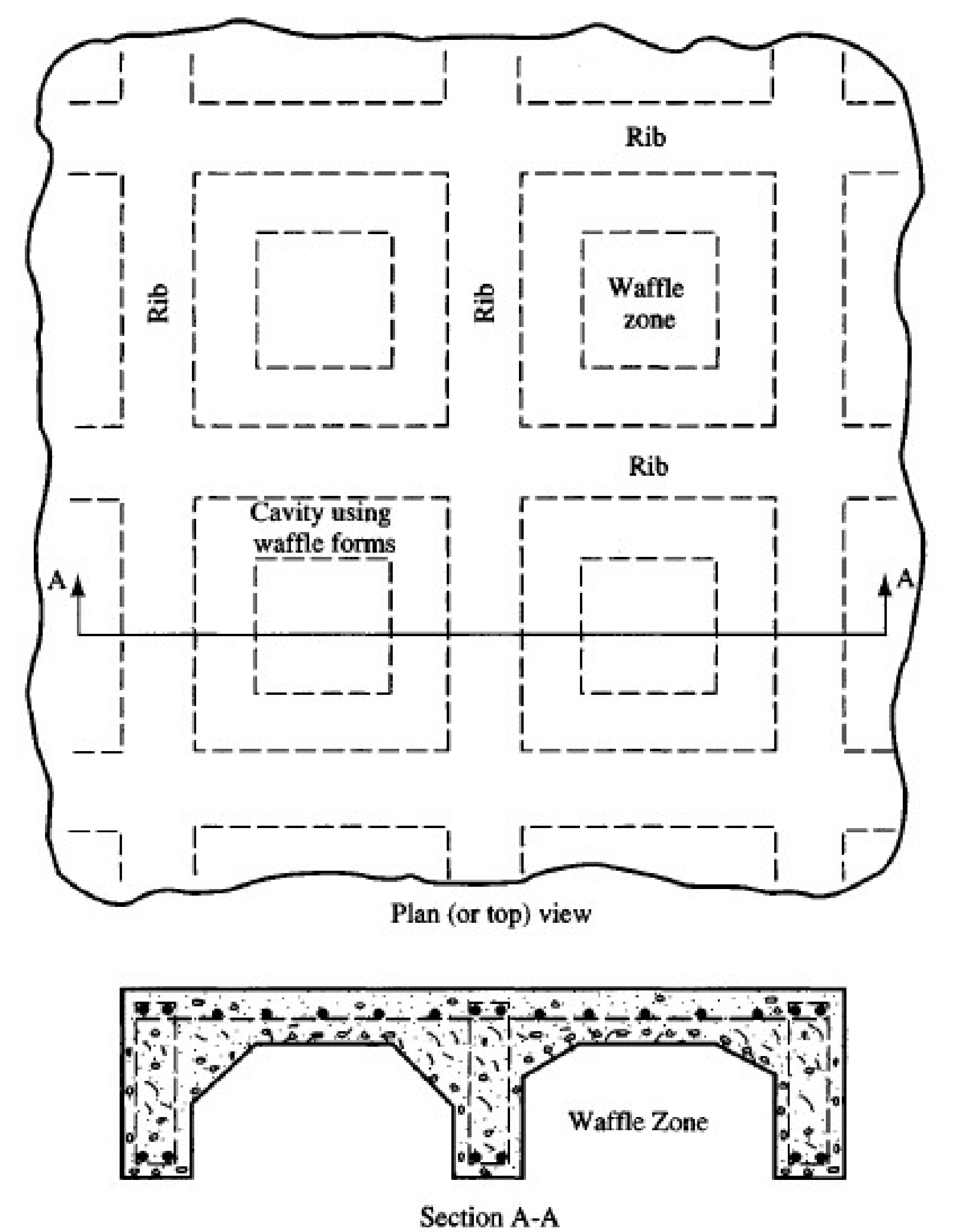
- Concrete mattress downstream of grade control structure.

- Riprap placed downstream of grade control structure.

Pipe Culvert in BC Soil



Waffle Slab for Expansive Soils



Classification of Bridges

Based on Mechanics

- Beam
- Cantilever
- Arch
- Suspension
- Cable-stayed
- Truss

Classification of Bridges

Material

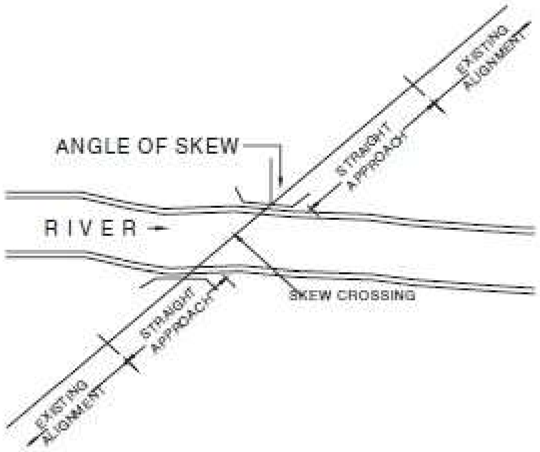
- Concrete
- Steel
- Timber
- Composite

Classification of Bridges

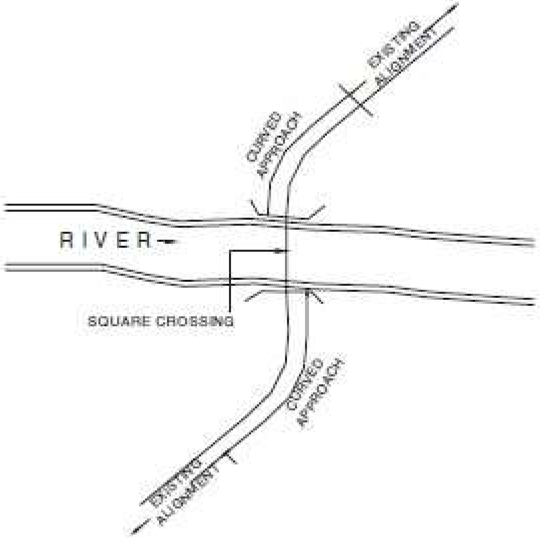
Support

- Simply Supported
- Continuous
- Fixed
- Cantilever

Crossings – Skew and Square

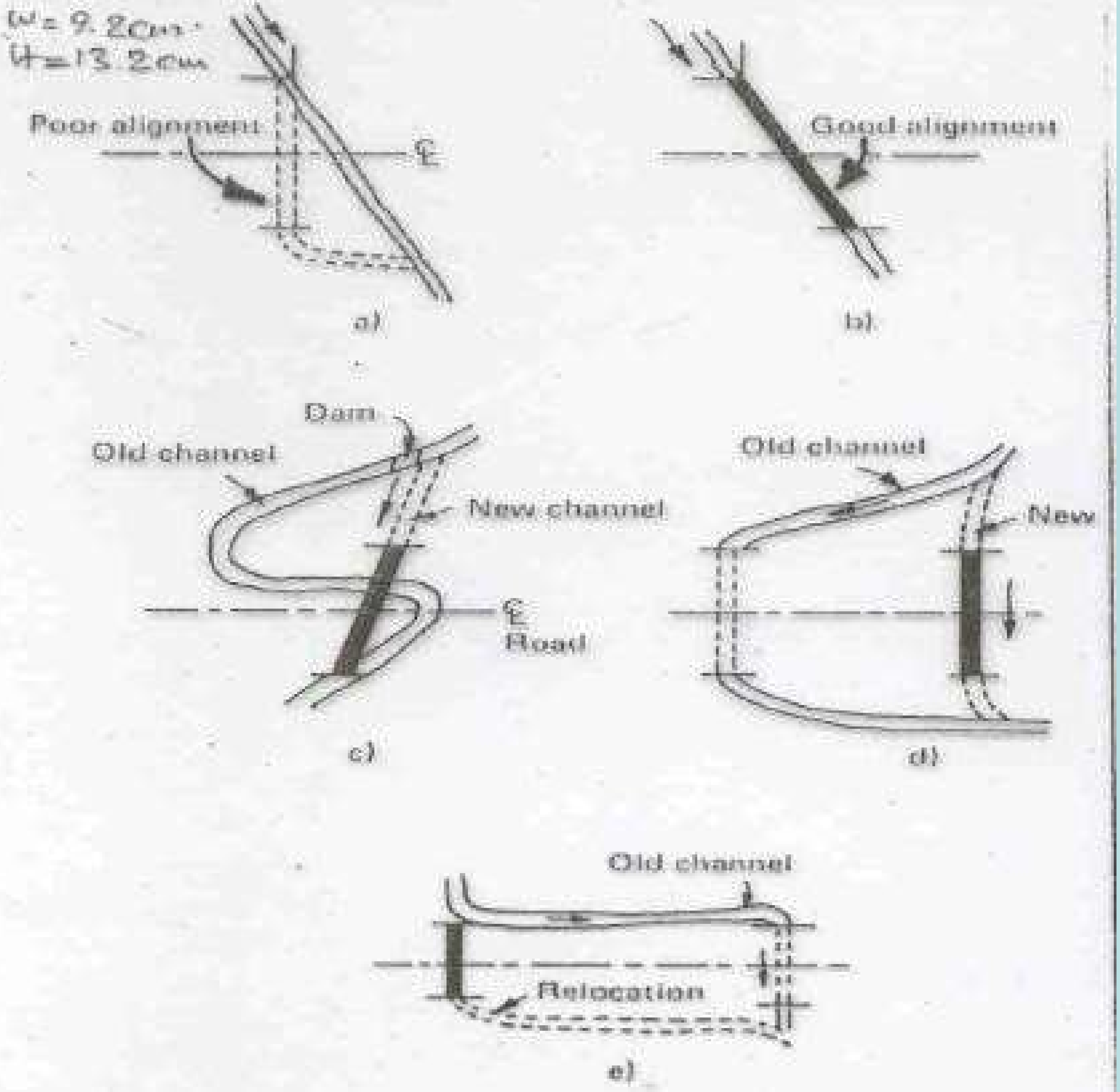


a) SKEW ALIGNMENT -SKEW CROSSING

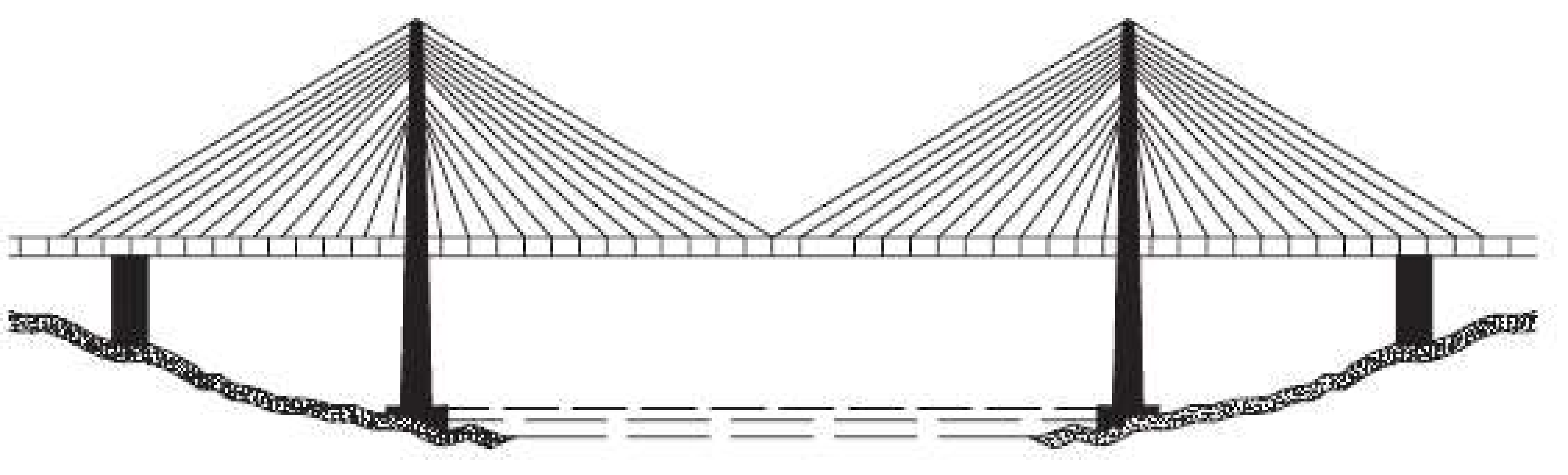


b) SKEW ALIGNMENT -SQUARE CROSSING

W= 9.20m
L=13.20m

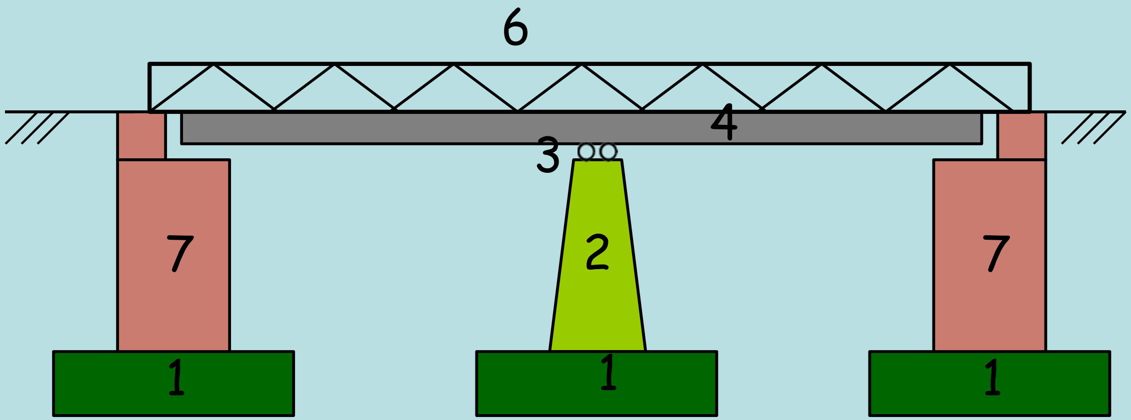


Cable-Stayed Bridge



Components of Bridge

1. Caisson/Raft Foundation
2. Bridge Pier
3. Bearing
4. Deck Slab
5. Roadway
6. Railing
7. Abutment



Bridge Design Process

Bridge Survey

- flood plain cross sections
- inspection reports
- existing bridge (scour, etc)
- water elevations
- photos
- existing roadway profile

Geotechnical Report

- soil / geological formations
- slopes and grading
- foundation problems
- soil prop.'s - phi angles etc

Factors affecting choice of superstructure

- location, city or rural
- span length
- vertical clearance
- maintainability
- environmental concerns
- transportation to site issues
- cost

Factors affecting choice of substructure

- location and geometry
- subsoil conditions
- height of column

Substructures

The substructure transfers the superstructure loads to the foundations.

Abutments

- Integral Abutment
- Non-Integral Abutment
- Semi-Deep Abutment - used when spanning divided highways to help shorten span
- Open C.C. Abutment - beam supported by columns and footings

Piers

- Open Concrete Piers - beams supported by columns and footings (or drilled shafts) or a concrete diaphragm (Pre-Stressed Girder)
- Pile Cap Bent - beams supported by piling
- Hammer Head Bent - single oval or rectangular column and footing.
- **Spread footings** - are used when rock or soil can support the structure.
- **Piles** - rectangular c.c. supported by HP or Cast in Place piles
- **Drilled Shafts/Well Foundations** - holes drilled into bedrock filled with concrete

Maximum Depth of Scour for Design of Foundations

- Piers: $2d_m$
- Abutments: $1.27d_m$ with Approach Retained or Lowest Bed level or $2d_m$ with Scour ALL Around
- Flood with Seismic Combination 90% of the above
- For Raft or Open Foundations: $1.27d_m$ for Straight Reach & $1.5d_m$ in Bends

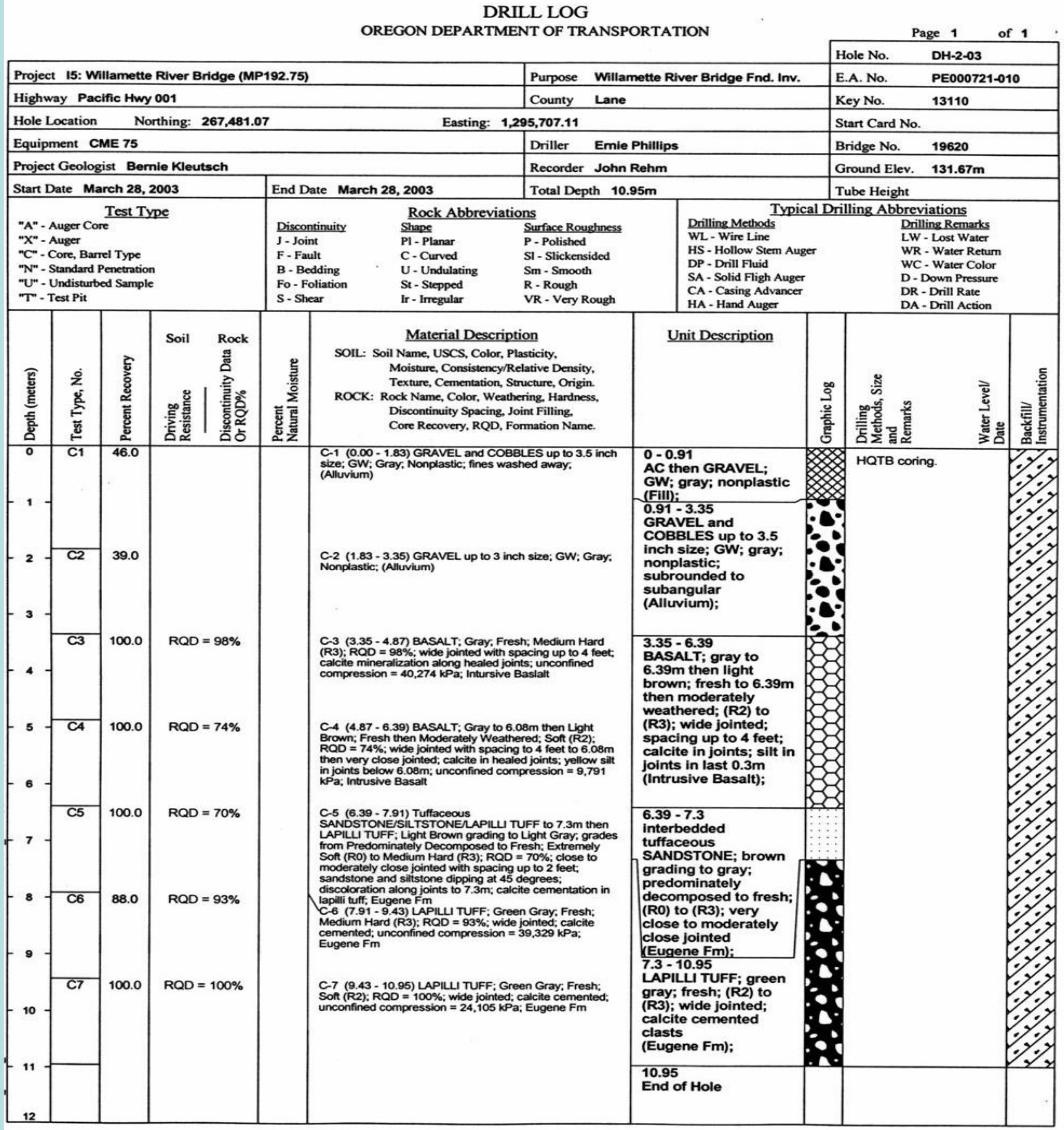
Design Limits

- Max. Bearing Pressure in Rock: < 3 MPA
- Differential Settlement: 1 in 400
- Factor of Safety Without With EQ.
- Against Overturning 2.0 1.5
- Against Sliding 1.5 1.25
- Against Deep Seated F 1.25 1.15

