# Scour and Scour Protection

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# Contents

- Scour Problems in Coastal Engineering
- Prediction of Scour
- Design of Scour Protection
- Design of Scour Blankets

CEM Chapters VI-5-3-f And VI-5-6 (Author: Steven A. Hughes)

# Definition of Scour

Scour is the removal by hydrodynamic forces of granular bed material in the vicinity of Coastal Structures.

**Note:** ***Scour*** is a specific form of the more general term ***"erosion."***

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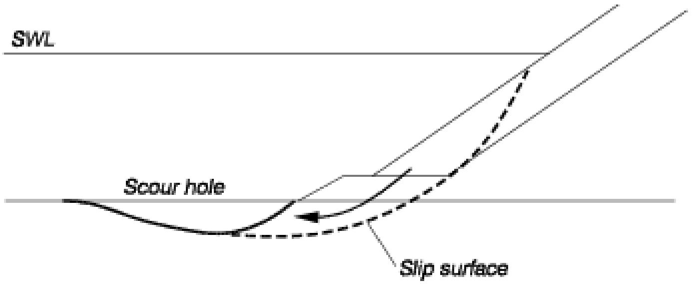
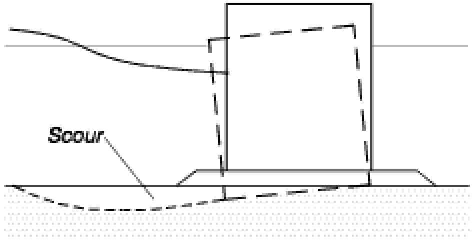
# Scour Problems

## Typical Scour Failures




*Sliding of main armour due to seabed scour*

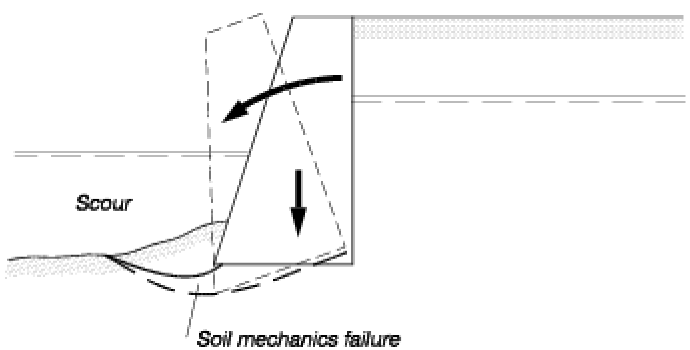
- *Formation of scour hole close to the foot of the structure due to wave and current action. The toe is functioning as support for the main armour as long as the toe erosion does not cause undermining of the armour.*
- *Reduced stabilizing forces causes slip failure to occur which results in sliding of armour.*




*Scour in seabed, seaward tilt and settlement*

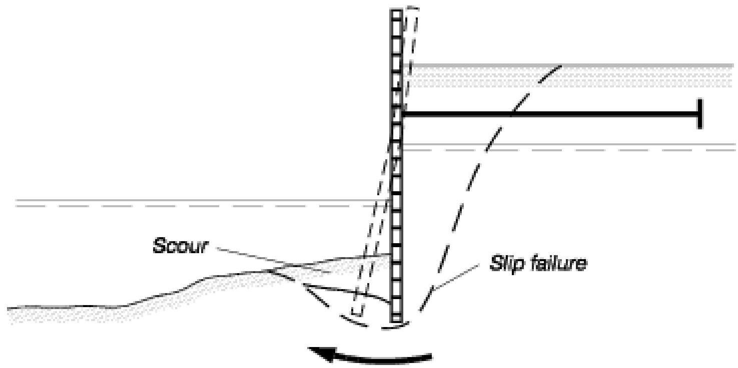
- *Scour in front of a caisson due to waves and currents might cause seaward tilt and settlement of the caisson.*
- *The critical wave load situations are when deep wave troughs occur at the caisson front.*

# Typical Scour Failures




*Seaward overturning and settlement of gravity wall*

- *Scour in front of the wall reduces both the passive resistance and the bearing capacity of the foundation soil.*
- *The resulting load from the active backfill pressure, the high groundwater table and the weight of the wall cause a bearing capacity failure in the soil resulting in a foreward overturning and some settlement of the wall.*




*Toe scour undercut and rotation of sheet wall*

- *Toe scour and undercut reduces/eliminates the passive pressure from the soil.*
- *Subsequent rotation of the wall when the loads from the active soil pressure and the pressure from the groundwater exceeds the passive pressure.*

# Scour Problems

## Impacts of Scour-Related Damage to Structures

- Project functionality is decreased
- Repair and replacement costs
- Damage to upland property / flood damage
- Client's confidence in project decreased

