

# Design of Piles Socketed in Rock

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# Socketed Piles

- **Socketed piles are either partially or fully embedded in rock.**
- **These piles are usually constructed by drill and blast excavation then concrete casting in the excavated hole.**
- **Typically, socketed piles are placed vertically because of construction associated difficulties of battered piles.**

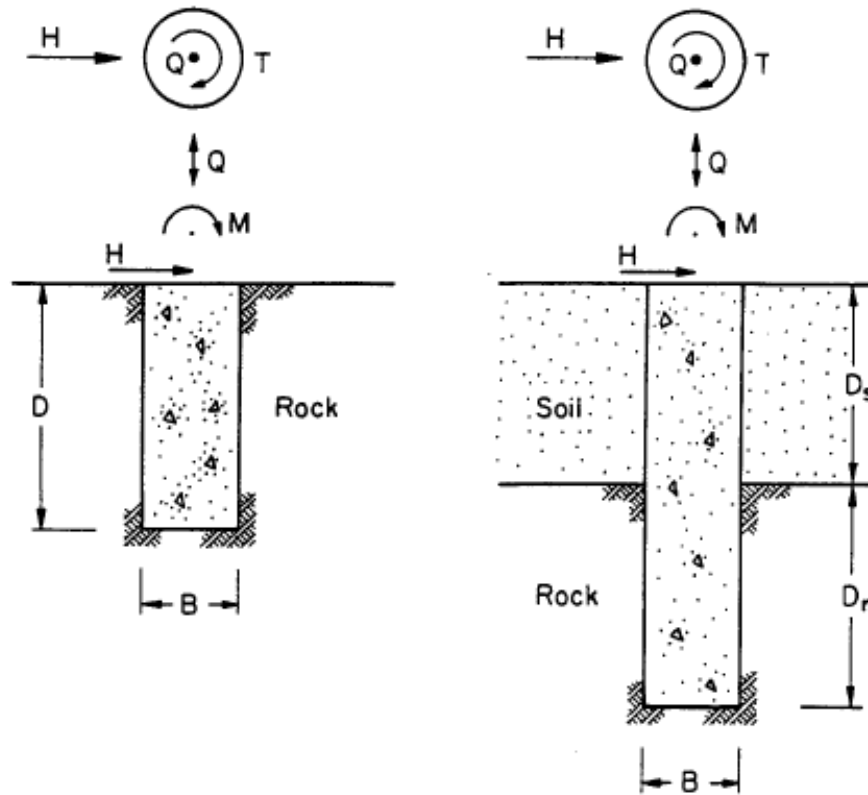
# Driven Piles

- For driven piles, refusal almost takes place on top of rock stratum.
- For weak rock (e.g. chalk) which can be penetrated, many factors (area in contact with rock, rock quality and driving effects) may not be known. The pile capacity can then be determined based on pile load testing.

# Drilled Cast-in-place Shafts

- For drilled piles, it is easier to define the design-needed parameters including:
  - area in contact with rock,
  - rock quality and
  - execution effects.

# Definition



a) Rock at Ground Surface

b) Overlying Soil

# Carrying Capacity

- **Socketed piles can resist three modes of loading:**
  - **Axial (either compression or uplift).**
  - **Lateral.**
  - **Torsional.**

# Design Criteria

- **Similar to other foundation type, the design is controlled by:**
  - **Adequate stability.**
  - **Serviceability (e.g. maximum settlement, differential settlement, distortion).**
  - **Economy.**

# Ultimate Load

- Typically, the design of socketed piles is controlled by deformation criteria (serviceability) rather than stability.
- However, an adequate safety factor should be maintained.

# Load Transfer

- The applied loads are transferred through end bearing and friction in the rock bearing layer.
- There is some frictional/adhesion resistance along the pile shaft passing through the soil layers. However, such resistance is too small and may be neglected.

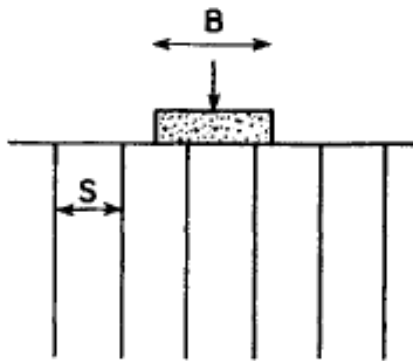
# Load Transfer

- The load distribution between friction and end bearing depends on the engineering characteristics of the socket.
- These characteristics include:
  - Rock roughness.
  - Relative stiffness of rock mass relative to the pile material.
  - Allowable pile movement.