Other Project Considerations:

- In-Water Work Periods
- Environmental Restrictions
- Noise or Vibration Constraints
- Construction Access/Traffic Control

Exploration Log



DRILL LOG
OREGON DEPARTMENT OF TRANSPORTATION

Page 1 of 1

Project I5: Willamette River Bridge (MP192.75)		Hole No. DH-2-03
	Purpose Willamette River Bridge Fnd. Inv.	E.A. No. PE000721-010
Highway Pacific Hwy 001	County Lane	Key No. 13110
Hole Location Northing: 267,481.07 Easting: 1,295,707.11		Start Card No.
Equipment CME 75	Driller Ernie Phillips	Bridge No. 19620
Project Geologist Bernie Kleutsch	Recorder John Rehm	Ground Elev. 131.67m
Start Date March 28, 2003 / End Date March 28, 2003	Total Depth 10.95m	Tube Height

Test Type
"A" - Auger Core
"X" - Auger
"C" - Core, Barrel Type
"N" - Standard Penetration
"U" - Undisturbed Sample
"T" - Test Pit

Rock Abbreviations

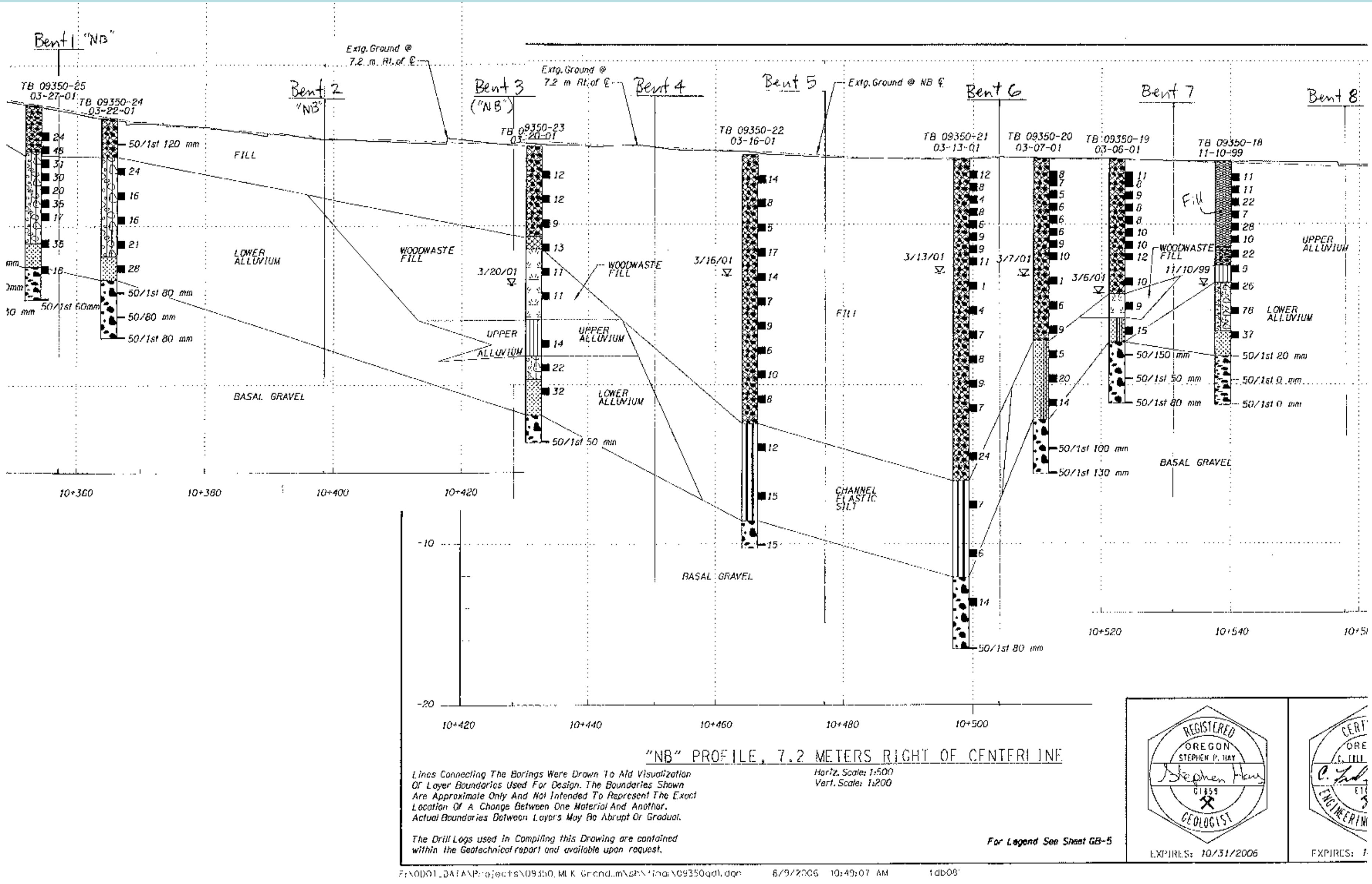
Discontinuity	Shape	Surface Roughness
J - Joint	Pl - Planar	P - Polished
F - Fault	C - Curved	Sl - Slickensided
B - Bedding	U - Undulating	Sm - Smooth
Fo - Foliation	St - Stepped	R - Rough
S - Shear	Ir - Irregular	VR - Very Rough

Typical Drilling Abbreviations

Drilling Methods	Drilling Remarks
WL - Wire Line	LW - Lost Water
HS - Hollow Stem Auger	WR - Water Return
DP - Drill Fluid	WC - Water Color
SA - Solid Fligh Auger	D - Down Pressure
CA - Casing Advancer	DR - Drill Rate
HA - Hand Auger	DA - Drill Action

Depth (meters)	Test Type, No.	Percent Recovery	Soil: Driving Resistance	Rock: Discontinuity Data Or RQD%	Percent Natural Moisture	Material Description SOIL: Soil Name, USCS, Color, Plasticity, Moisture, Consistency/Relative Density, Texture, Cementation, Structure, Origin. ROCK: Rock Name, Color, Weathering, Hardness, Discontinuity Spacing, Joint Filling, Core Recovery, RQD, Formation Name.	Unit Description	Graphic Log	Drilling Methods, Size and Remarks	Water Level/ Date	Backfill/ Instrumentation
0 1	C1	46.0				C-1 (0.00 - 1.83) GRAVEL and COBBLES up to 3.5 inch size; GW; Gray; Nonplastic; fines washed away; (Alluvium)	**0 - 0.91** **AC then GRAVEL; GW; gray; nonplastic (Fill);** **0.91 - 3.35** **GRAVEL and COBBLES up to 3.5 inch size; GW; gray; nonplastic; subrounded to subangular (Alluvium);**		HQTB coring.		
2 3	C2	39.0				C-2 (1.83 - 3.35) GRAVEL up to 3 inch size; GW; Gray; Nonplastic; (Alluvium)					
4	C3	100.0		RQD = 98%		C-3 (3.35 - 4.87) BASALT; Gray; Fresh; Medium Hard (R3); RQD = 98%; wide jointed with spacing up to 4 feet; calcite mineralization along healed joints; unconfined compression = 40,274 kPa; Intursive Baslalt	**3.35 - 6.39** **BASALT; gray to 6.39m then light brown; fresh to 6.39m then moderately weathered; (R2) to (R3); wide jointed; spacing up to 4 feet; calcite in joints; silt in joints in last 0.3m (Intrusive Basalt);**				
5 6	C4	100.0		RQD = 74%		C-4 (4.87 - 6.39) BASALT; Gray to 6.08m then Light Brown; Fresh then Moderately Weathered; Soft (R2); RQD = 74%; wide jointed with spacing to 4 feet to 6.08m then very close jointed; calcite in healed joints; yellow silt in joints below 6.08m; unconfined compression = 9,791 kPa; Intrusive Basalt					
7	C5	100.0		RQD = 70%		C-5 (6.39 - 7.91) Tuffaceous SANDSTONE/SILTSTONE/LAPILLI TUFF to 7.3m then LAPILLI TUFF; Light Brown grading to Light Gray; grades from Predominately Decomposed to Fresh; Extremely Soft (R0) to Medium Hard (R3); RQD = 70%; close to moderately close jointed with spacing up to 2 feet; sandstone and siltstone dipping at 45 degrees; discoloration along joints to 7.3m; calcite cementation in lapilli tuff; Eugene Fm	**6.39 - 7.3** **interbedded tuffaceous SANDSTONE; brown grading to gray; predominately decomposed to fresh; (R0) to (R3); very close to moderately close jointed (Eugene Fm);**				
8 9	C6	88.0		RQD = 93%		C-6 (7.91 - 9.43) LAPILLI TUFF; Green Gray; Fresh; Medium Hard (R3); RQD = 93%; wide jointed; calcite cemented; unconfined compression = 39,329 kPa; Eugene Fm	**7.3 - 10.95** **LAPILLI TUFF; green gray; fresh; (R2) to (R3); wide jointed; calcite cemented clasts (Eugene Fm);**				
10	C7	100.0		RQD = 100%		C-7 (9.43 - 10.95) LAPILLI TUFF; Green Gray; Fresh; Soft (R2); RQD = 100%; wide jointed; calcite cemented; unconfined compression = 24,105 kPa; Eugene Fm					
11 12							**10.95** **End of Hole**				

Subsurface Geologic Profile



"NB" PROFILE, 7.2 METERS RIGHT OF CENTERLINE

Lines Connecting The Borings Were Drawn To Aid Visualization Of Layer Boundaries Used For Design. The Boundaries Shown Are Approximate Only And Not Intended To Represent The Exact Location Of A Change Between One Material And Another. Actual Boundaries Between Layers May Be Abrupt Or Gradual.

The Drill Logs used in Compiling this Drawing are contained within the Geotechnical report and available upon request.

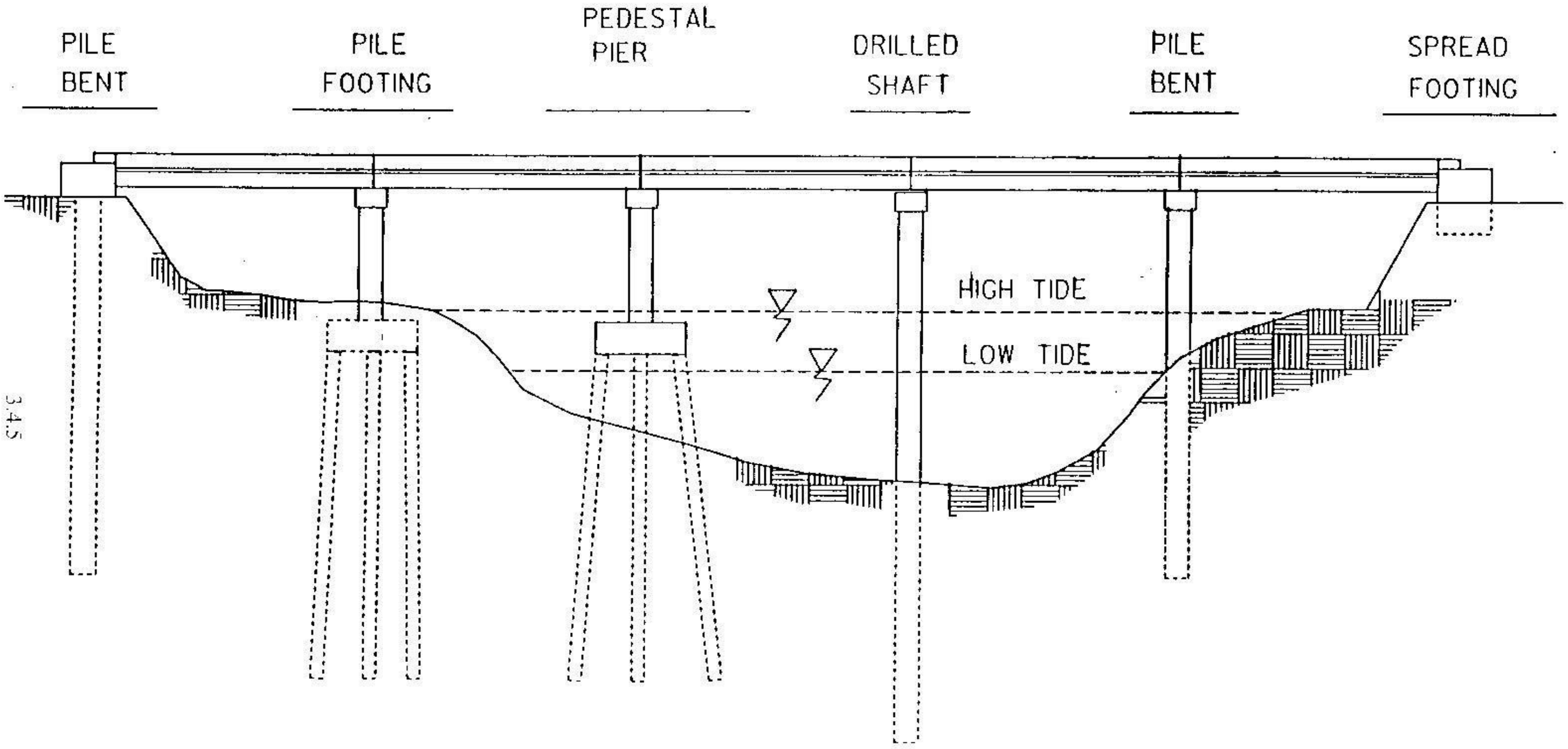
Horiz. Scale: 1:500
Vert. Scale: 1:200

For Legend See Sheet GB-5

F:\ODOT_DATA\Projects\09350_MLK Grand...m\gb\final\09350gd1.dgn 6/9/2006 10:49:07 AM 1db08

Foundation type depends on combinations of:

- Foundation Materials & Conditions
- Structure Type & Loads
- Performance Criteria
- Site Conditions/Construction Constraints
- Extreme Event Effects
- Seismic Loads (Liquefaction Potential)
- Scour Depths
- Costs & Construction Time



BRIDGE FOUNDATION TYPES

Types of Foundations

Shallow Foundations

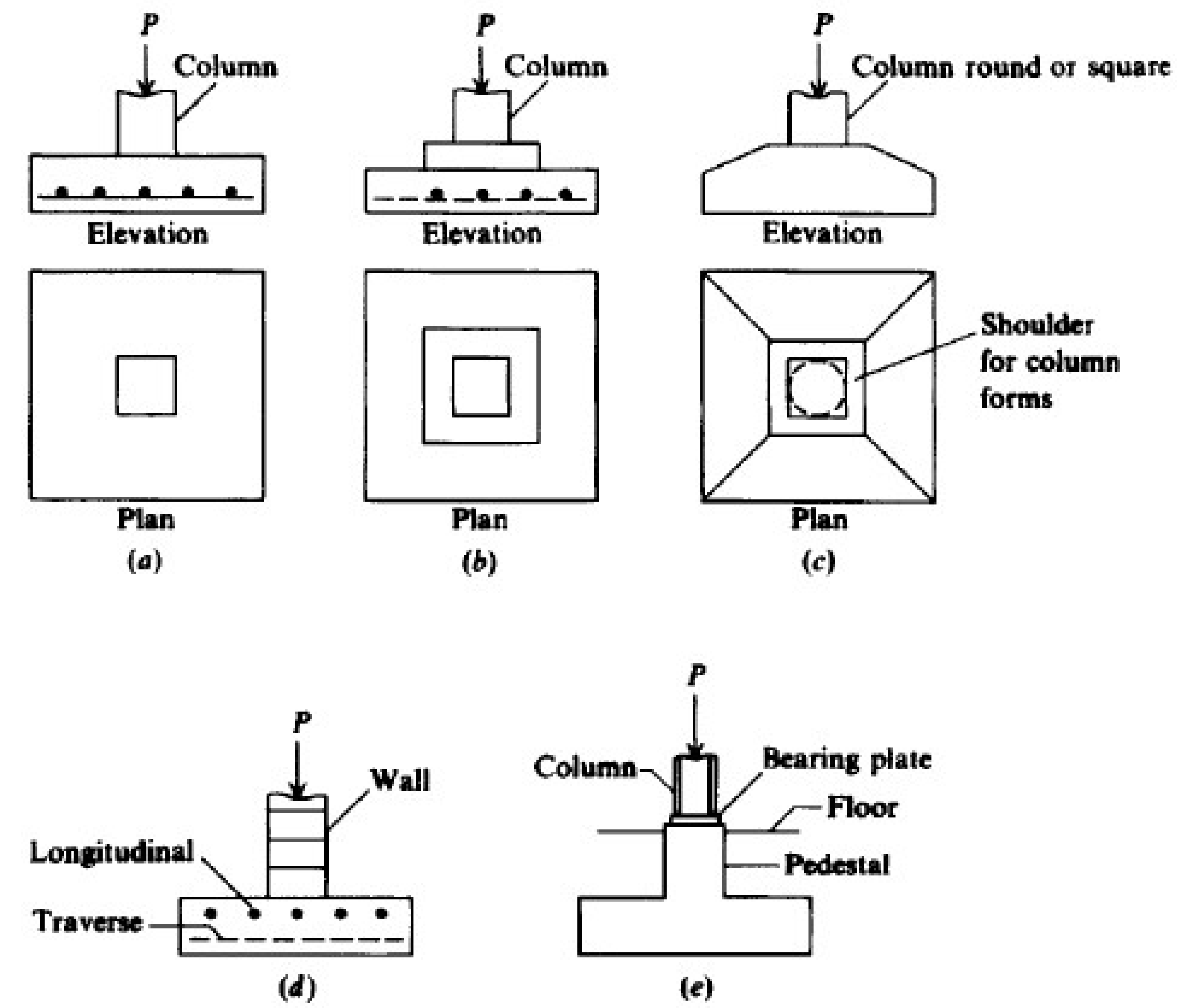
Spread Footings (on engineered fill)