## Physical Processes

### Scour occurs whenever...

Hydrodynamic **bottom shear stresses** >
Sediment **critical shear stress**

***Clear Water Scour*** **:** Sediment motion is localized

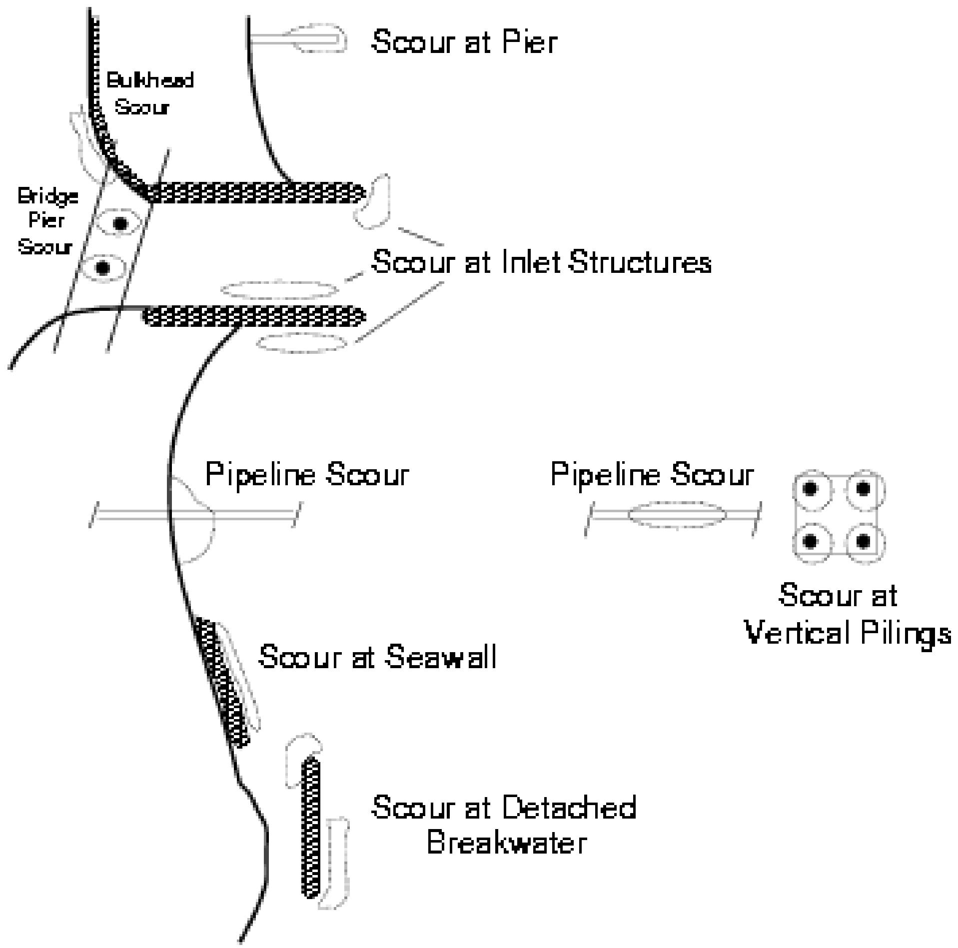
***Live Bed Scour*** **:** Entire bottom is mobilized with locally higher stresses

# Hydrodynamic Conditions

Scour results from any of the following
(acting singularly or in combination)

- **Localized orbital velocity increases due to reflected waves**
- **Focusing of wave energy by structures that induces breaking**
- **Structure alignments that redirect currents and accelerate flows**
- **Flow constrictions that accelerate flow**
- **Downward directed breaking waves that mobilize sediment**
- **Flow separation and creation of vortices**
- **Transitions from hard bottom to erodible bed**
- **Wave pressure differentials and groundwater flow producing "quick" condition**

## Common Scour Problems



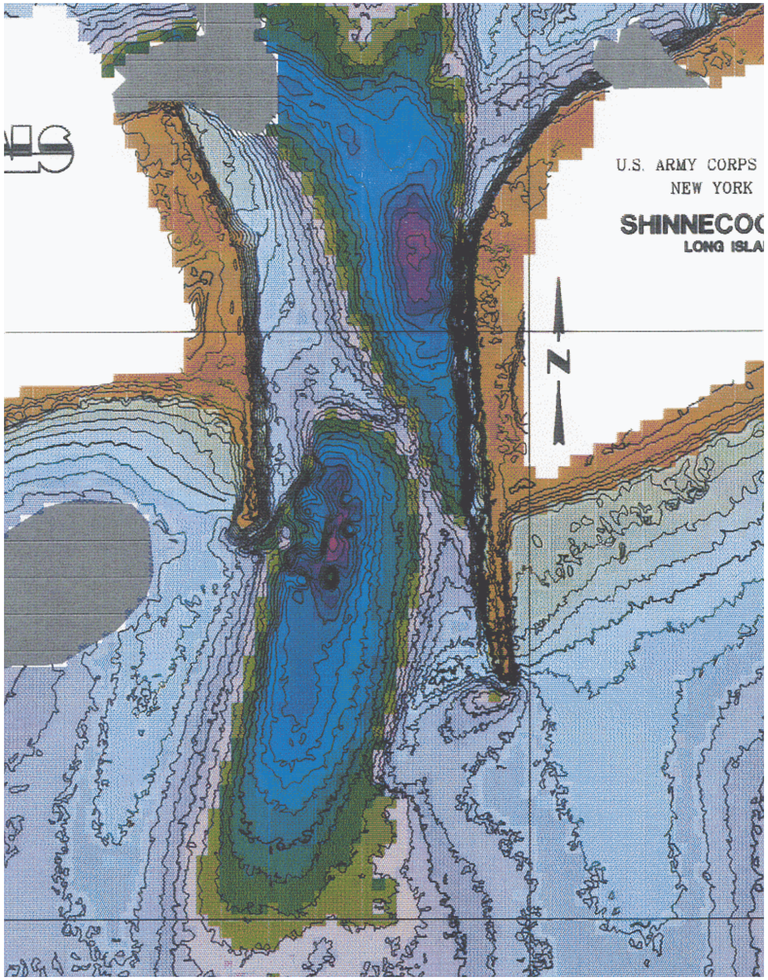
# Other Scour Occurrences

- Any structure founded on the seafloor can experience scour at downstream side (surge barriers, sills, etc.)
- Small pad footings can be undermined
- Structure transition and termination points can have local accelerations
- Scour in advance of new construction