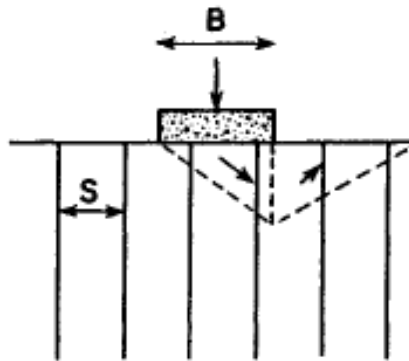
# Tip Resistance

- At working load, a small proportion of the applied compressive load is transferred to the pile tip (typically 10-20 %).
- The tip resistance will mobilize only after large pile movement that would have caused slip along concrete rock interface.

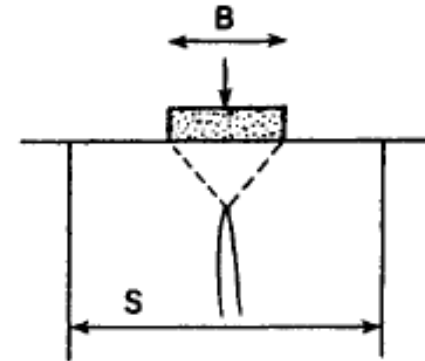
# Tip Resistance Failure Modes



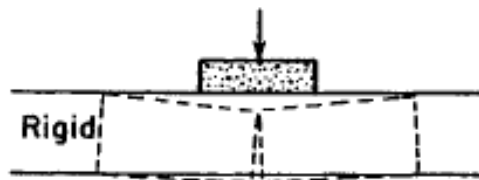
Open joints,  $S < B$   
Uniaxial compression



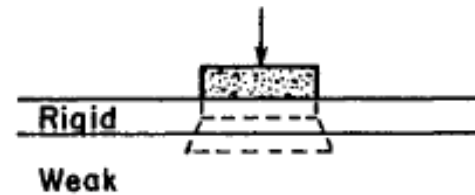
Closed joints,  $S < B$   
Shear zone



Wide joints,  $S > B$   
Splitting



Thick rigid layer  
Flexure



Thin rigid layer  
Punching

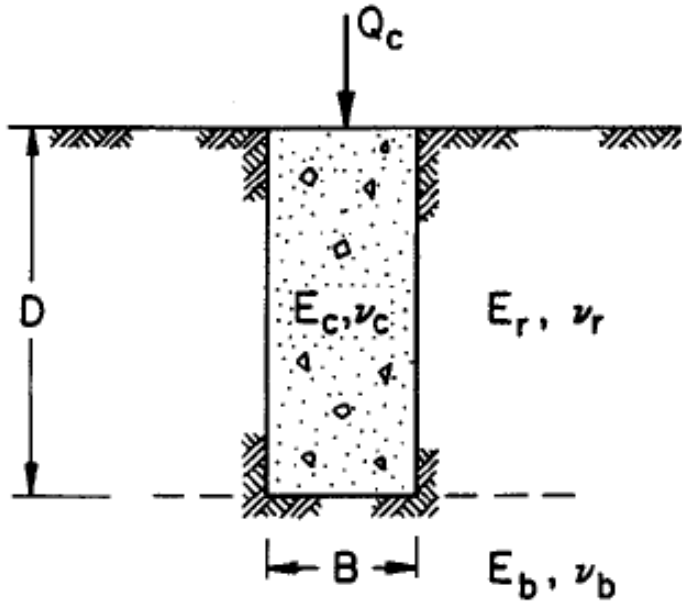
# Tip Resistance Failure Modes

- For  $S < B$  with open joints, failure will probably take place to uniaxial compression of rock columns.
- For  $S < B$  with closed joints, a wedge failure will probably take place.
- For  $S > B$ , splitting under the foundation takes place which probably leads to a general shear failure.