MSE Abutment Wall

Deep Foundations

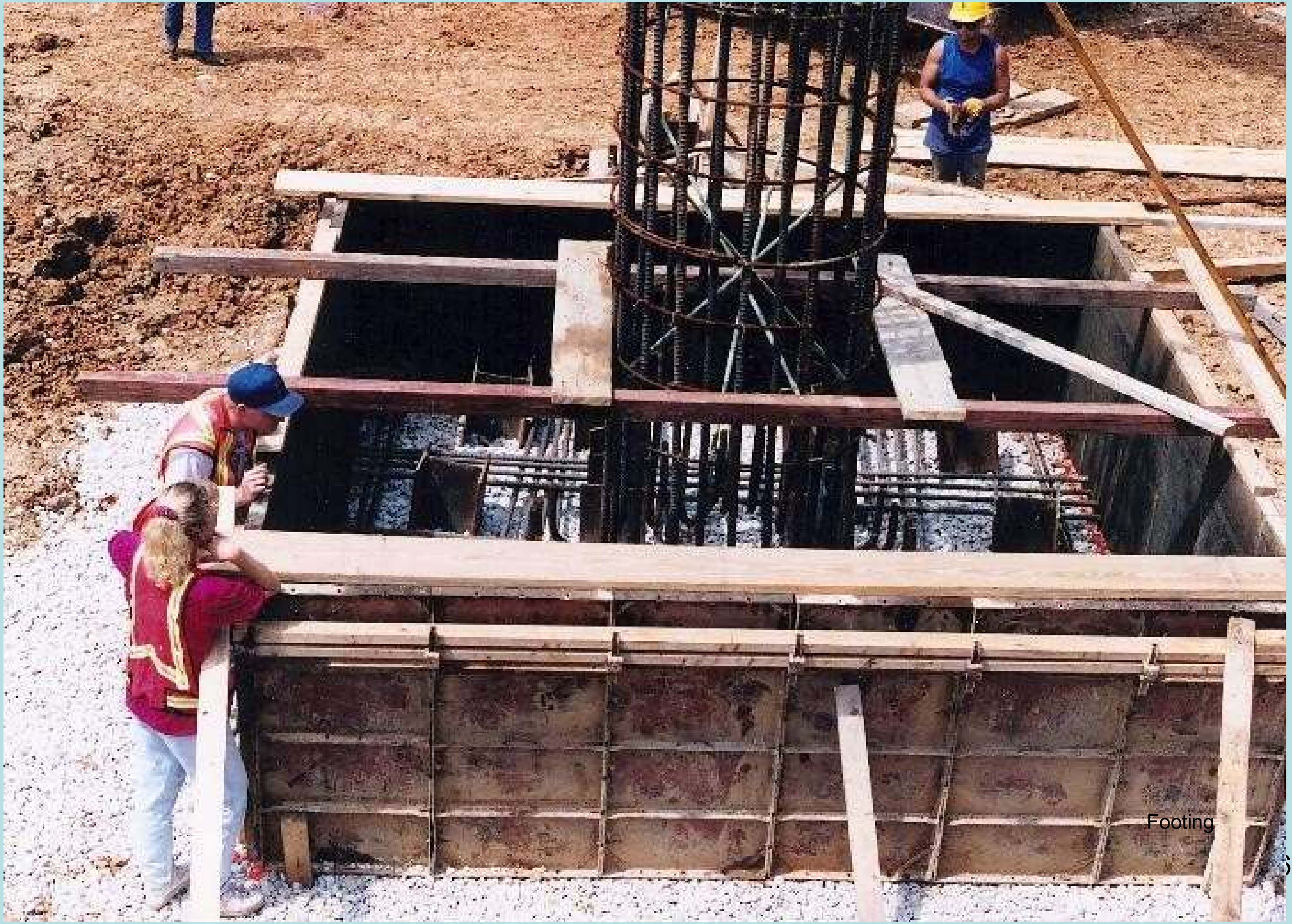
- Driven Piles
- Drilled Shafts/Bored Piles
- Micropiles

Typical Isolated Footings



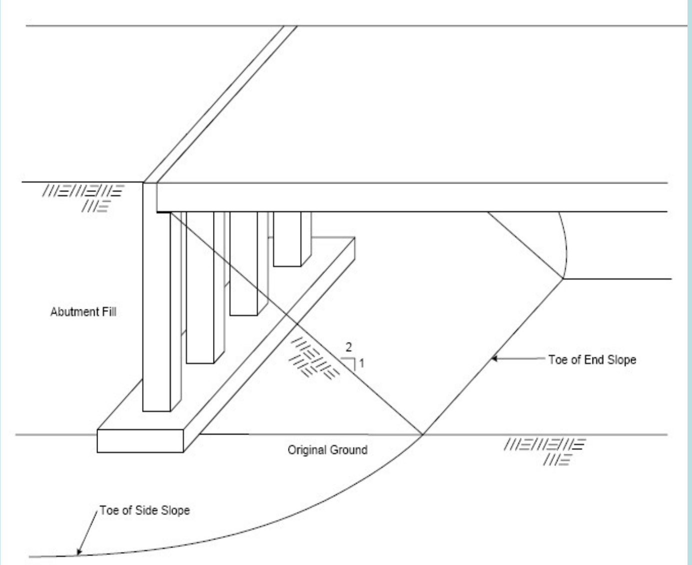
Column Footing

Pile Cap Column Footing

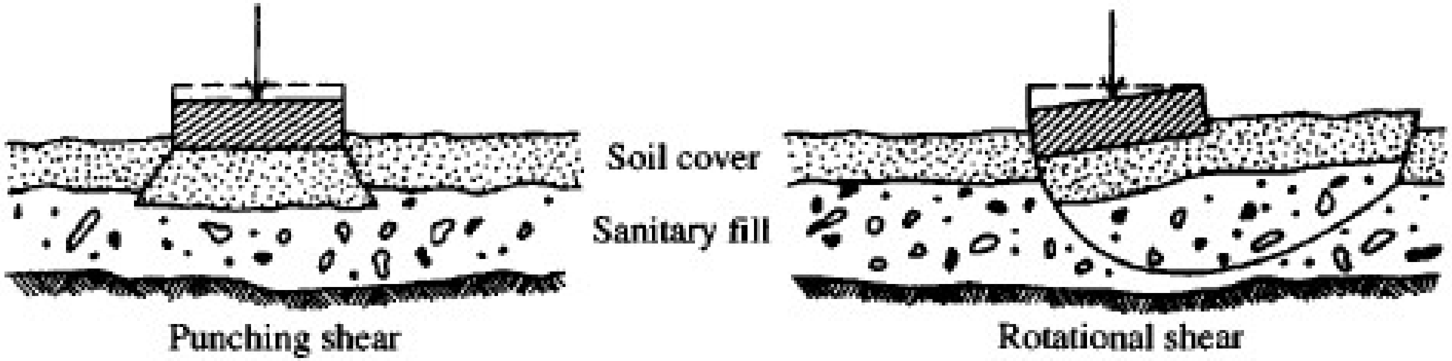


Spread Footing Design

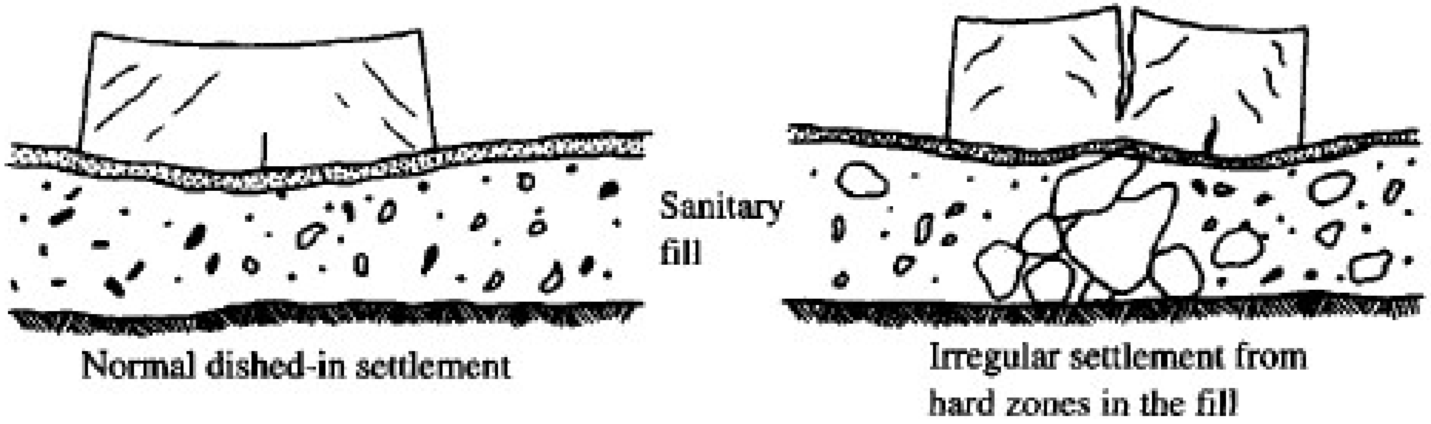
- Settlement
- Bearing Resistance
- Sliding Resistance
- Overturning (eccentricity)
- Overall Stability (slope stability)



Thin Weak Deposit

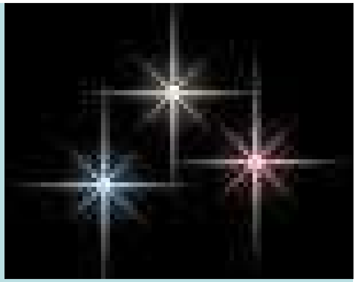


(a) Bearing capacity.



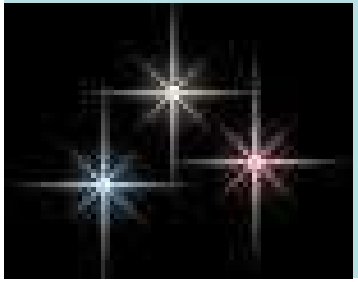
(b) Settlements.

Footing Depth

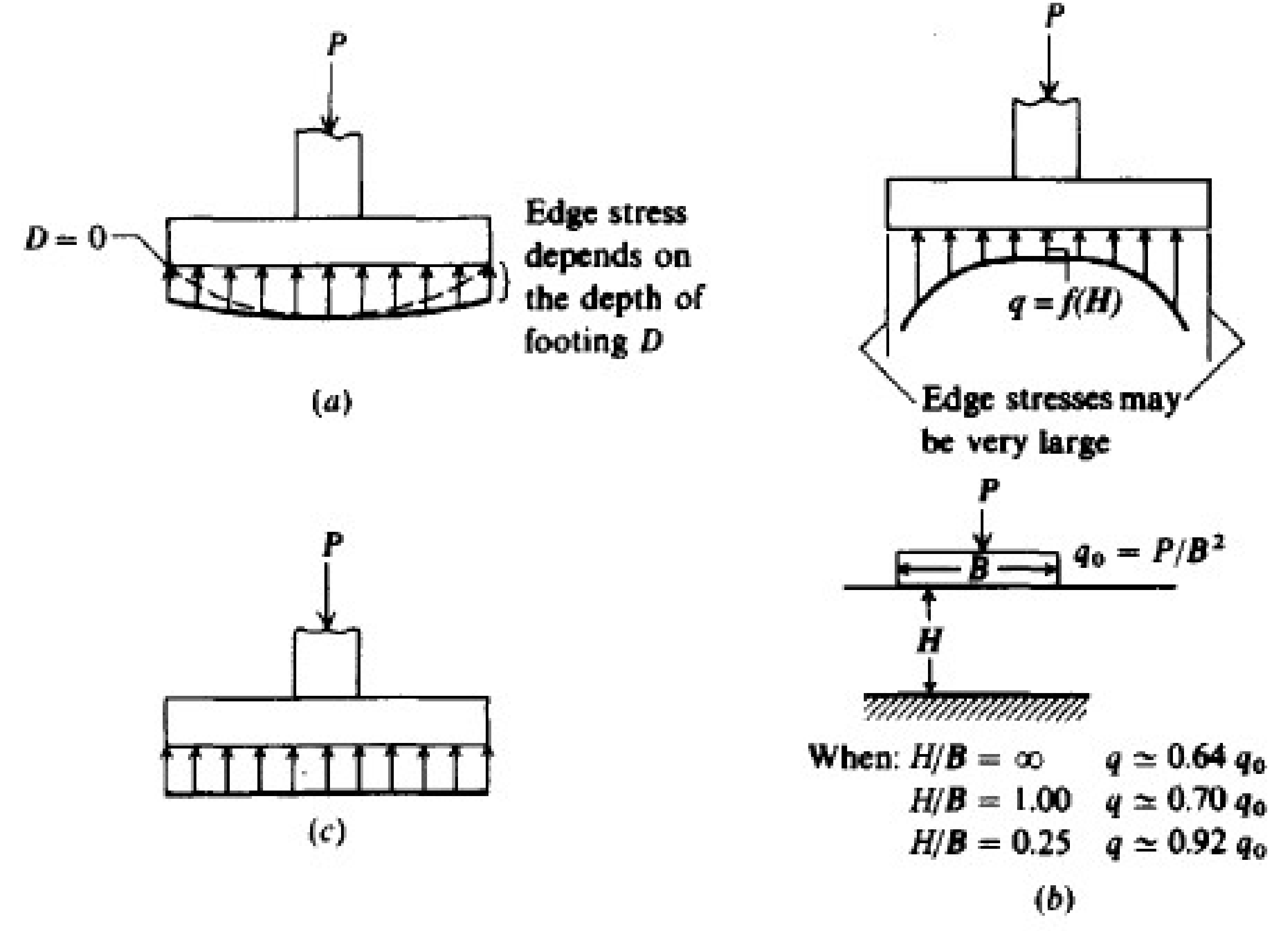


- 1. Depth of Erosion/Scour
- 2. Fill/Uncompacted
- 2. Zone of Moisture Changes
- 3. Organic Matter
- 4. Maximum Depth of Unsupported Excavation

$$z_f = \frac{2c}{(\mathrm{SF})\gamma\sqrt{K}} - \frac{q_o}{(\mathrm{SF})\gamma}$$

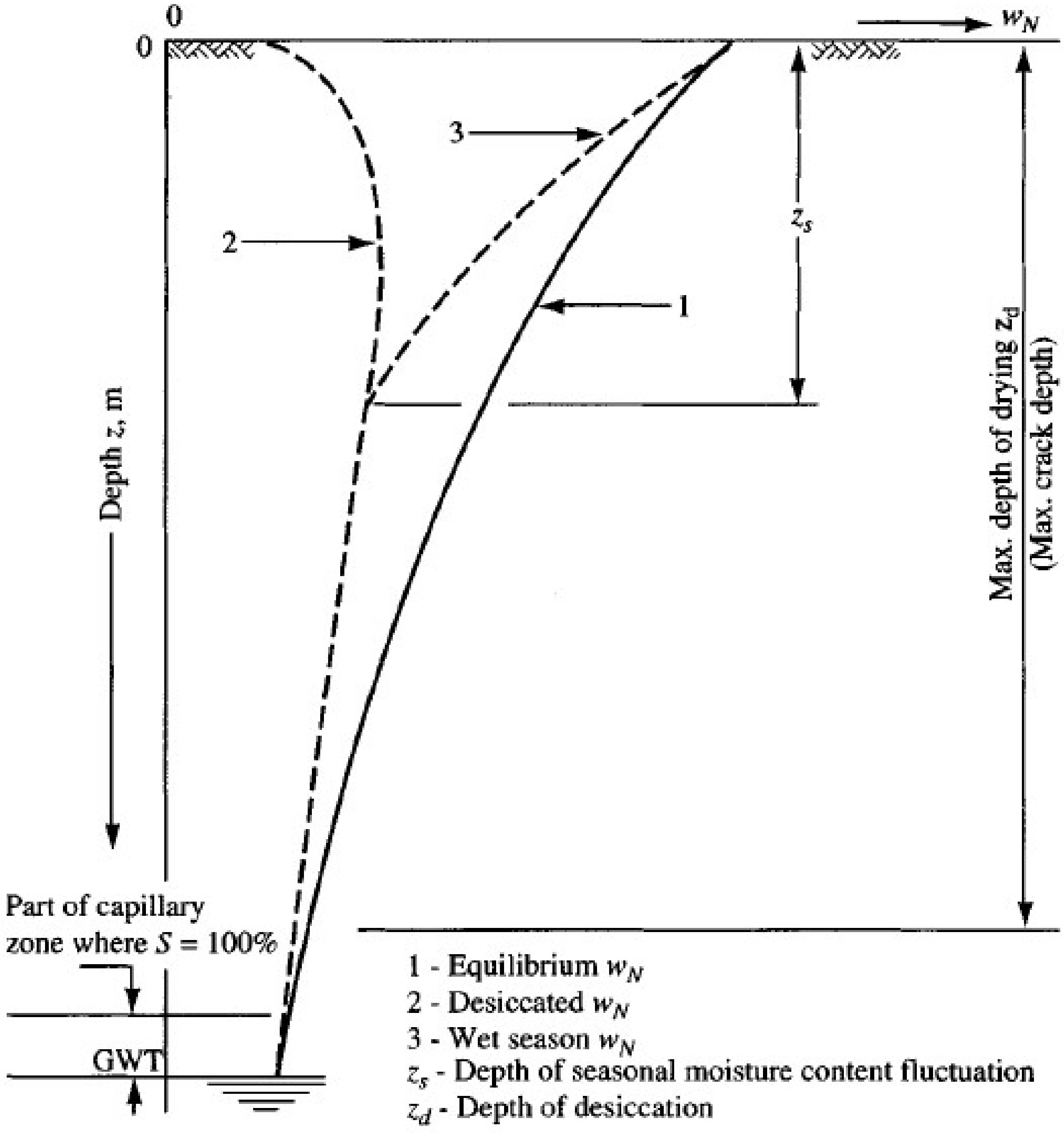


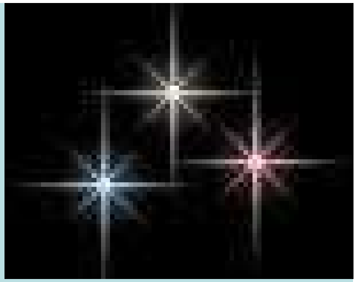
Contact Pressures



Effect of Raising Water Table

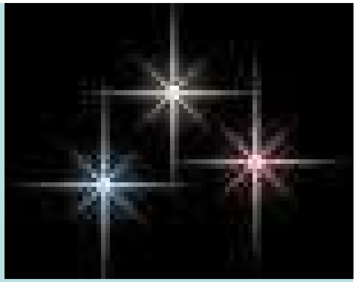
- The Foundation may Float
- Additional Settlement due to reduced Effective Stress