# Example of Inlet Scour

## Shinnecock Inlet
Long Island, New York

Scour caused by flood
and
ebb jet flow separations



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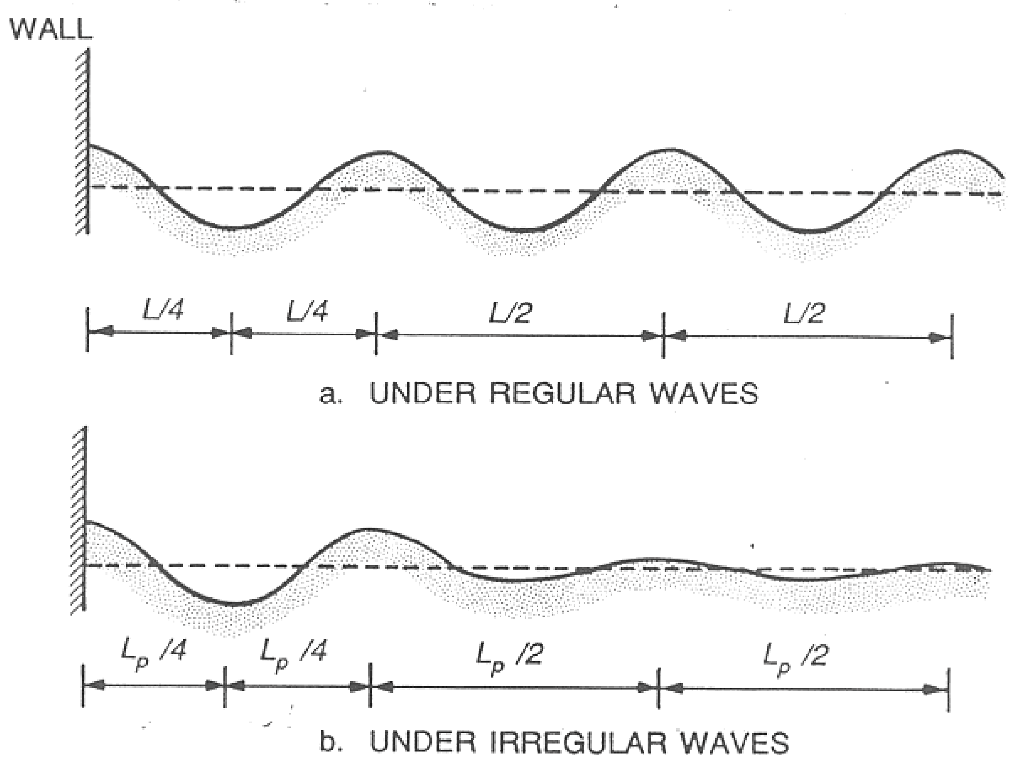
## Scour at Vertical Walls

### Nonbreaking Waves




(AFTER XIE 1981)

# Prediction of Scour

# Scour at Vertical Walls

## Nonbreaking Waves

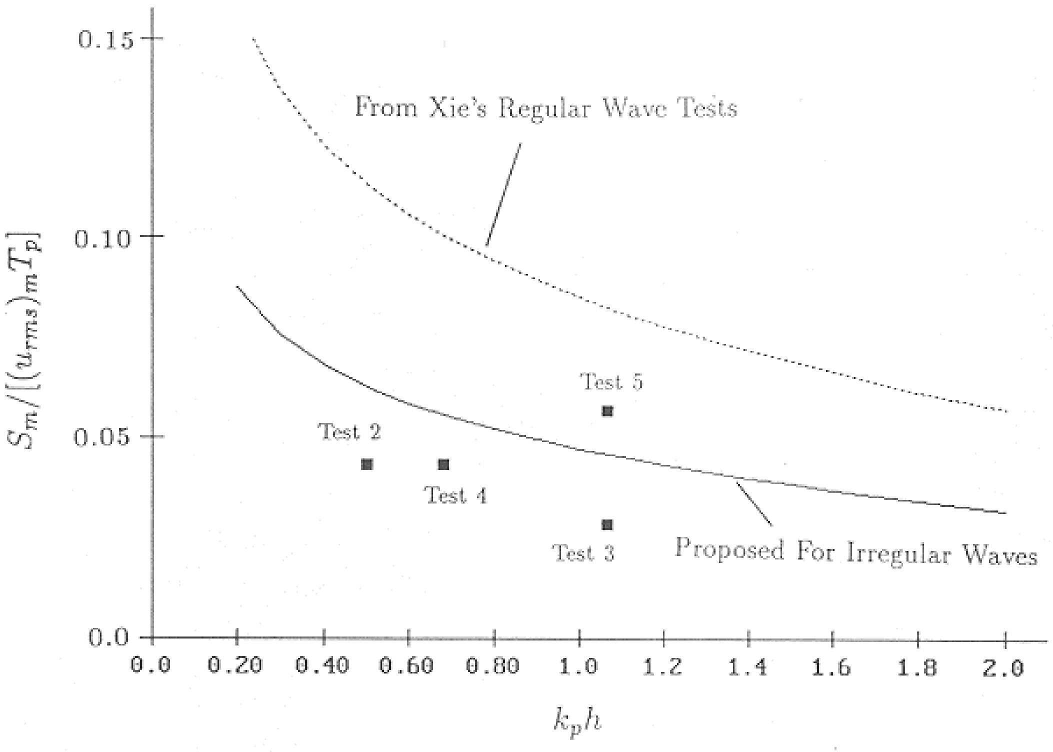
$$\frac{S_m}{(u_{rms})_m \, T_p} = \frac{0.05}{[\sinh(k_p h)]^{0.35}}$$

where

$$\frac{(u_{rms})_m}{g \, k_p \, T_p \, H_{mo}} = \frac{\sqrt{2}}{4\pi \cosh(k_p h)} \left[0.54 \cosh\left(\frac{1.5 - k_p h}{2.8}\right)\right]$$

and

- $S_m$ – Maximum scour depth at node $(L/2)$
- $h$ – Water depth
- $T_p$ – Peak spectral wave period
- $(u_{rms})_m$ – Root-mean-square of horizontal velocity
- $k_p$ – Wave number associated with $T_p$
- $g$ – Gravity
- $H_{mo}$ – Significant wave height