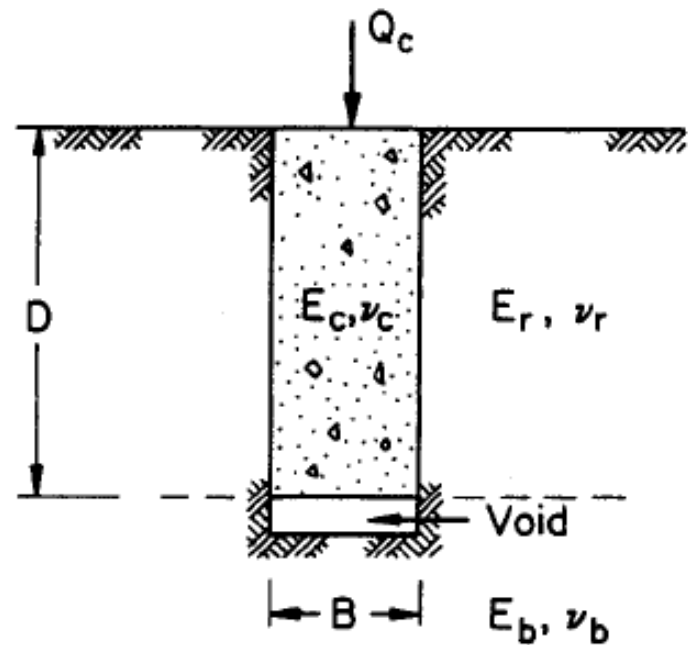
# Tip Resistance Failure Modes

- For a thick rigid rock stratum underlain by weak soil, failure would probably be due to flexure.
- For a thin rigid rock stratum overlying a weak soil layer, failure would be due to punching.

# Piles Subjected to Compression

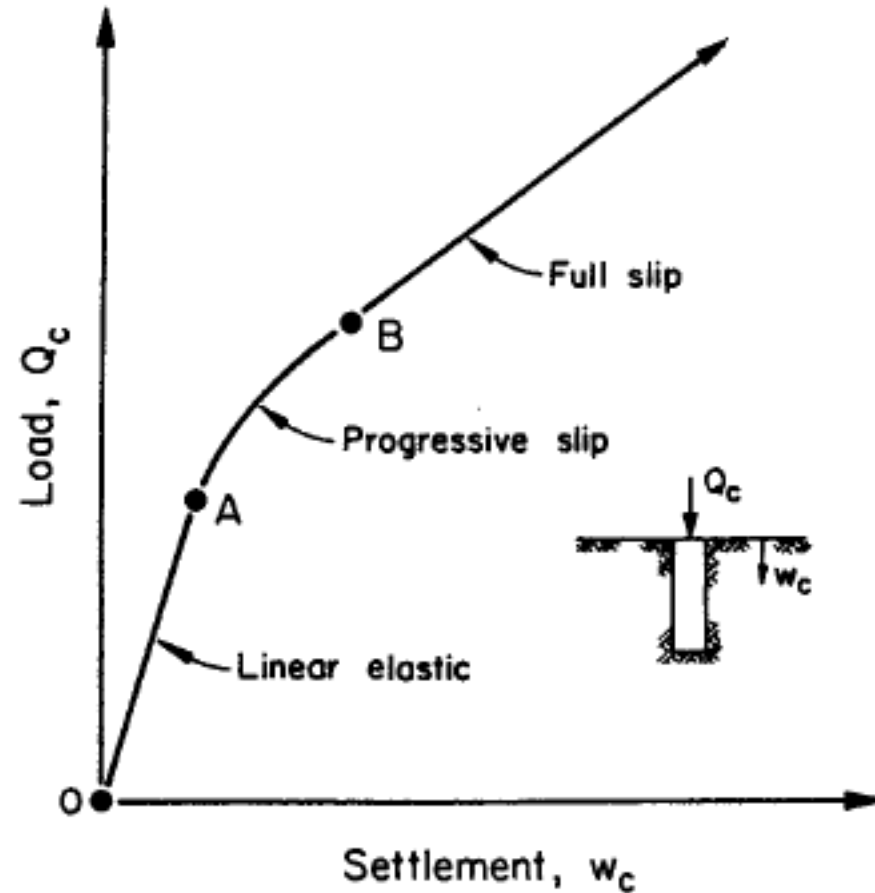


a) Complete Socket



b) Shear Socket

# Idealized Load-Displacement Response under Compression



# Idealized Load-Displacement Response under Compression

- **OA:** the socket behaves according to linear elasticity.
- **AB:** the shear stress reaches peak along the concrete-rock interface. More load is transferred to the pile tip as slip progressively takes place.
- **Beyond point B:** more load is transferred to the pile tip.

# Expected Pile Movement

- For pile movement  $< 10$  mm, load is transferred mainly through friction.
- For pile movement  $> 10$ mm, pile capacity should be computed based on end bearing resistance only.
- Typically, the allowable pile movement is very small so it is recommended to consider only friction in the design.

# Drilled Cast-in-place Shafts Bearing

The allowable design load for a circular drilled shaft of radius (r) is computed by:

$$(Q_{\text{all}})_{\text{bearing}} = q_{\text{un}} \cdot K_{\text{sp}} \cdot f_{\text{d}} \cdot \pi r^2$$

Where:

$q_{\text{un}}$  = avg unconfined compressive strength of rock cores.