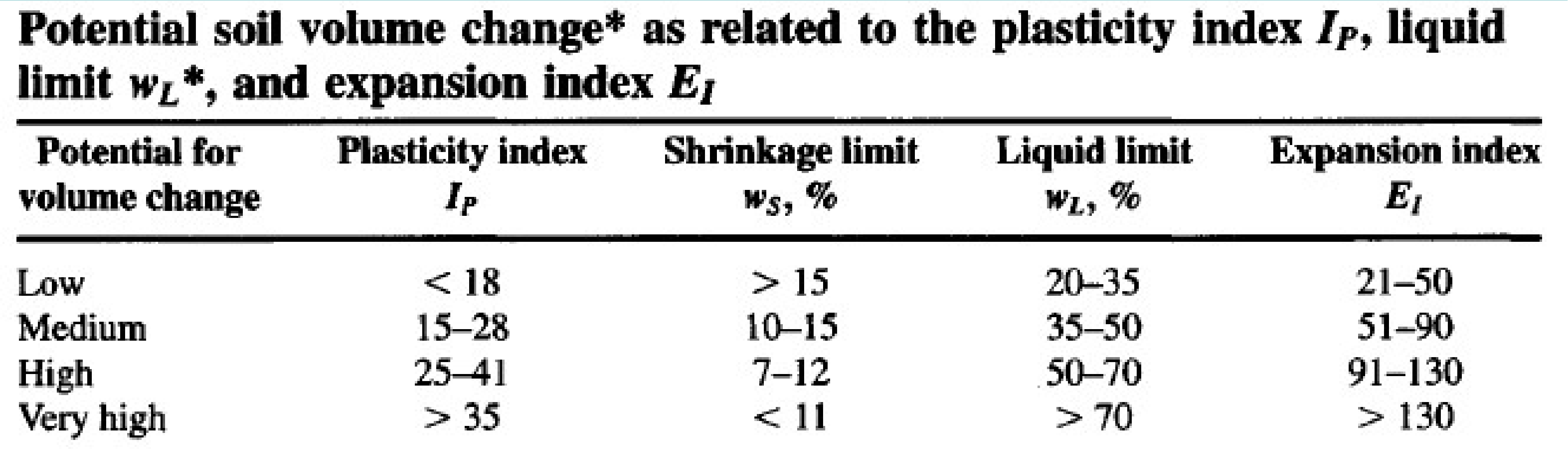




Zone of Fluctuation in Expansive Soils

Identification of Expansive Soils; Min. Pressure Reqd. and Swell Potential



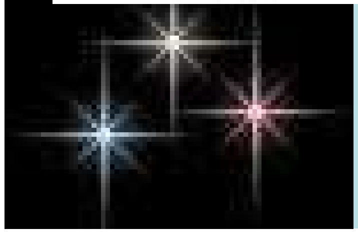


Potential soil volume change* as related to the plasticity index I_P, liquid limit w_L*, and expansion index E_I

Potential for volume change	Plasticity index I_P	Shrinkage limit w_S, %	Liquid limit w_L, %	Expansion index E_I
Low	< 18	> 15	20–35	21–50
Medium	15–28	10–15	35–50	51–90
High	25–41	7–12	50–70	91–130
Very high	> 35	< 11	> 70	> 130

$$\log P_s = 2.132 + 0.0208 w_L + 0.665 \rho_d - 0.0269 w_N \qquad (\text{kg/cm}^2)$$

$$\log S_p = 0.0367 w_L - 0.0833 w_N + 0.458 \qquad (\text{percent})$$

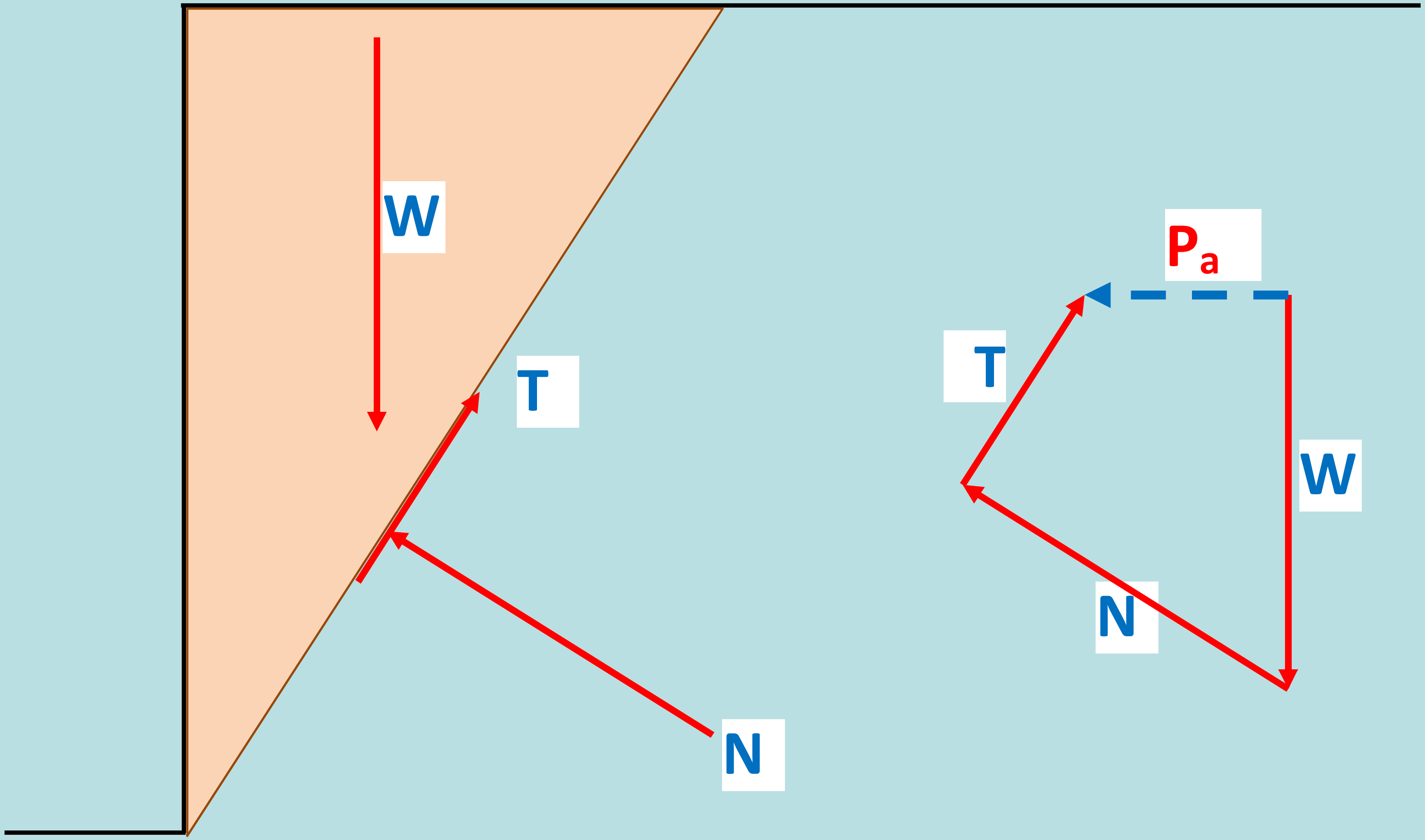


Reinforced Soil Structures for Bridge Approaches & Abutments

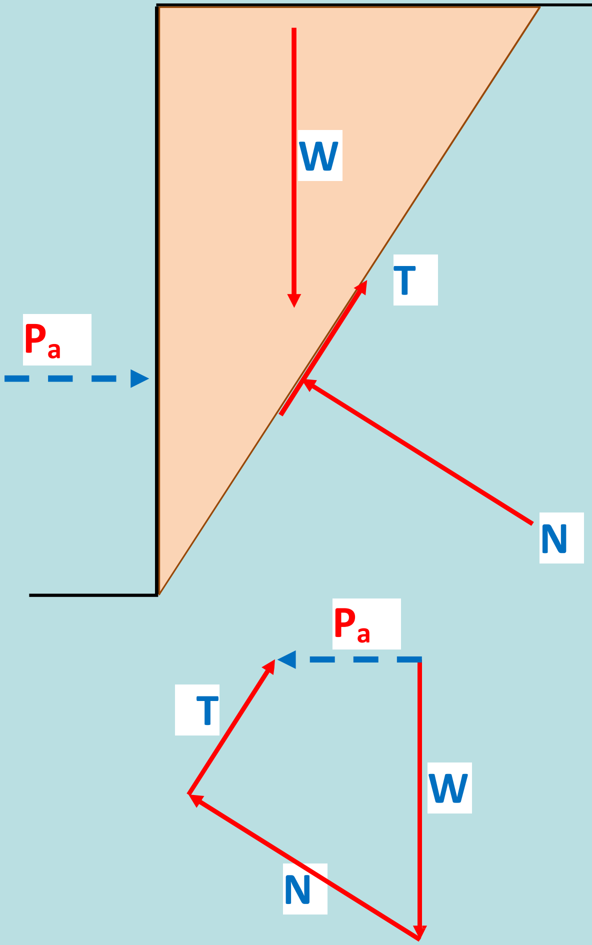
Contents

- Externally/Internally stabilized
- Reinforced soil walls & Reinforced soil slopes
- Extensible versus inextensible reinforcement
- Role of facing
- Reinforced soil walls

Equilibrium of a Wedge of Soil



Externally Stabilized Retaining Structures

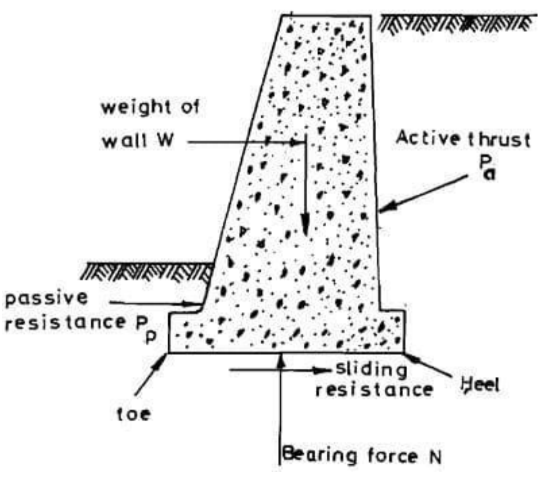


Externally Stabilized Retaining Structures

- Mass Gravity
  - Masonry
  - PCC
  - Gabions / Cribs
- RCC
  - Cantilever
  - Counterfort
  - Buttressed
- Embedded
  - Sheet piles
  - Bored piles
  - Diaphragm walls

Mass Gravity Retaining Walls

PCC Retaining Walls

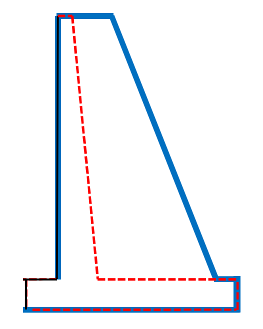


RR Masonry Retaining Walls

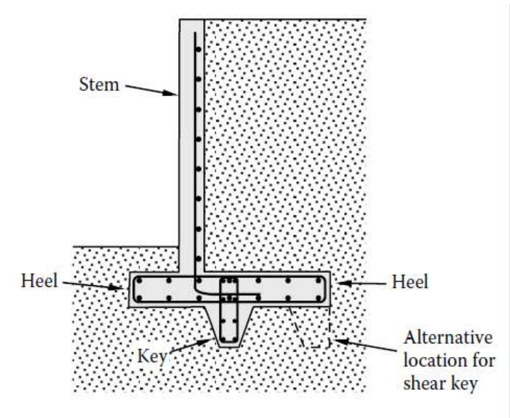
Gabion Retaining Walls

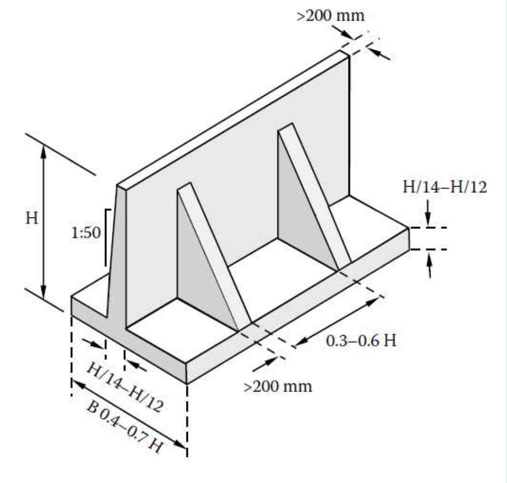
Crib Retaining Walls

RCC Retaining Walls

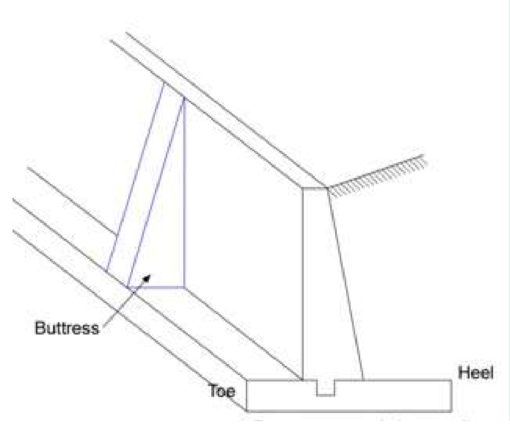


Cantilever Retaining Wall



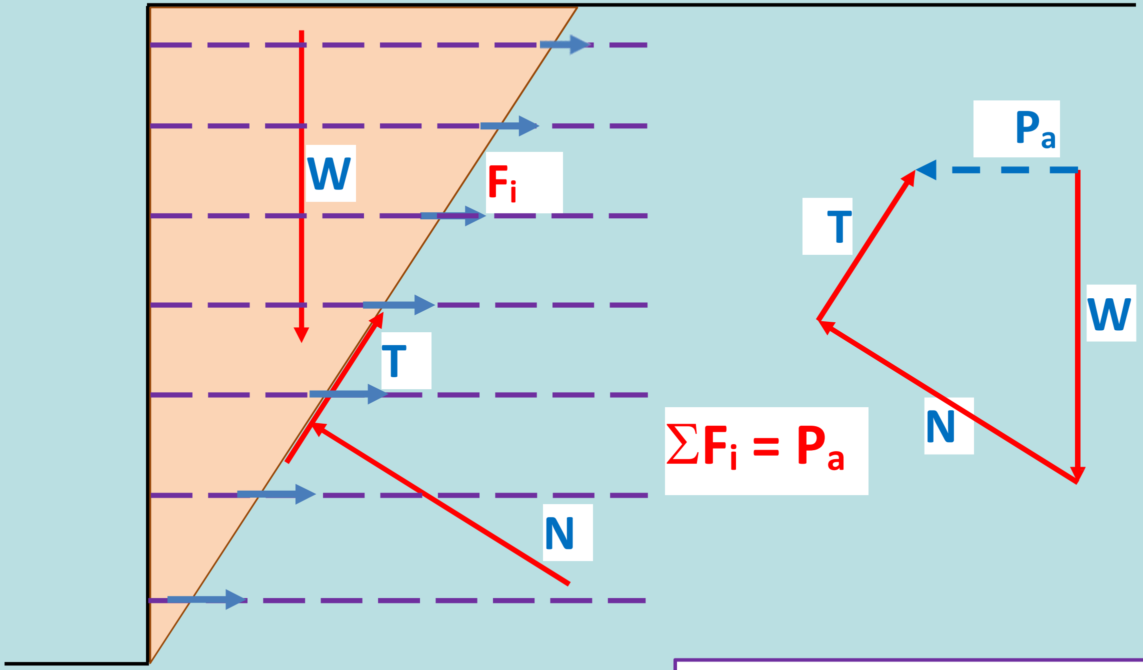


Counterfort Retaining Wall



Buttress Retaining Wall

Internally stabilized retaining structures

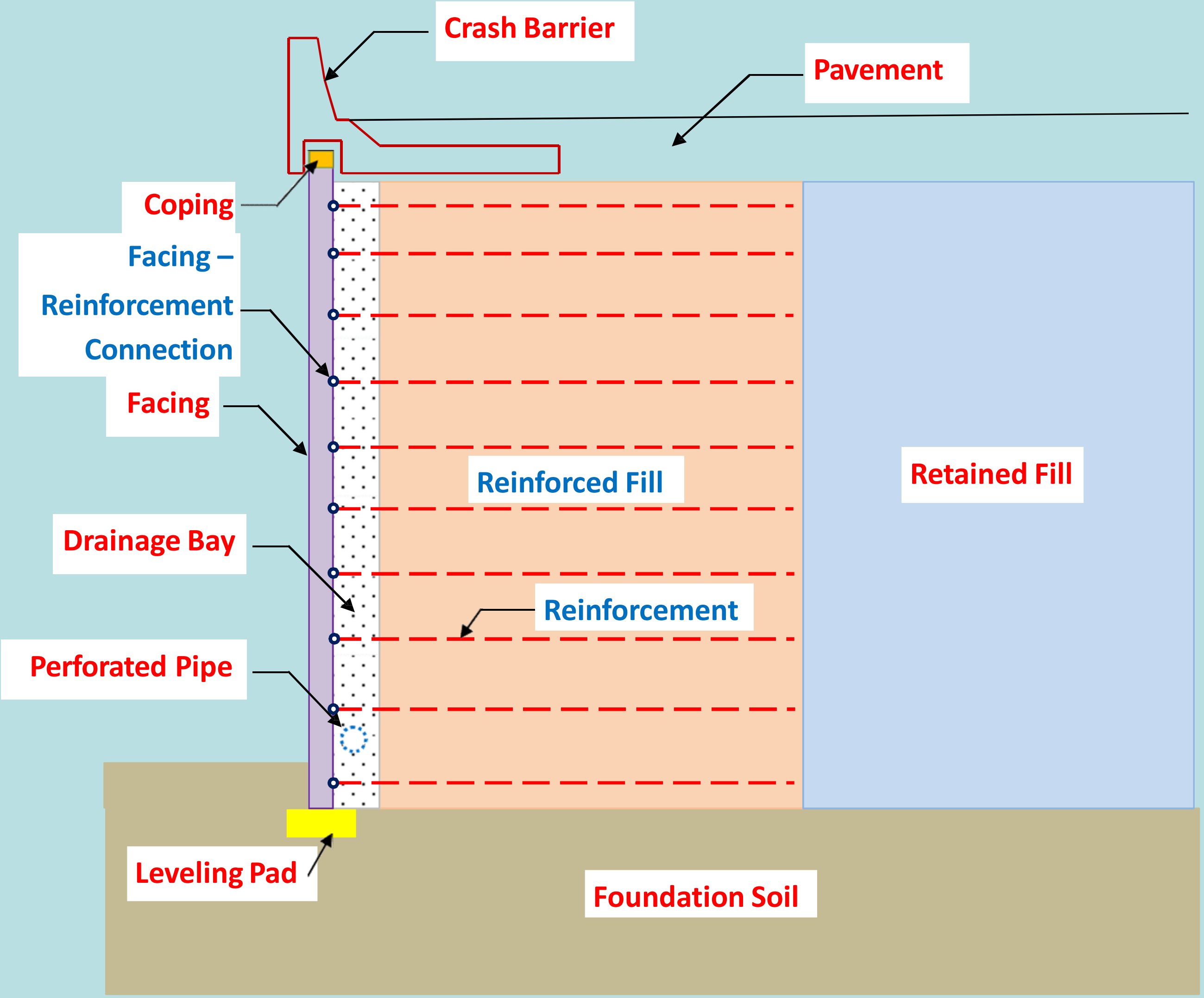


$\Sigma F_i = P_a$

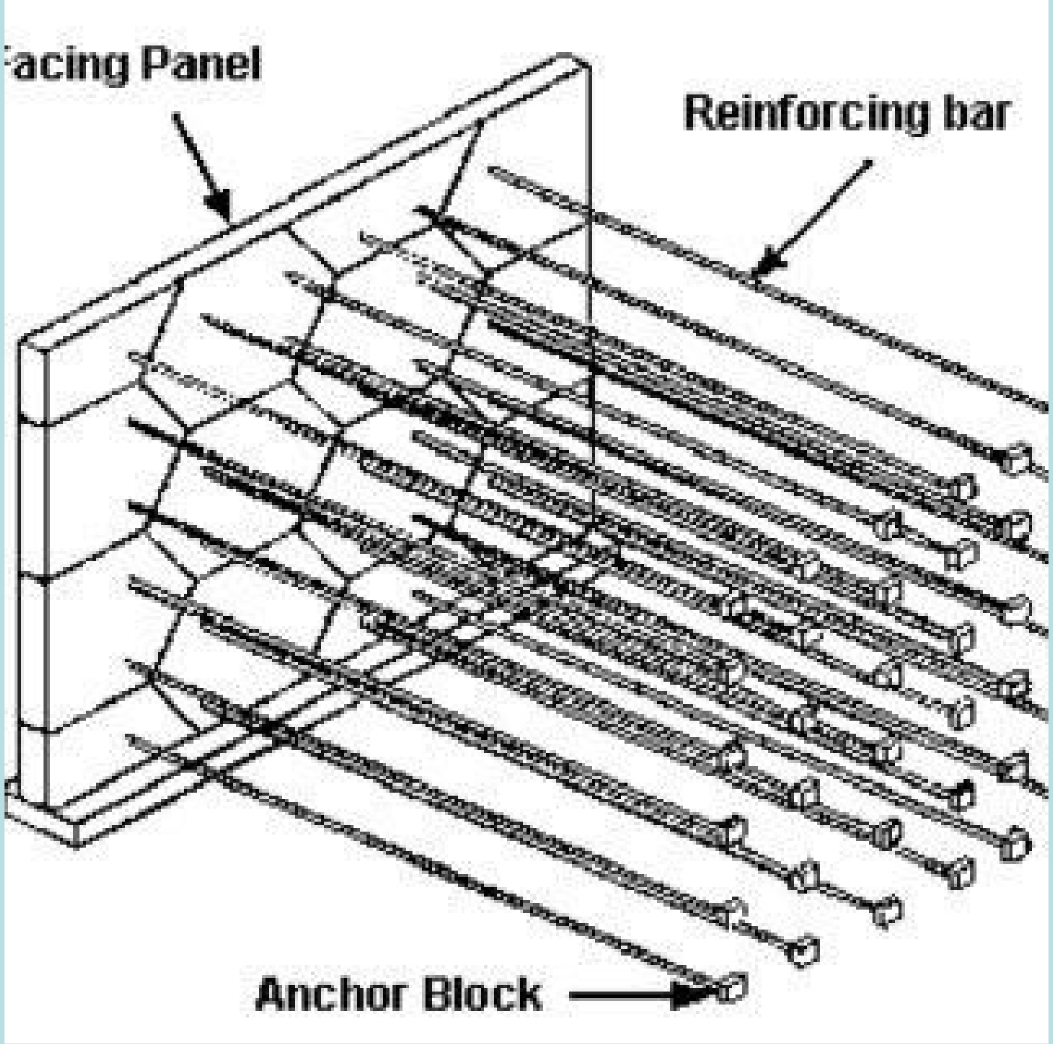
Internally Stabilized Retaining Structures