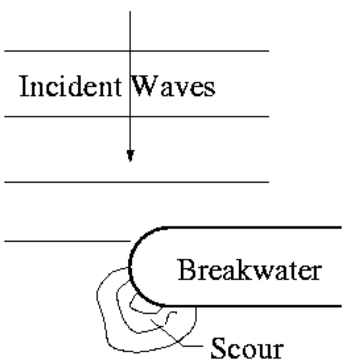


# Scour at Vertical Walls

## Nonbreaking Waves

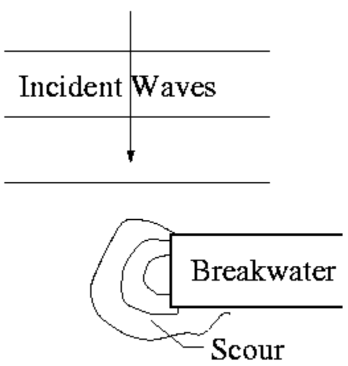
**Round, Vertical Breakwater Head**

$$\frac{S_m}{B} = 0.5\left[1 - e^{-0.175\,(KC-1)}\right]$$




**Square, Vertical Breakwater Head**

$$\frac{S_m}{B} = -0.09 + 0.123\,KC$$




Where

$$KC = \frac{U_m T_p}{B}$$

and

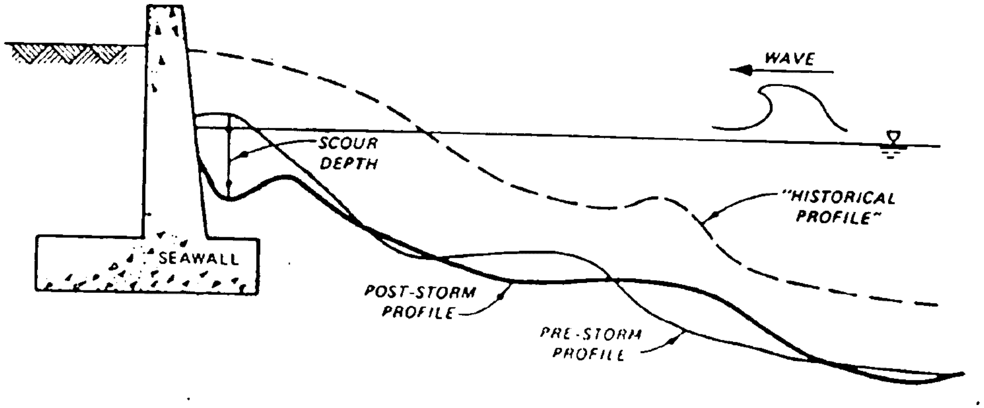
| | | |
|---|---|---|
| $S_m$ | – | Maximum scour depth from bed level |
| $B$ | – | Diameter of circular head |
| $T$ | – | Regular wave period |
| $U_m$ | – | Maximum wave orbital velocity at bed |
| $KC$ | – | Keulegan-Carpenter number |

# Scour at Vertical Walls

## Breaking Waves

### Rules of Thumb:

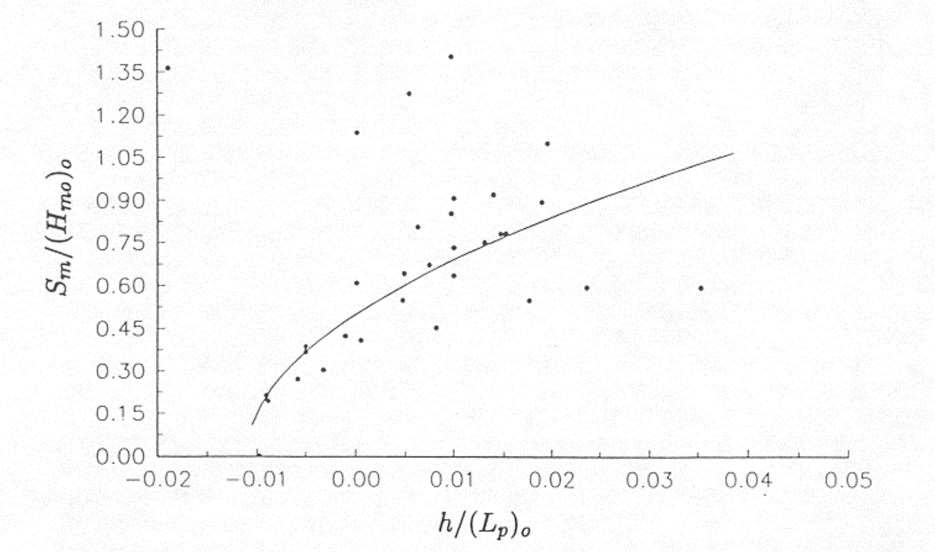
- Maximum scour depth: $S_m = H_{max}$ or $S_m = h$
- Maximum scour when wall is at breaking wave plunge point
- Reduction in reflection reduces scour
- Currents will increase reflection



## Scour at Vertical Walls

### Breaking Waves

$$\frac{S_m}{(H_{mo})_o} = \sqrt{22.72\,\frac{h}{(L_p)_o} + 0.25}$$




Where

$S_m$ – Maximum scour depth from bed level

$(H_{mo})_o$ – Deepwater significant wave height

$h$ – Pre-scour water depth at wall

$(L_p)_o$ – Deepwater wavelength associated with $T_p$

**Range of Validity**

$$0.011 < \frac{h}{(L_p)_o} < 0.045 \quad \text{and} \quad 0.015 < \frac{(H_{mo})_o}{(L_p)_o} < 0.04$$

# Scour at Sloping Structures

## Rules of Thumb

- Generally, analytical methods are lacking
- Nonbreaking wave-induced scour is not significant
- Maximum breaking wave scour will be less than a vertical wall
- Scour depth decreases with structure reflection coefficient
- Along-structure currents can greatly increase scour depth
- Obliquely-incident waves will increase scour because of Mach-stem and generation of along-structure currents

# Scour at Sloping Structures

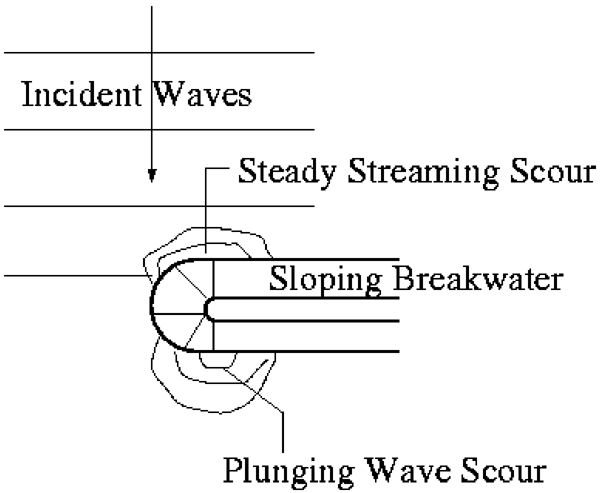
## Sloping Structure Roundheads

**Scour by Steady Streaming**

$$\frac{S_m}{B} = 0.04\left[1 - e^{-4.0\,(KC-0.05)}\right]$$

**Scour by Plunging Waves**

$$\frac{S_m}{H_s} = 0.01\left(\frac{T_p\sqrt{g\,H_s}}{h}\right)^{3/2}$$




Where

$$KC = \frac{U_m\,T_p}{B}$$

and

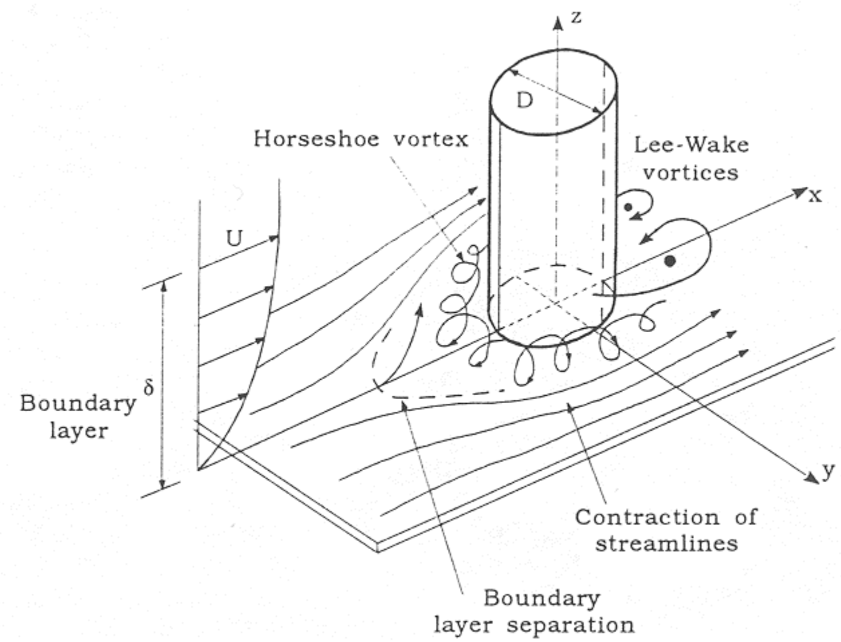
$S_m$ – Maximum scour depth from bed level
$B$ – Diameter of circular head at bed
$T$ – Regular wave period
$U_m$ – Maximum wave orbital velocity at bed
$H_s$ – Significant wave height
$KC$ – Keulegan-Carpenter number

## Scour at Vertical Piles

### Small Diameter Piles - (D < L/10)

### Physical Processes

- Horseshoe vortex forms
- Vortex shedding in lee of pile
- Local flow accelerations