- **Reinforced soil walls**
- **Anchored earth walls**
- **Soil nail walls**

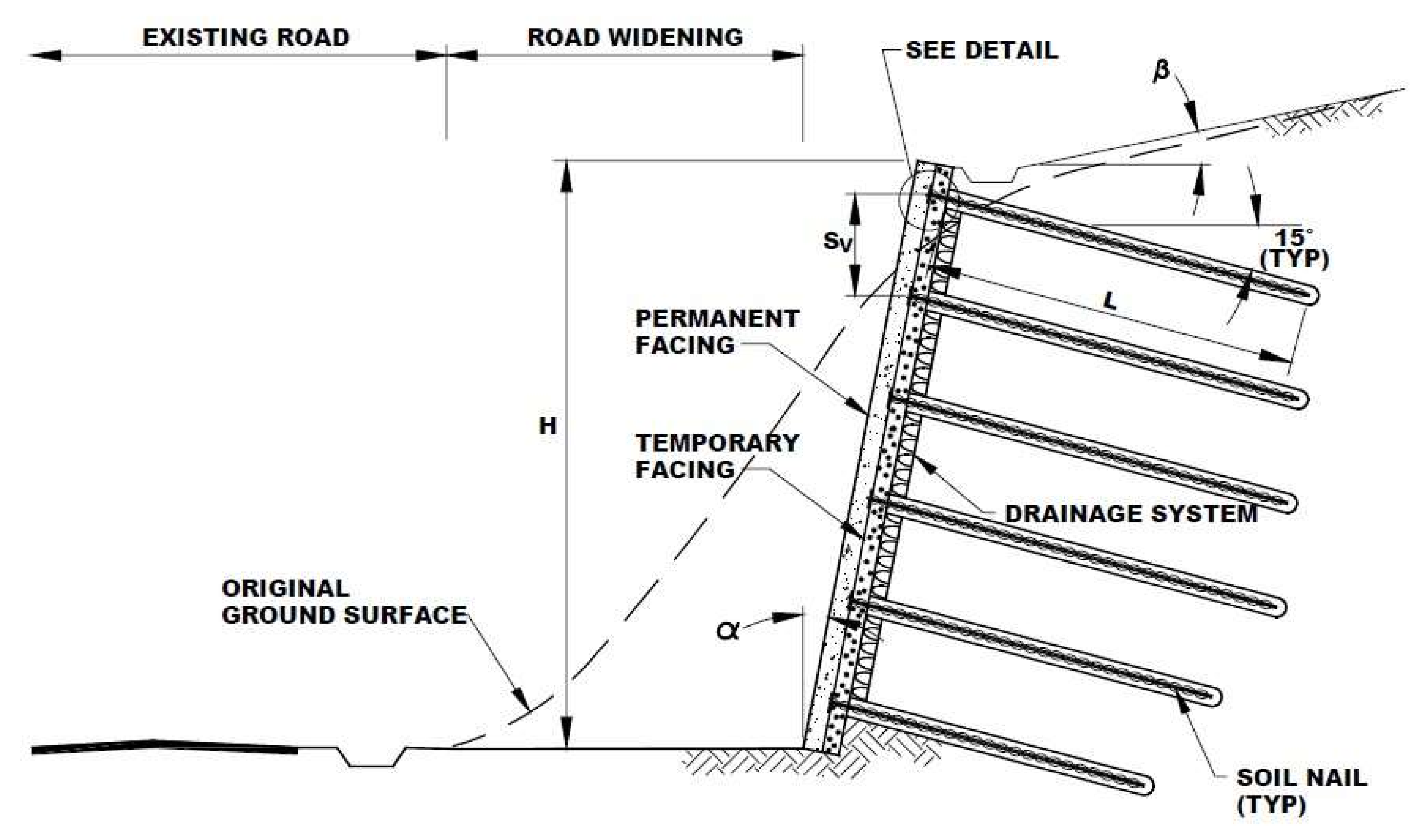
Reinforced Soil Walls



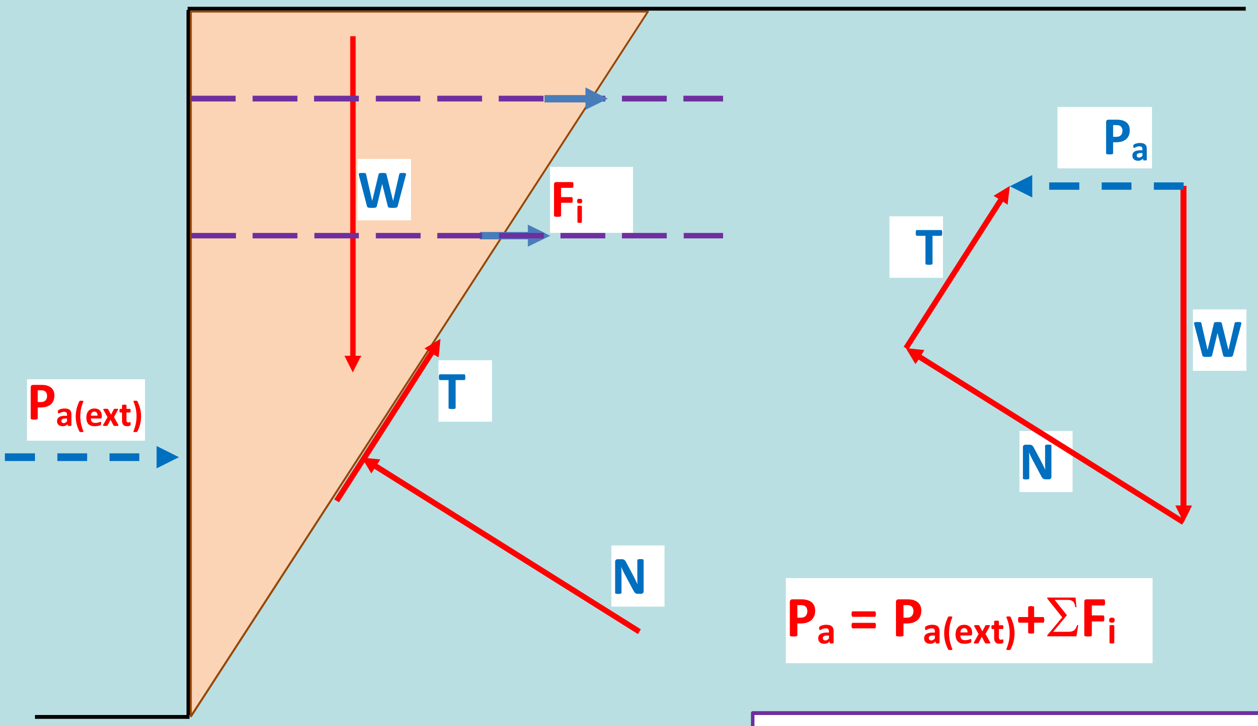
Anchored Earth Walls



Soil Nail Walls



Mixed Type of Retaining Structures

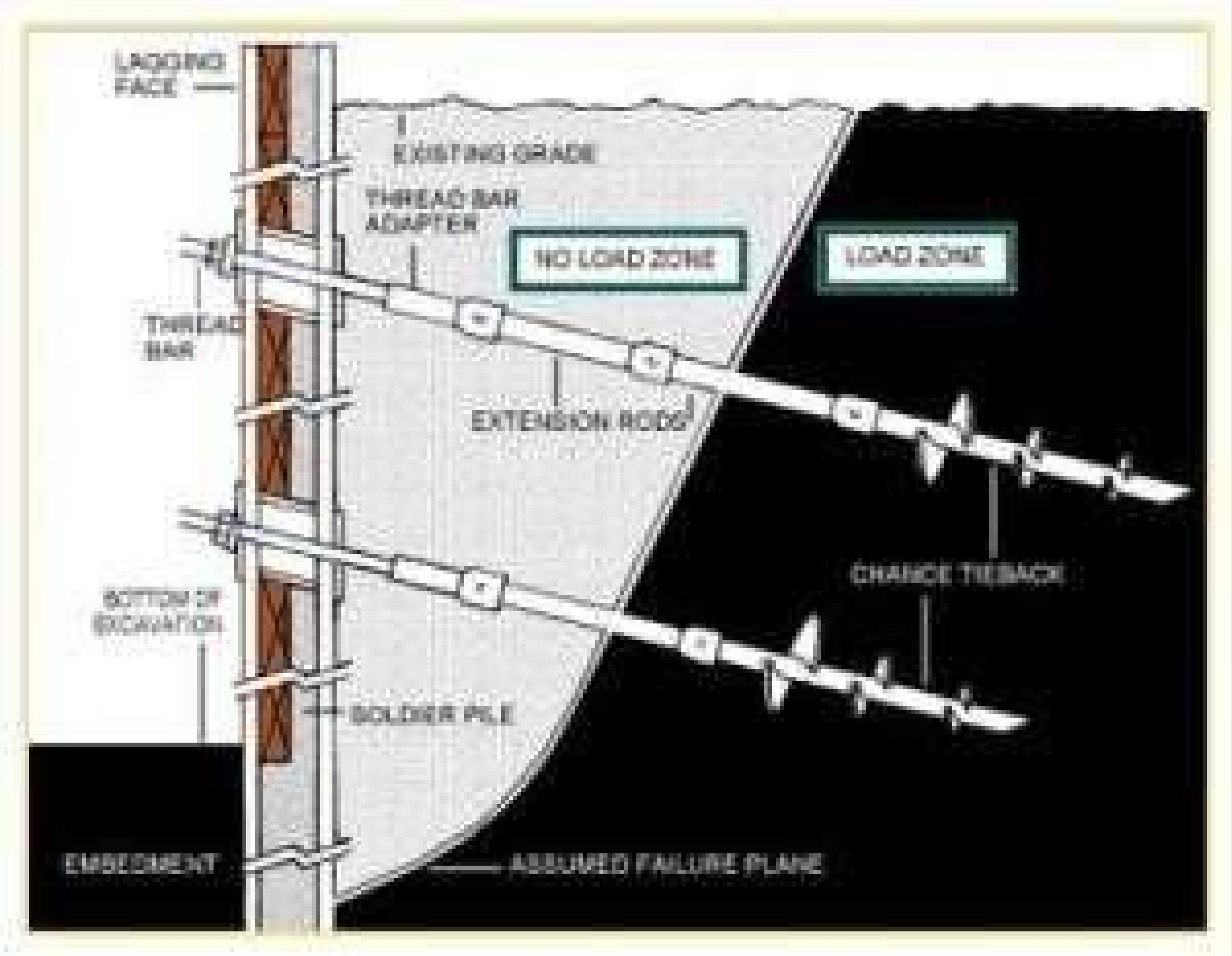


$P_a = P_{a(ext)} + \Sigma F_i$

Mixed Type of Retaining Structures

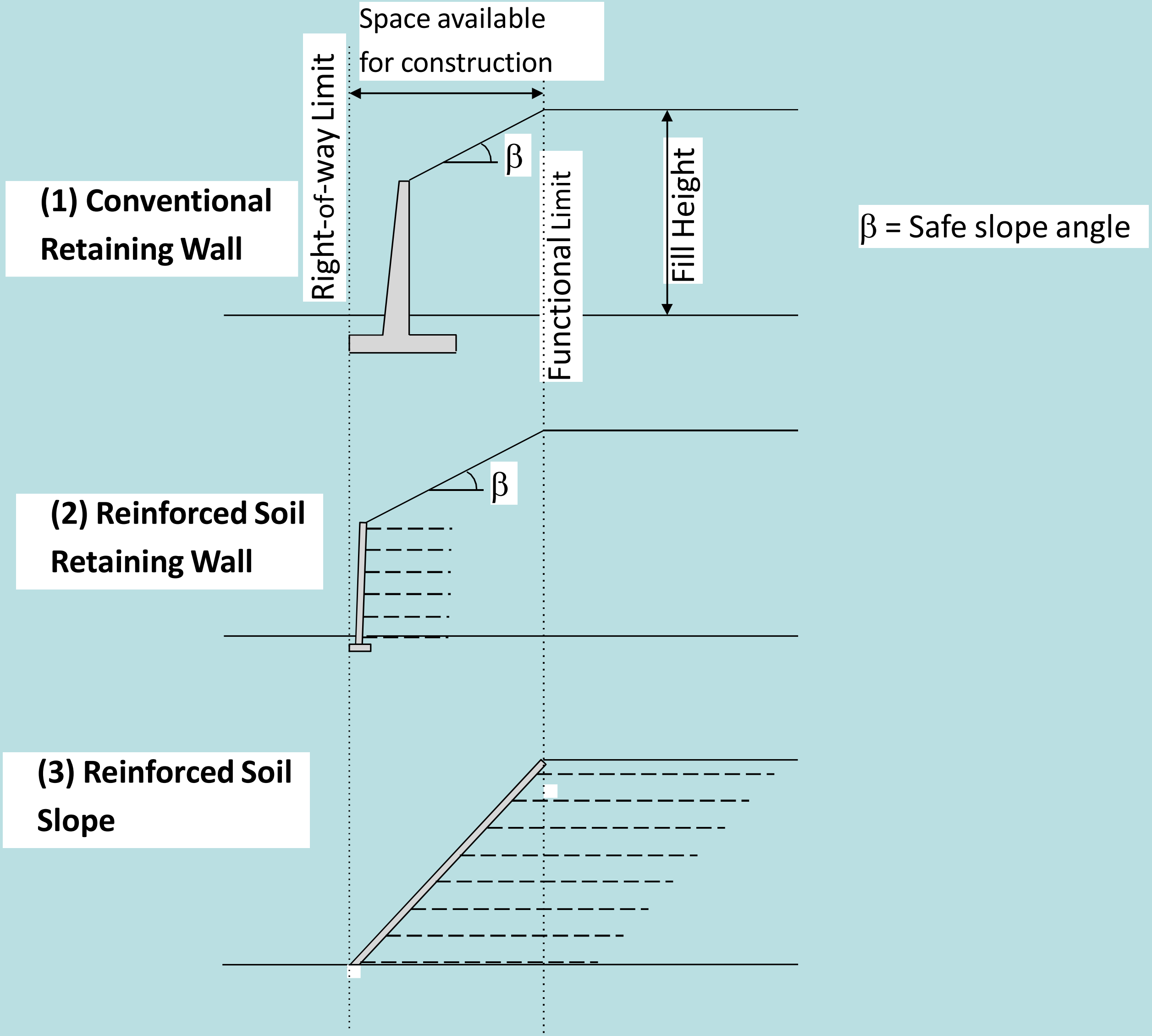
- Anchored sheet piles
- Tie-back retaining walls

Tie-back Retaining Walls



Reinforced Soil Walls & Reinforced Soil Slopes

Fill Retention Options



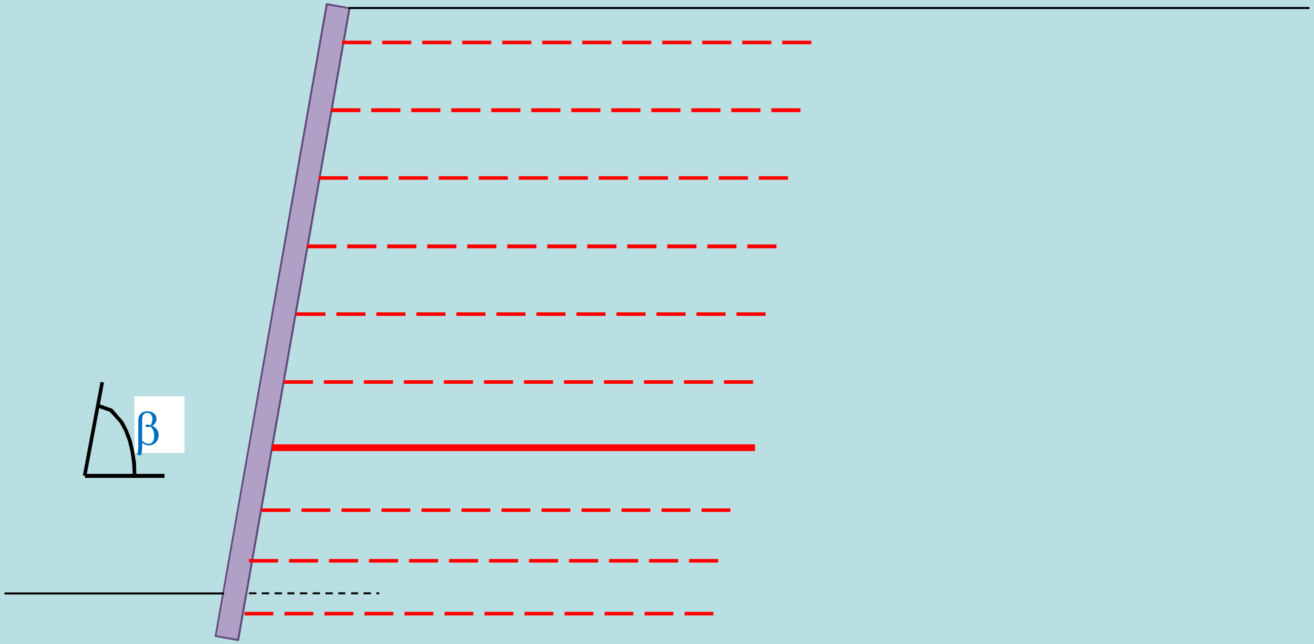
(1) Conventional Retaining Wall

(2) Reinforced Soil Retaining Wall

(3) Reinforced Soil Slope

β = Safe slope angle

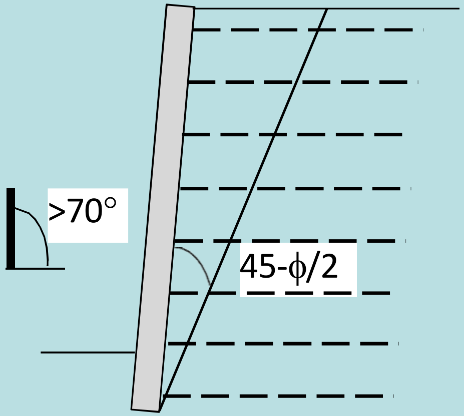
Definition of Reinforced Soil Wall and Slope