### Key Parameters

- Current magnitude
- Orbital wave velocity
- Pile diameter

**(Sediment size and pile shape less important)**

## Scour at Vertical Piles

### Small Diameter Piles

**Rule of Thumb** (somewhat conservative)

***Maximum scour depth is equal to about twice the pile diameter***

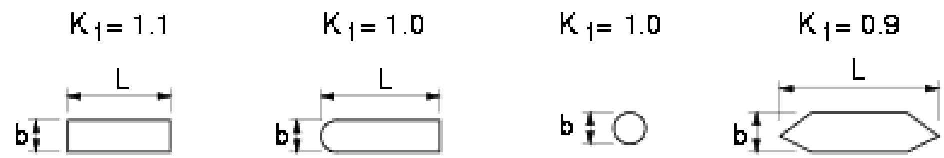
# Scour at Vertical Piles

## Scour by Currents -Small Diameter Piles

$$\frac{S_m}{h} = 2.0\ K_1\ K_2 \left(\frac{b}{h}\right)^{0.65} F_r^{0.43}$$

Where

| | | |
|---|---|---|
| $S_m$ | – | Maximum scour depth below average bed level |
| $h$ | – | Water depth upstream of pile |
| $b$ | – | Pile width |
| $F_r$ | – | Flow Froude number $[F_r = U/\sqrt{(gh)}]$ |
| $U$ | – | Mean current velocity magnitude |
| $K_1$ | – | Pile shape factor |
| $K_2$ | – | Pile orientation factor |
| $\theta$ | – | Angle of pile orientation |
| $L$ | – | Pile length |




(a) Square Nose (b) Round Nose (c) Cylinder (d) Sharp Nose

$$K_2 = \left(\cos\theta + \frac{L}{b}\sin\theta\right)^{0.62}$$

# Prediction of Scour

## Scour at Vertical Piles

### Scour by Waves -Small Diameter Piles

- **Cylindrical Pile**

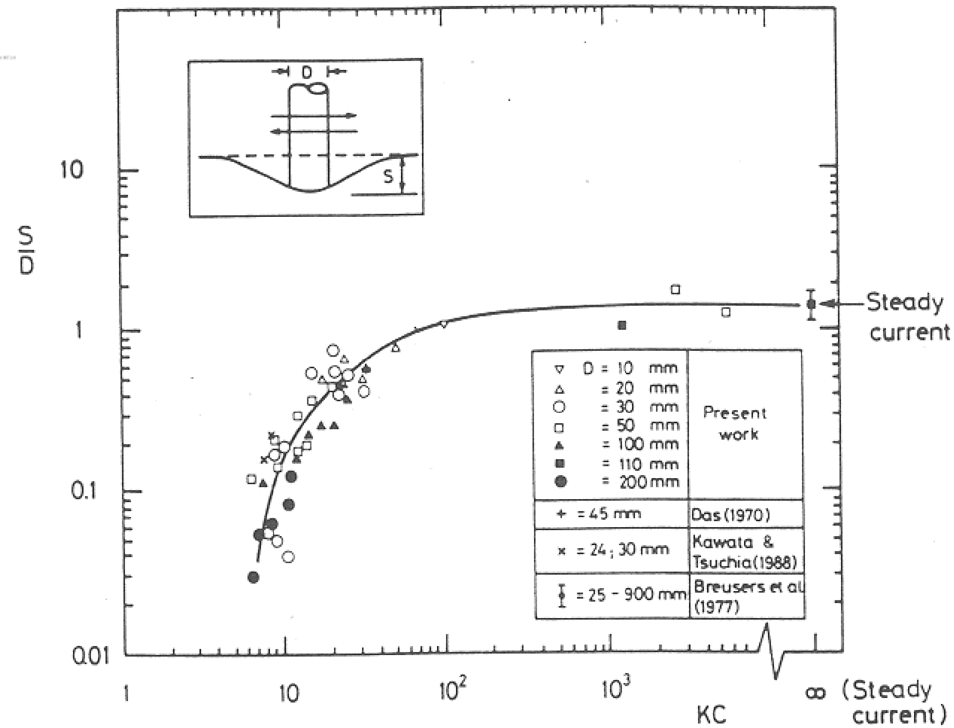
$$\frac{S_m}{D} = 1.3\left[1 - e^{-0.03\,(KC-6)}\right] \qquad \text{for } KC \geq 6$$

- **Square Pile 90 deg. to Flow**

$$\frac{S_m}{D} = 2.0\left[1 - e^{-0.015\,(KC-11)}\right] \qquad \text{for } KC \geq 11$$

- **Square Pile 45 deg. to Flow**

$$\frac{S_m}{D} = 2.0\left[1 - e^{-0.019\,(KC-3)}\right] \qquad \text{for } KC \geq 3$$



# Scour at Vertical Piles

## Scour by Waves and Currents

- No analytical methods available
- Scour depth increases when even a small current is added to waves
- Breaking waves increase scour over scour caused by currents alone
- Inverted cone shape is similar for both cases

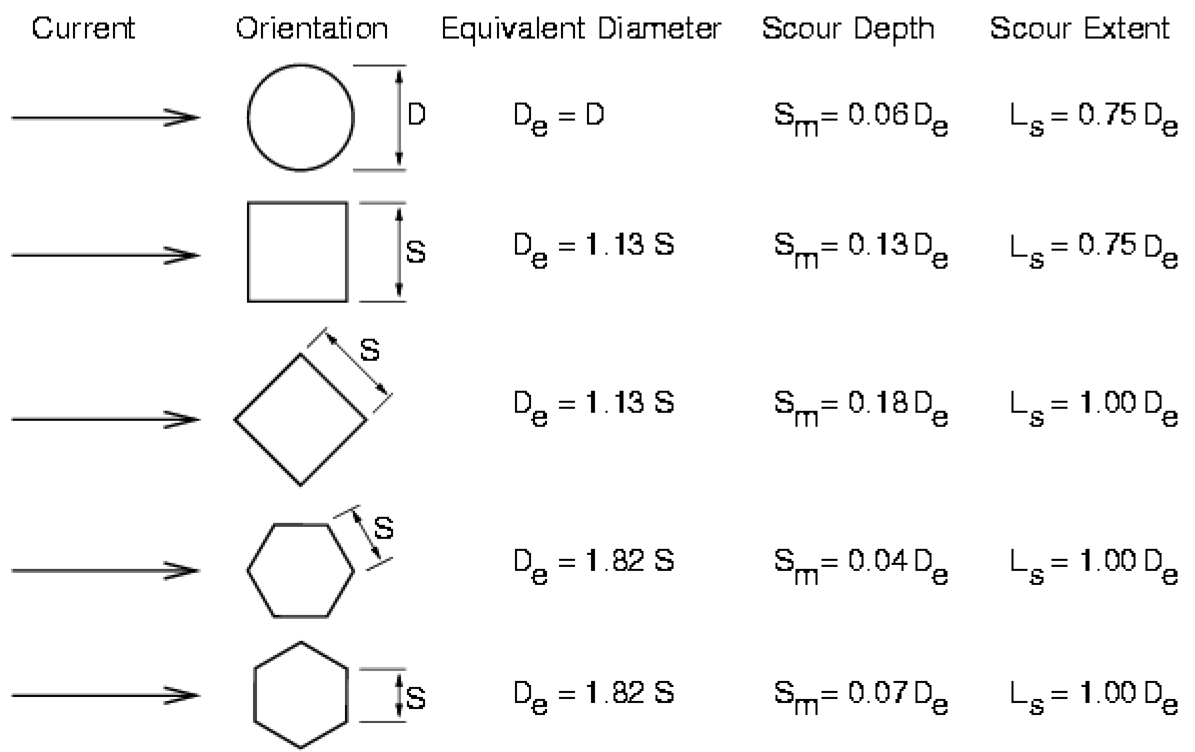
### Rule of Thumb

***Estimate maximum scour depth using formula for currents alone***

# Scour at Vertical Piles

## Large Diameter Piles - (D > L/10)

- Coincident waves and currents
- Wave diffraction occurs
- Maximum scour occurs at corners of square piles
- Scour extent used to design scour protection



# Scour at Pipelines

## Pipelines Outside the Surf Zone

### Scour Problem

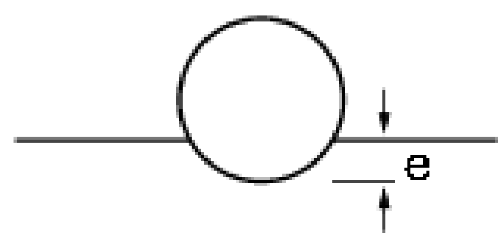
- Scour can lead to partial burial
- Problem is differential scour due to different soil types
- Pipeline is left spanning a gap

### Scour Process

- Begins with seepage increasing beneath pipeline
- Rapid scour phase (*tunnel erosion*)
- Final scour by *lee-wake erosion*

Pipeline Scour


Pipeline Embedment



# Scour at Pipelines

## Pipelines Outside the Surf Zone

### Scour by Currents

**For** $U/U_c > 1$ **(Live-bed scour)**

$$\frac{S_m}{D} = 0.6 \pm 0.1$$

### Scour by Waves

$$\frac{S_m}{D} = 0.1\sqrt{KC}\left(1 - 1.4\,\frac{e}{D}\right) + \frac{e}{D}$$

**Valid for** $e/D < 0.5$

# Scour at Pipelines

## Pipelines Through the Surf Zone

- Pipelines will be damaged if uncovered and exposed to strong waves and longshore currents
- Once exposed, additional scour occurs
- No design guidance is available

## Rule of Thumb

***Burial depth should exceed expected profile lowering at all places***

# Other Scour Problems

- Scour downstream of sills and stone blankets due to currents
- Scour downstream of hard bottoms due to currents
- Scour at control structures due to plunging jets
- Scour at two- and three-dimensional culverts
- Scour at abutments and spur dikes

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CEM Chapters VI-5-3-f And VI-5-6 (Author: Steven A. Hughes)

# Design of Scour Protection

## Toe Scour Apron Rules of Thumb

- Based on survey of successful field practice
- Often protection is extension of bedding or filter layer
- Minimum Apron Thickness: 0.6 to 1.0 m (1.0 to 1.5 m in NW)
- Minimum Apron Width: 1.5 m (3 m to 7.5 m in NW)
- Material: Quarrystone to 0.3 m diameter, gabions, mats, etc.

**Rules of thumb are inadequate when:**

1. depth < 2 x breaking wave height
2. Reflection coefficient > 0.25 (about 1:3 slope)

## Sheetpile Retaining Walls

### Geotechnical Considerations

$$W = 2.0\ d_e$$

### Hydrodynamic Considerations

$$W = 2.0\ H_i \qquad \text{or} \qquad W = 0.4\ d_s$$

Where

$W$ – Width of scour apron
$d_e$ – Depth of sheetpile penetration
$H_i$ – Incident wave height
$d_s$ – Water depth at wall

## Sheetpile Retaining Walls

### Apron Stone Size:

- **WAVES:** For heavy wave action, use toe protection guidance **(VI-5-3-d)**
- **CURRENTS**: For strong currents use scour blanket criterion **(VI-5-3-f)**
- **WAVES AND CURRENTS:** Estimate individually, then increase largest by factor of 1.5