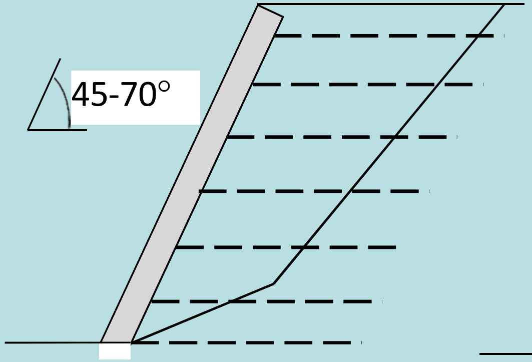
β ≥ 70° : **Reinforced Soil Wall**

β < 70° : **Reinforced Soil Slope**

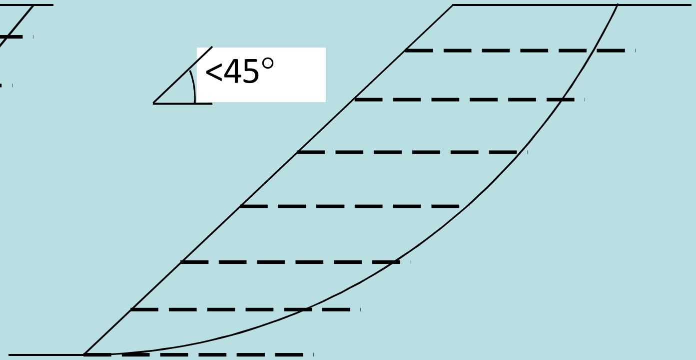
Reinforced Wall, Steep & Shallow Slope



Reinforced Soil Wall



Reinforced Soil
Steep Slope



Reinforced Soil
Shallow Slope

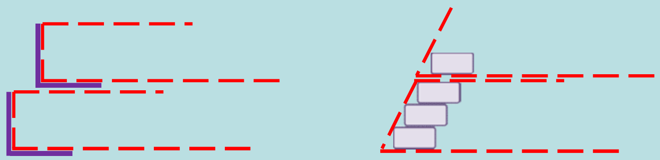
	RS Wall	RS Steep Slope	RS Shallow Slope
Slope face angle	> 70°	45 - 70°	≤ 45°
Critical failure surface	Planar	Two-part wedge	Circular arc
Embedment below GL	Min. H/20	Usually not required	
Facing	Required	Required	Not required
Reinforced fill	% Fines ≤ 15, PI ≤ 6	% Fines ≤ 50, PI ≤ 20	

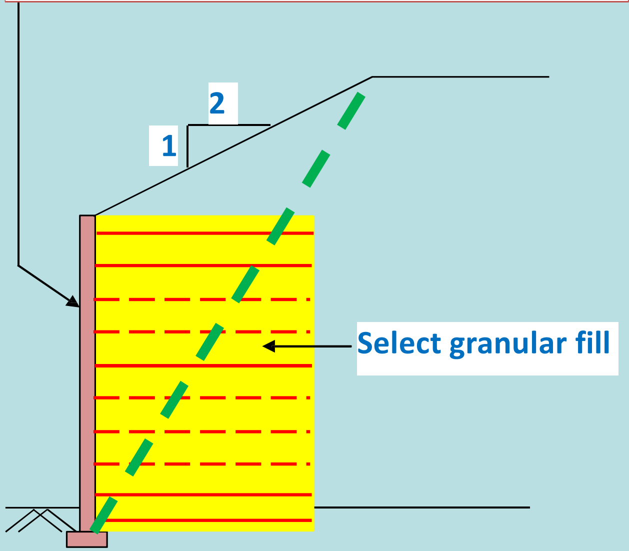
Cost comparison – Walls vs. Slopes

Facing

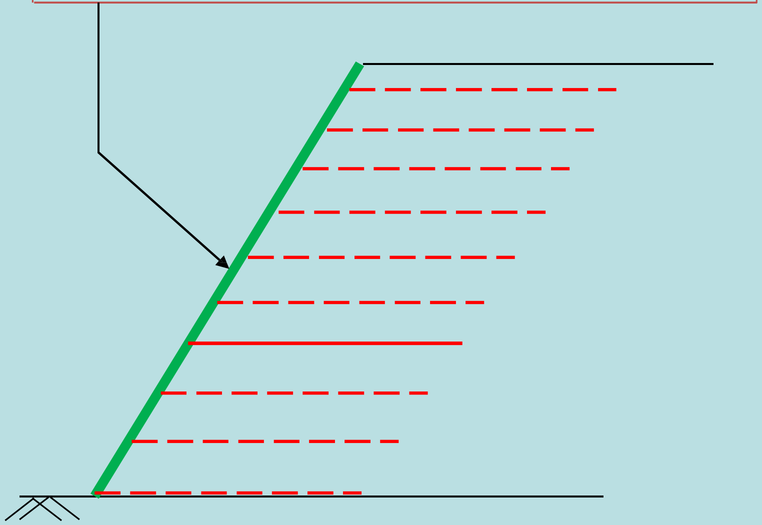
- Precast concrete discrete panels
- Precast concrete segmental blocks
- Gabions
- Welded wire mesh with stone fill

Facings for Steep Slopes





Reinforced Soil Wall

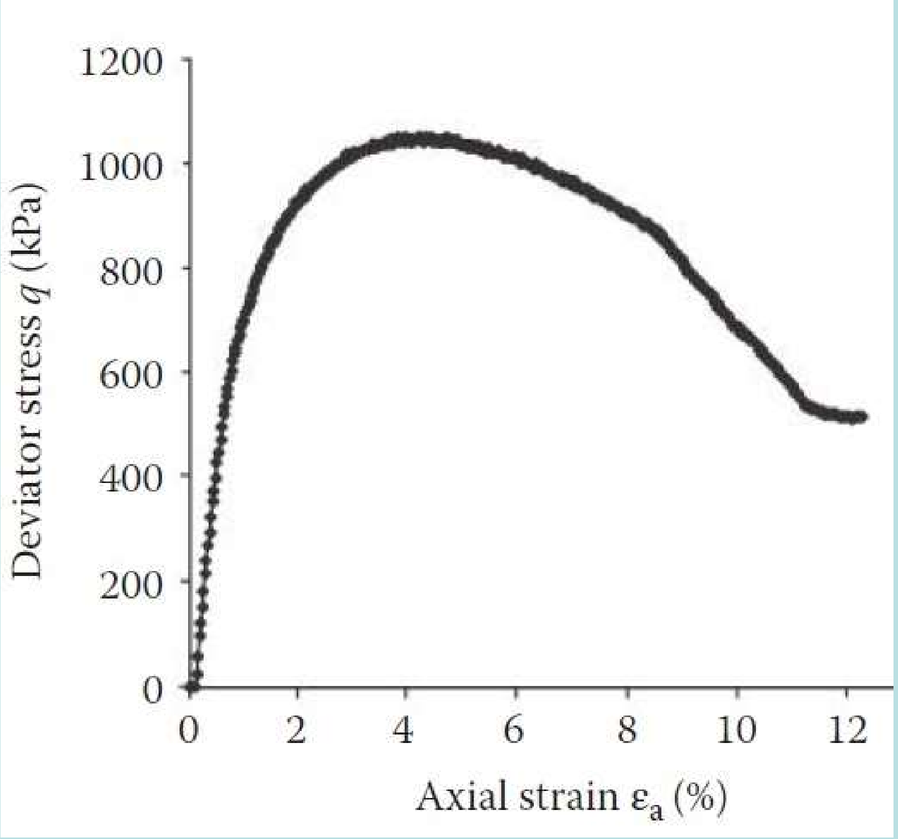


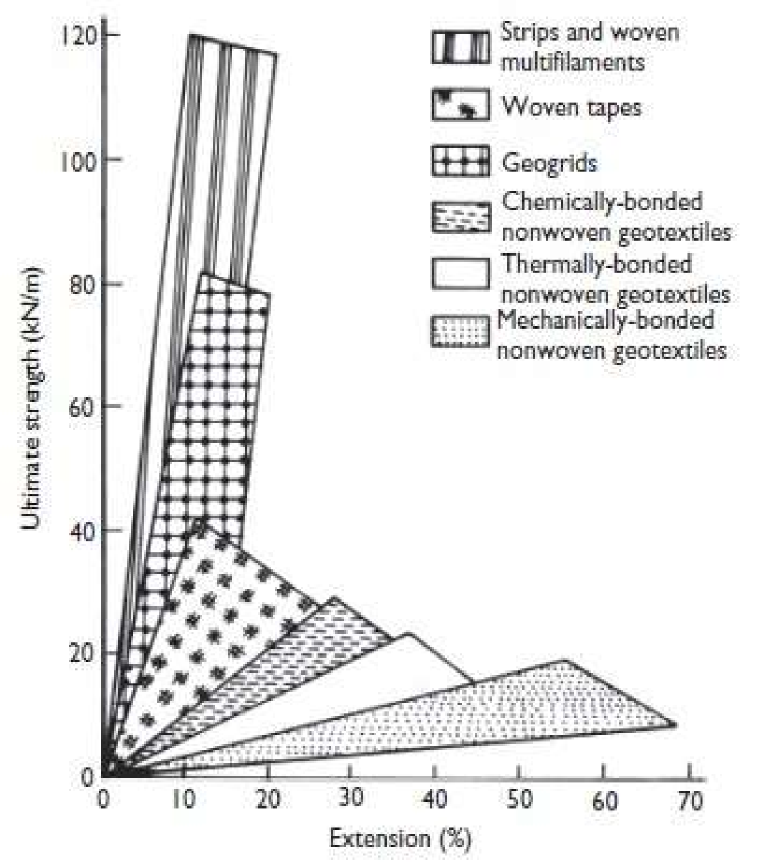
Reinforced Soil Slope

Advantage - reinforced soil slopes

- Most economic solution in many cases
- Use locally available soils
- No need of concrete panels or blocks
- Faster construction
- Sustainable and aesthetically pleasing

Stress-strain behaviour of soil and reinforcement





Based on structure stiffness

Typical steel strip reinforced soil wall

$$S_r = \frac{E\ b\ t}{S_h S_v}$$

$$= \frac{200000 * 0.050 * 0.004}{0.8 * 0.8}$$

= 62.5 MPa

Typical Geogrid reinforced soil wall

$$S_r = \frac{J\ R_c}{S_v} = \frac{1000 * 1}{0.8}$$

= 1250 kPa

= 1.25 MPa

S_r > 20 MPa, Inextensible

S_r < 20 MPa, extensible

Reinforcement types

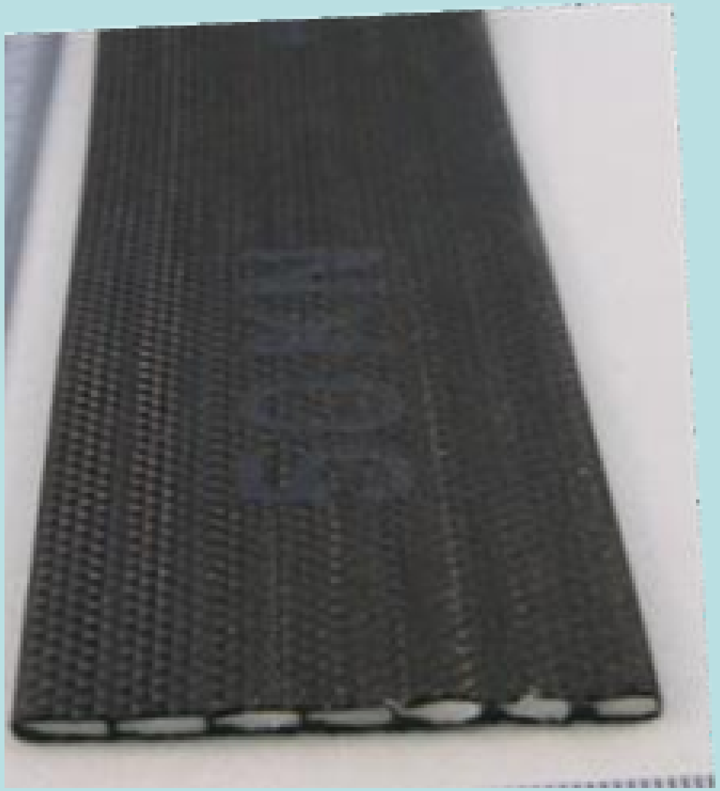
- **Inextensible**
  - Steel strips
  - Welded steel bar mats
  - Welded steel wire mesh
- **Extensible**
  - Geogrids
  - Geotextiles

Strain in reinforcement at design loads (BS 8006)

- **Extensible Reinforcement:** sustains design loads at strains greater than 1 %

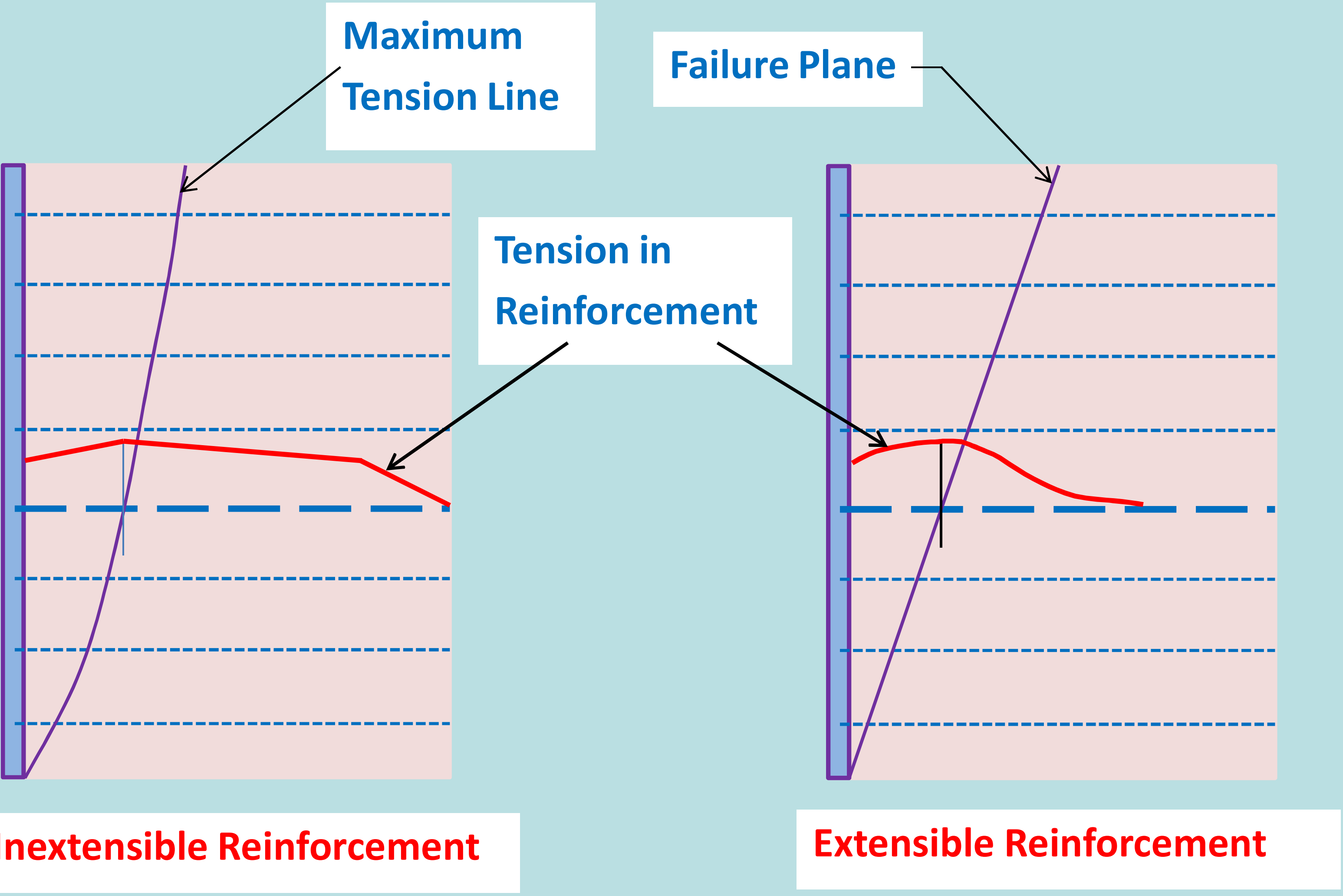
- **Inextensible Reinforcement:** sustains design loads at strains less than 1 %

Geostrips / Polymeric Straps



- Made of high tenacity polyester filament yarns
- Elongation at break typically 10-12%