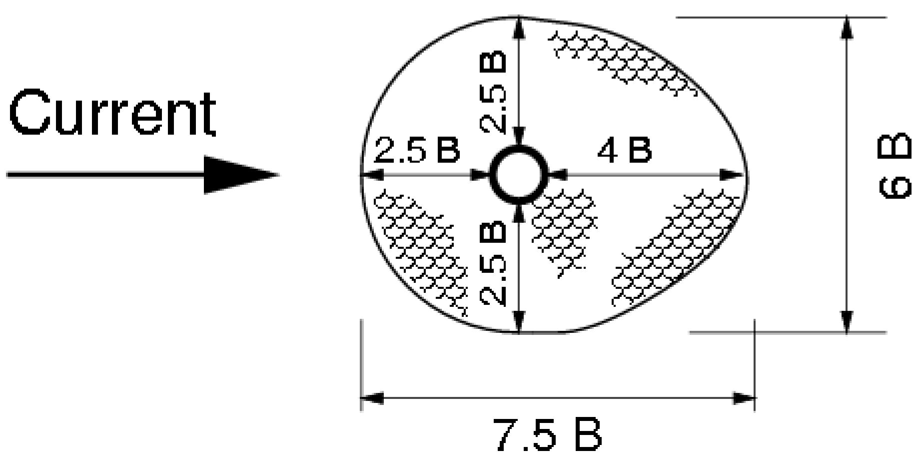
# Sloping-Front Structures

- Adequate scour protection usually provided by toe protection design
- Additional protection might be needed for strong lateral currents
- Inlet structures are a special case

# Vertical Piles

## Currents

Size stone according to scour blanket guidance




## Waves

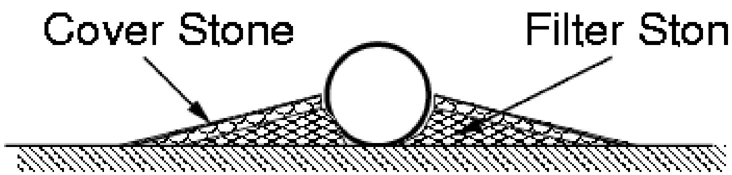
Rule of Thumb:

Blanket width about twice maximum scour depth

# Submerged Pipelines

## Outside Surf Zone:

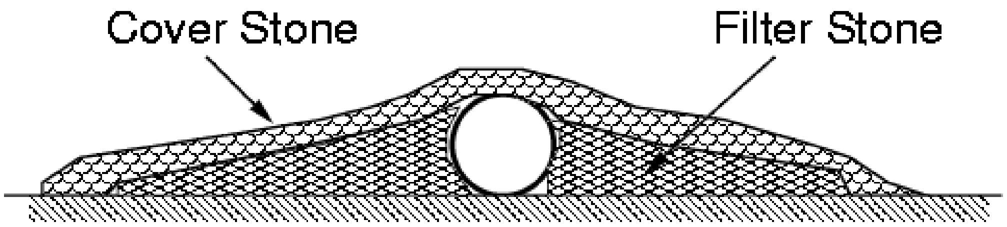
- Burial
- Partial covering
- Complete covering



(a) Scour Protection by Partial Covering

## Inside Surf Zone:

*Burial is only option*



(b) Scour Protection by Complete Coverage

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## Stability in Current Field

$$\frac{W_{30}}{w_a\, h^3} = \frac{\pi}{6}(S_f\, C_s)^3 \left[\left(\frac{w_w}{w_a - w_w}\right)^{1/2}\left(\frac{\bar{u}}{\sqrt{K_1 g h}}\right)\right]^{15/2}$$

With

$$K_1 = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}}$$

Where

- $W_{30}$ – Weight at which 30% of stones are smaller by weight
- $w_a$ – Specific weight of blanket stone
- $w_w$ – Specific weight of water
- $h$ – Water depth
- $g$ – Gravity
- $\bar{u}$ – Mean current velocity over depth
- $S_f$ – Safety factor (1.1 minimum)
- $C_s$ – Stability coefficient (0.30 – angular stone; 0.38 – rounded stone)
- $\theta$ – Bottom slope angle
- $\phi$ – Blanket stone angle of repose ($\approx 40^o$)

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# Design of Scour Blankets

## Riprap Gradation

$$W_{50_{min}} = 1.7\, W_{30}$$

$$W_{100_{max}} = 8.5\, W_{30}$$

$$W_{100_{min}} = 3.4\, W_{30}$$

$$W_{50_{max}} = 2.6\, W_{30}$$

$$W_{15_{max}} = 1.3\, W_{30}$$

$$W_{15_{min}} = 0.5\, W_{30}$$

## Blanket Thickness

Above water (minimum - 0.3 m)

$$r = 2.5 \left( \frac{W_{30}}{w_a} \right)^{1/3}$$

Below water (minimum - 0.5 m)

$$r = 3.8 \left( \frac{W_{30}}{w_a} \right)^{1/3}$$

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# Design of Scour Blankets

## Example

- Depth = 20 ft
- Mean velocity = 8.2 ft/s
- Rounded stone
- Safety factor = 1.1
- Flat bottom

## Blanket Thickness

$$r = 3.8 \left( \frac{1.9\ lb}{165\ lb/ft^3} \right)^{1/3} = \underline{0.86\ lb}$$

Use r = 0.5 m = 1.6 ft

## Riprap Gradation

$$W_{30} = 1.9\ lb$$

$$W_{100_{max}} = 16.4\ lb$$
$$W_{100_{min}} = 6.6\ lb$$

$$W_{50_{max}} = 5.0\ lb$$
$$W_{50_{min}} = 3.3\ lb$$

$$W_{15_{max}} = 2.5\ lb$$
$$W_{15_{min}} = 1.0\ lb$$

# Scour Conclusions

- Scour at structures can cause damage leading to reduced project functionality
- Capability to predict maximum scour depth is lacking for many situations
- Important to identify dominant scour mechanism
- Design of scour protection is based largely on past experience
- Knowledge about scour of cohesive sediments is virtually nonexistent