Tension in the Reinforcement



Maximum Tension Line

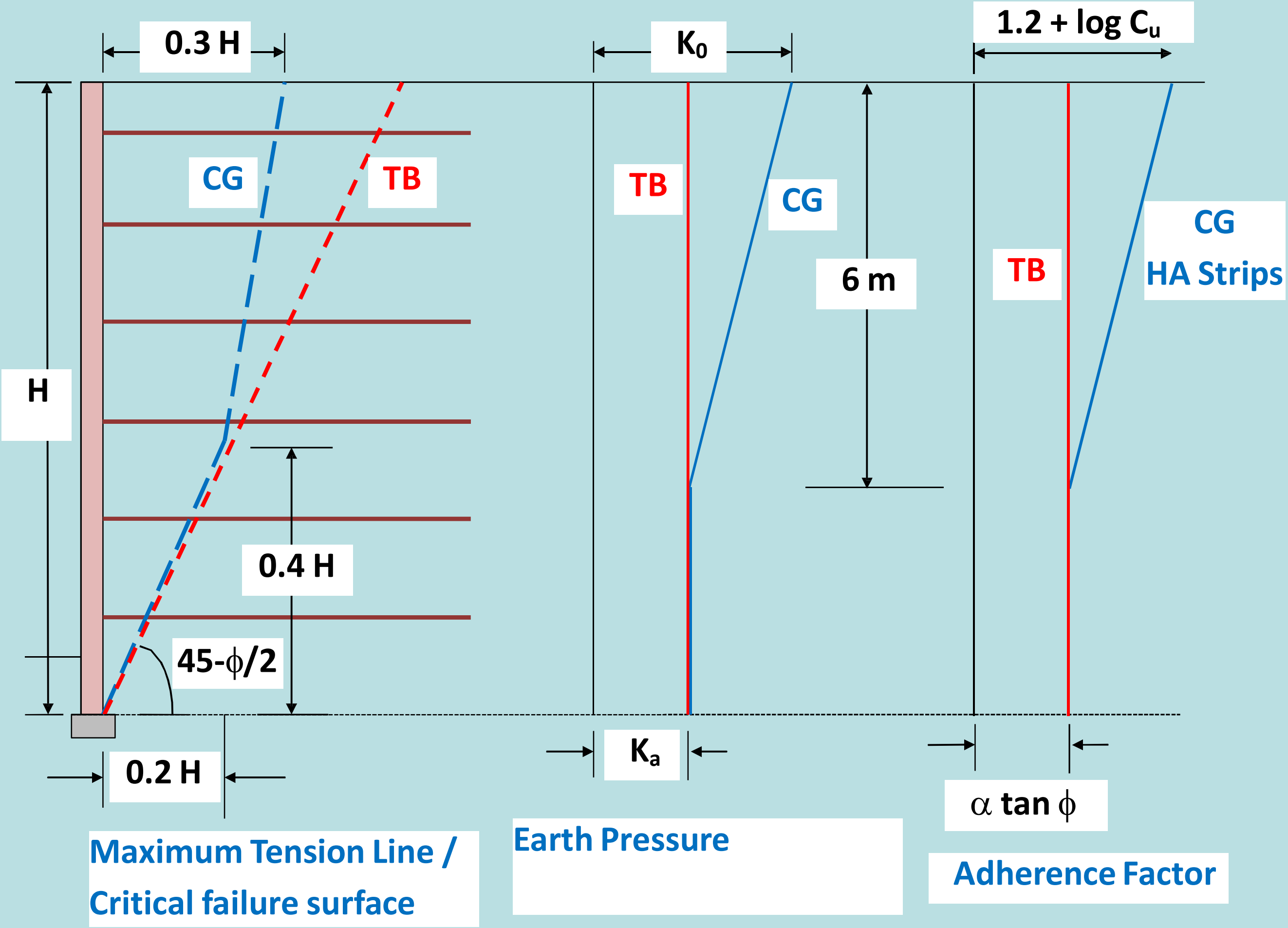
Failure Plane

Tension in Reinforcement

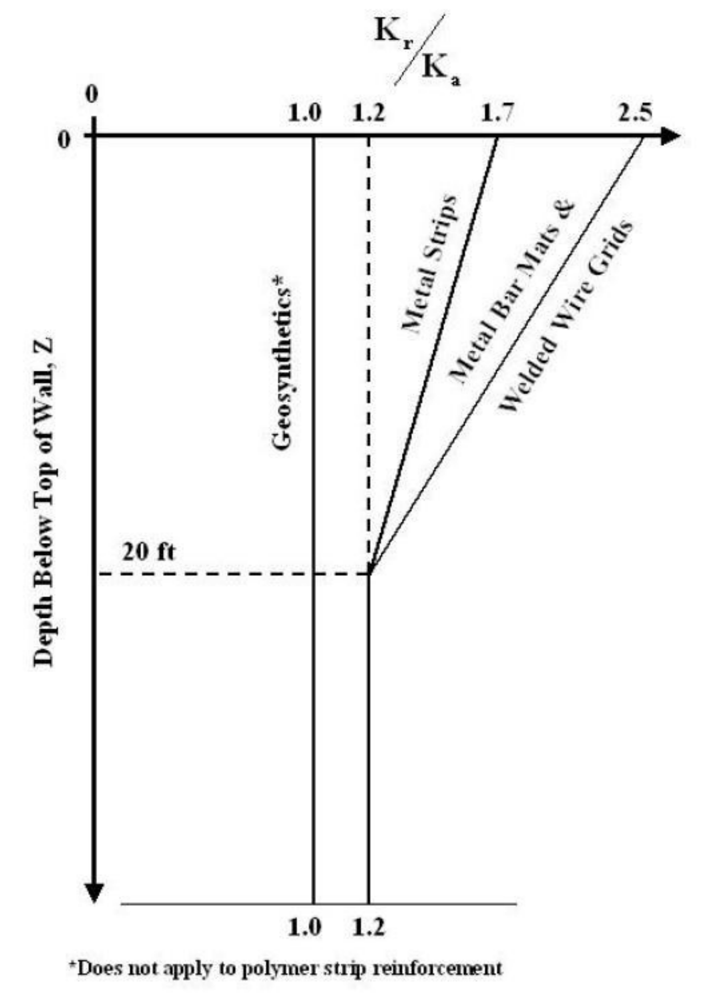
Inextensible Reinforcement

Extensible Reinforcement

Coherent Gravity & Tie-back Wedge Method

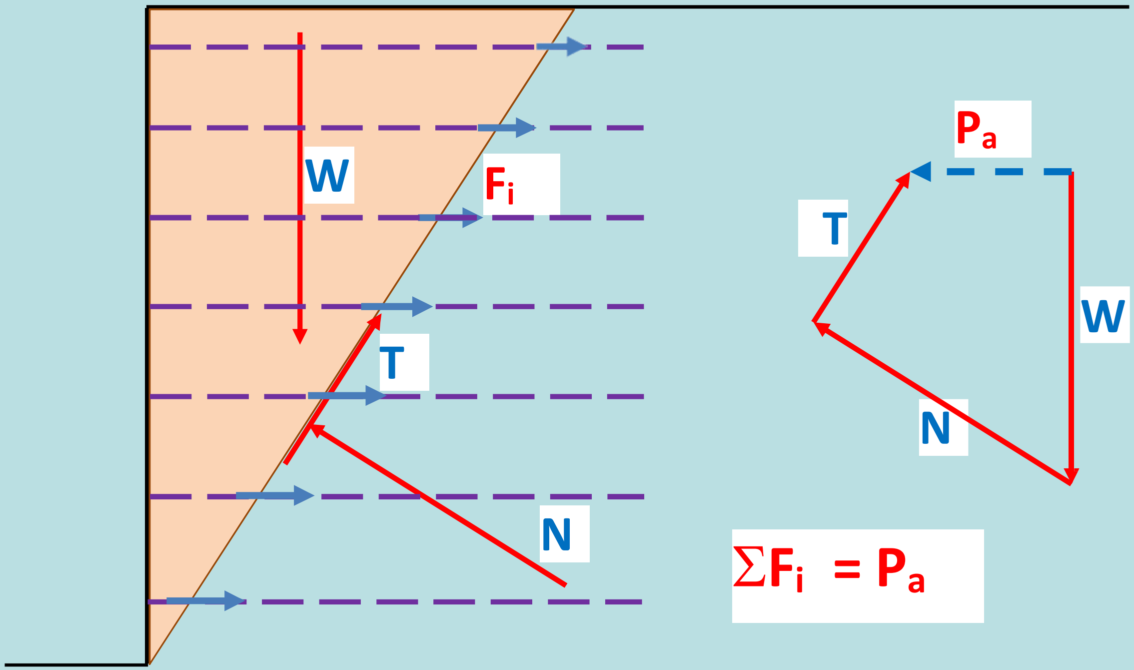


FHWA/AASHTO/ IRC Guidelines



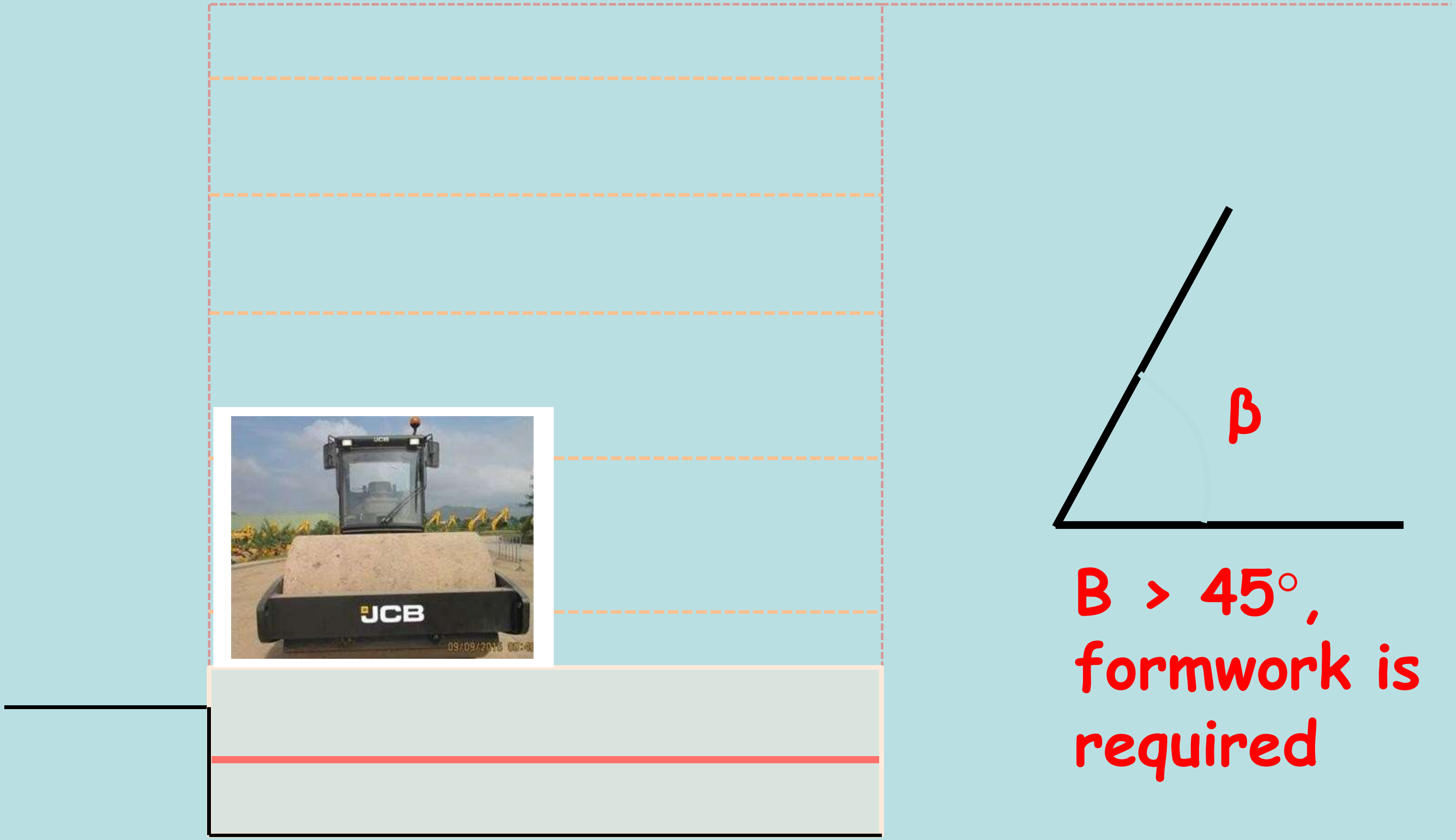
*Does not apply to polymer strip reinforcement

Why facing?



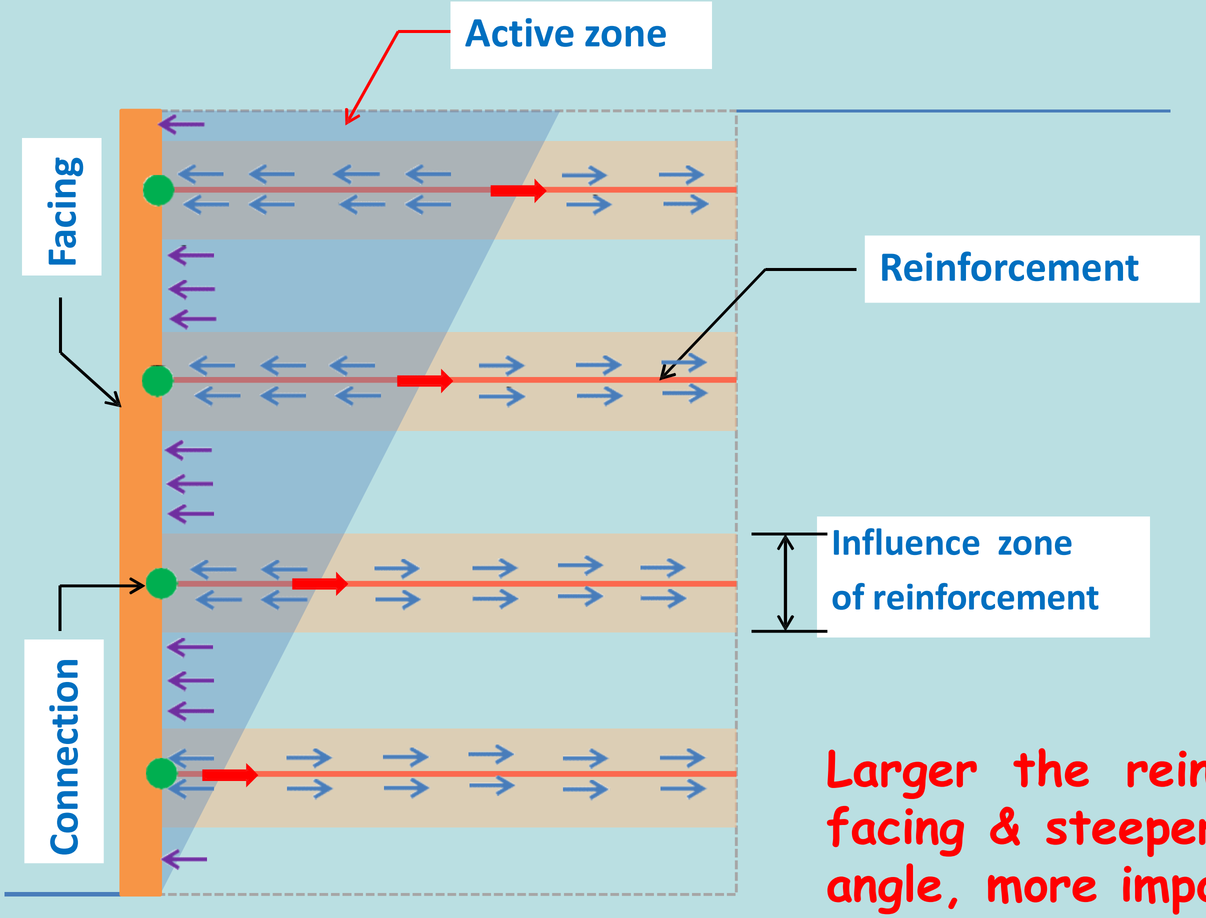
$\Sigma F_i = P_a$

Formwork during construction



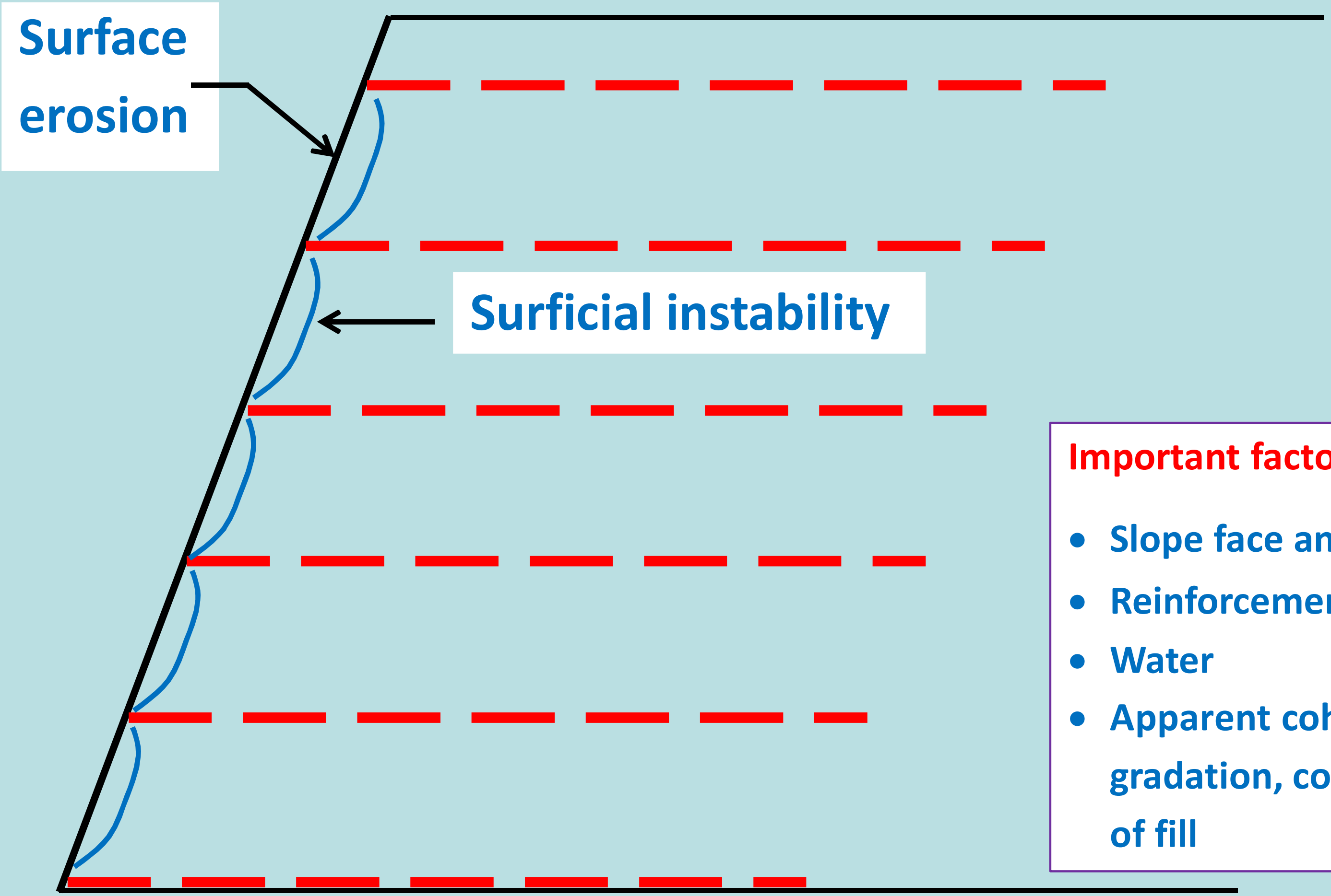
B > 45°, formwork is required

Assist reinforcement in retaining the active zone



Larger the reinforcement facing & steeper the face angle, more important this role of facing

Surficial instability and erosion



Important factors:

- Slope face angle
- Reinforcement spacing
- Water
- Apparent cohesion, gradation, compaction of fill

Aesthetics

Facing Options – Walls

- Full-height concrete panels
- Discrete/Segmental concrete panels
- Segmental concrete blocks
- Welded wire mesh
- Geocells
- Gabions
- Full-height Rigid facing

Facing Options – Reinforced Soil Steep Slopes (45<β<70°)

Wrap-around with vegetation

- With temporary formwork
- Bagwork facing
- Sacrifical welded wire mesh cages

Without Wrap-around

- Welded wire mesh with stone
- Gabions
- Geocells

Facing Options –

Reinforced Steep Slopes ($\beta \leq 45^\circ$)

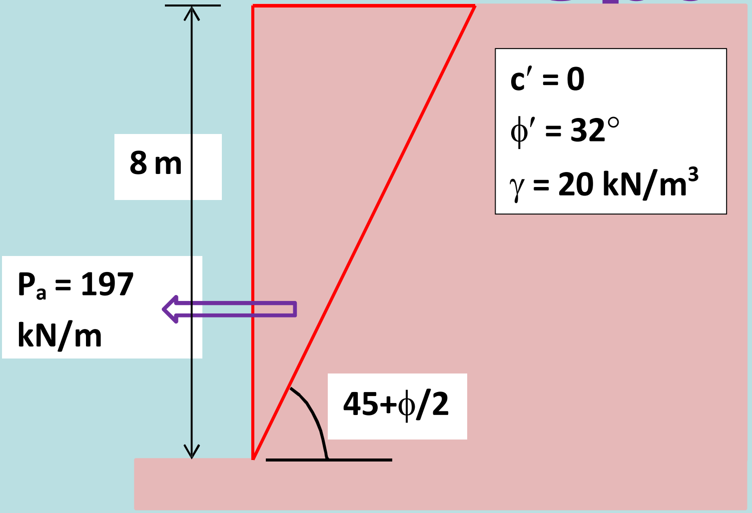
- No facing required
- Short length (1.2 -2.0 m) secondary reinforcements at 0.3 to 0.4 m spacing, to facilitate compaction and ensure surficial stability
- Vegetation for erosion control

Standard Model

- Extensible/in-extensible reinforcement with vertical spacing in the range of about 400-800 mm.
- Different types of facings; contribution of facing to stability usually ignored
- Designed using tie-back wedge/coherent gravity/simplified methods

Geosynthetic Reinforced Soil Walls with Closely Spaced Reinforcements

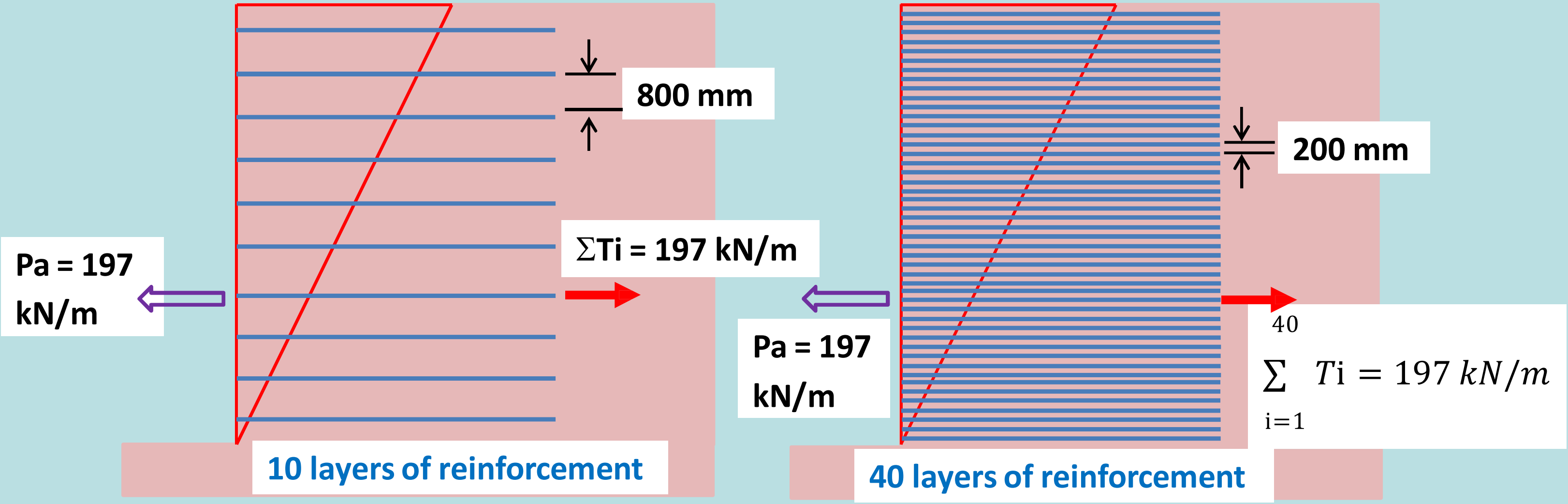
Effect of reinforcement spacing



c′ = 0
ϕ′ = 32°
γ = 20 kN/m³

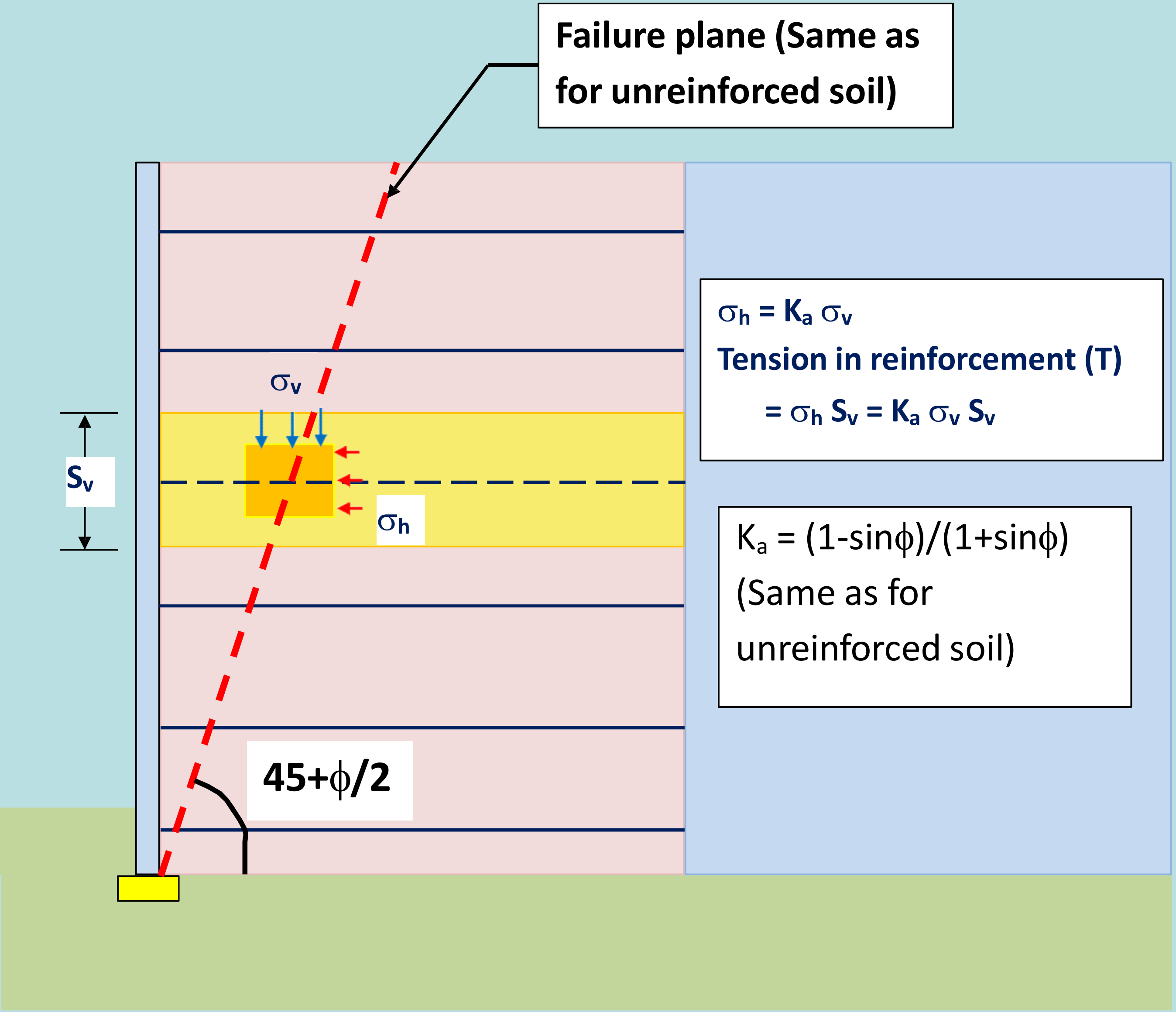
$$Ka = \frac{1 \quad sin32}{1+sin32} = 0.307$$

$$Pa = 0.5\,Ka\,\gamma\;H^2 = 197\;kN$$



$$\sum_{i=1}^{40} Ti = 197\;kN/m$$

Reinforcement as tie-backs



$\sigma_h = K_a\, \sigma_v$

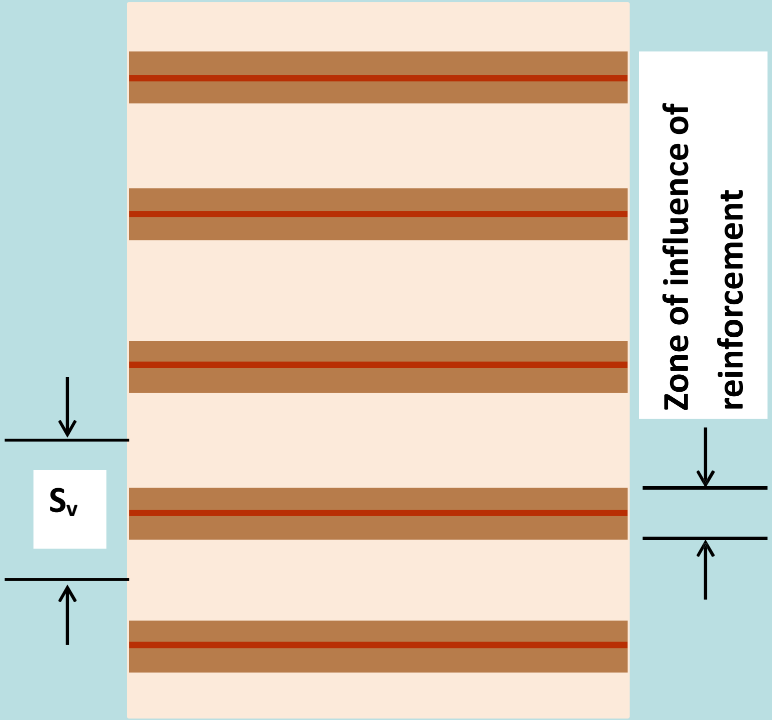
Tension in reinforcement (T)

$= \sigma_h S_v = K_a\, \sigma_v S_v$

$K_a = (1-\sin\phi)/(1+\sin\phi)$

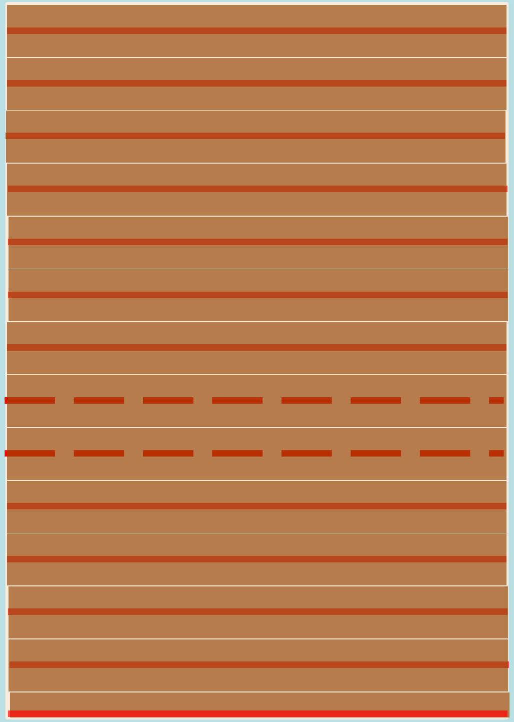
(Same as for unreinforced soil)

Effect of closely spaced reinforcement



Usual reinforced soil walls

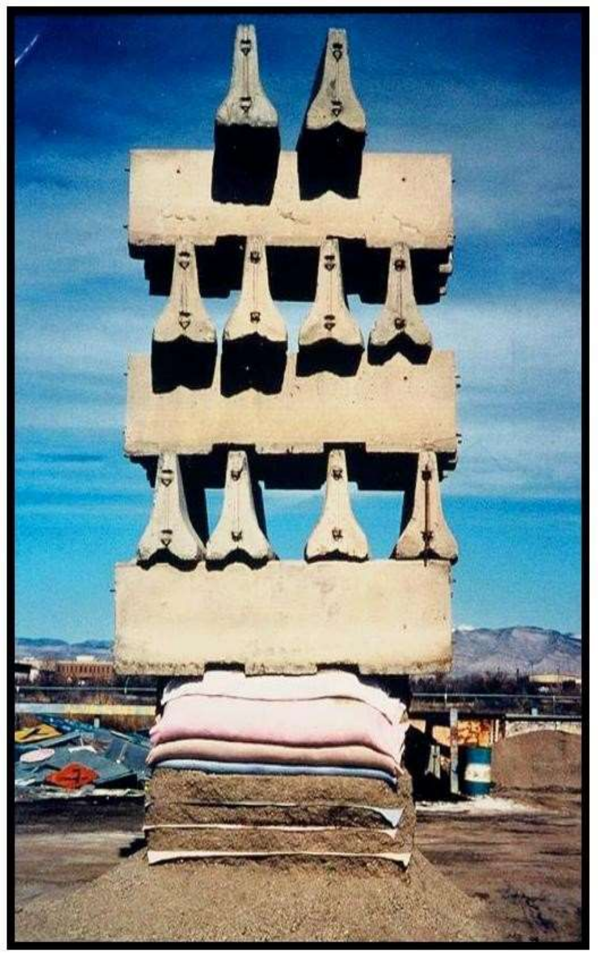
S_v = 400 – 800 mm (Typ.)



$S_v \leq$ 300 mm

Reinforced soil behaves as a real composite material

Effect of Close Spacing of Reinforcement



- **Even relatively weak reinforcements (here cotton bed sheets) can support large loads**

Effect of close spacing of Reinforcement

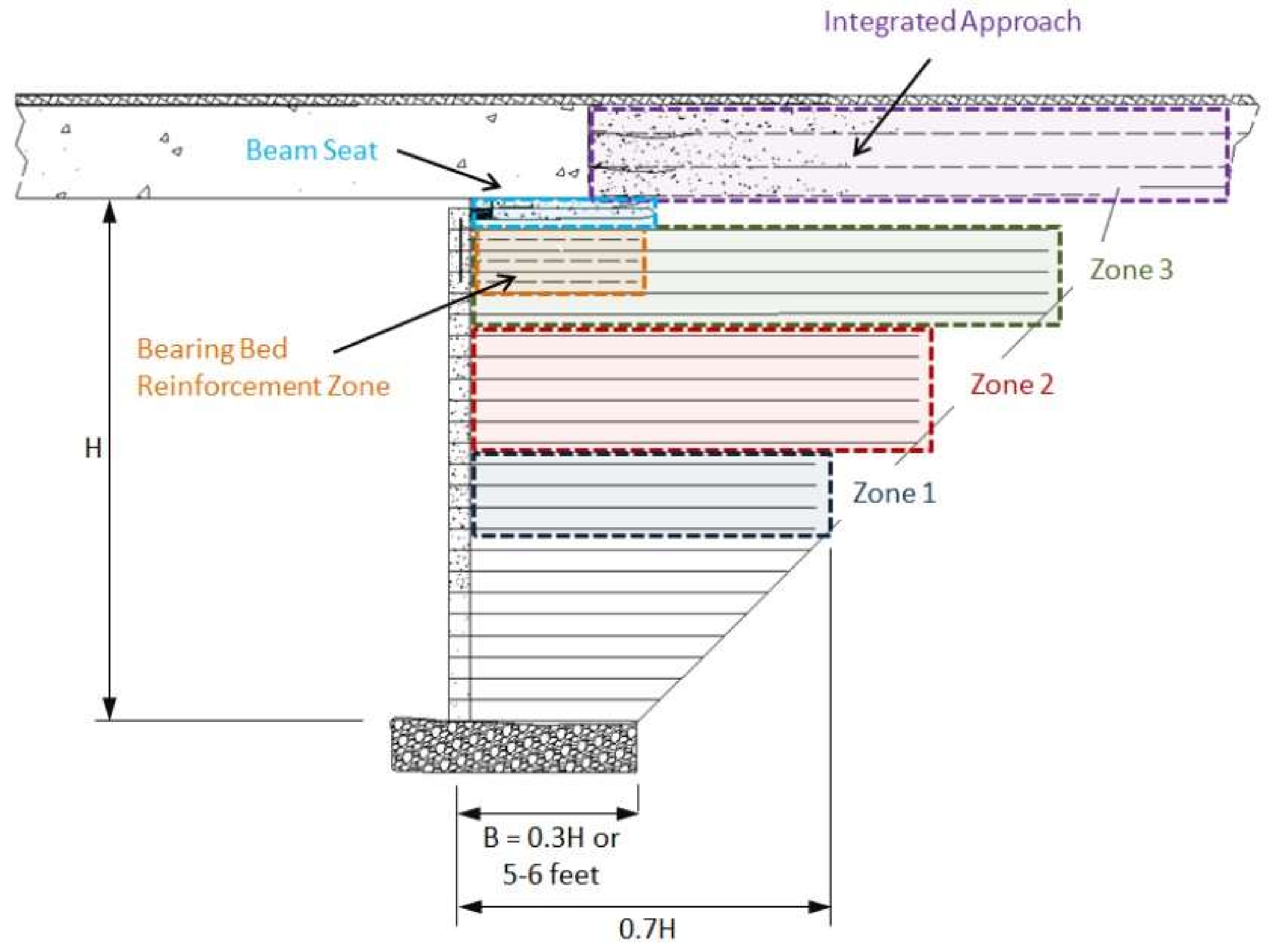
FHWA-TFHRC
GRS BRIDGE
PIER LOADED
TO 10 TSF
M. Adams

6 m high Geosynthetic Reinforced Soil Structure Loaded to 1000 kPa vertical stress – NO FAILURE

Effect of Close Spacing of Reinforcement

9 m high GRS with 30° negative batter supporting surcharge

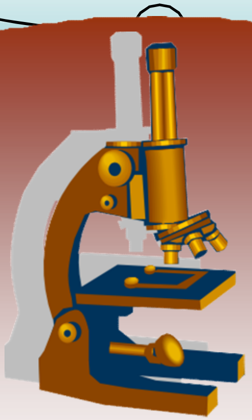
GRS Integral Bridge Abutments



FHWA suggested typical specs for GRS Bridge Abutments

- Vertical spacing = 200 mm
- Facing: Segmental concrete Blocks of 200 mm height
- Reinforcement: Woven polypropylene geotextile with tensile strength of 70 kN/m
- Fill: Well-graded granular fill with $\phi \geq 38°$

GEOTECHNICAL ENGINEERING



IS A SCIENCE

BUT ITS PRACTICE

AN ART