$F_{\text{d}}$  = depth factor =  $(1 + 0.4L_{\text{s}}/B_{\text{s}})$ .

$L_{\text{s}}$  = penetration depth within the rock stratum.

$B_{\text{s}}$  = Diameter of rock socket.

# Drilled Cast-in-place Shafts Bearing

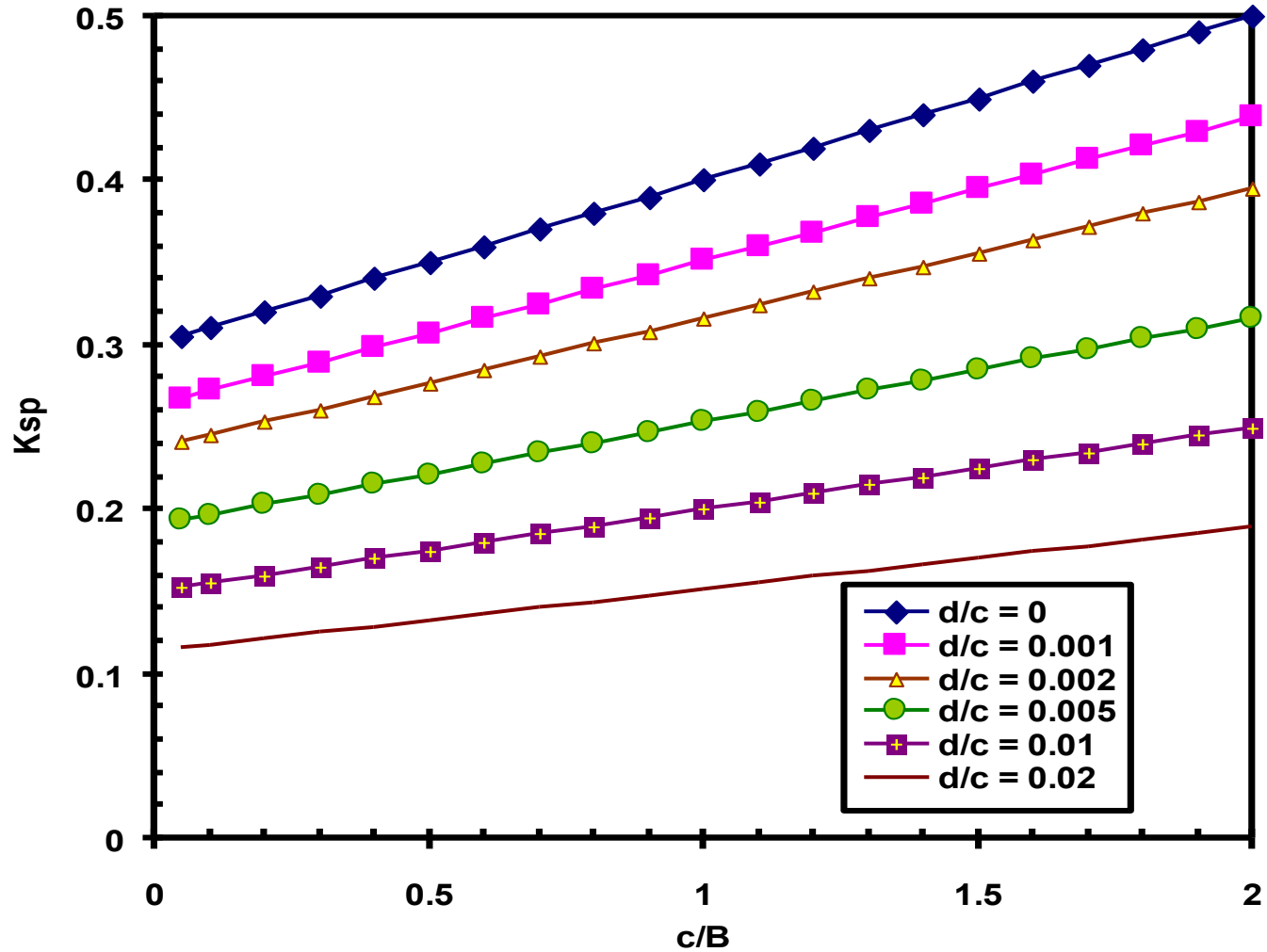
$$K_{sp} = (3 + c/B) / (10 * (1 + 300\delta / c)^{0.5})$$

**c** = rock joint spacing.

**$\delta$**  = joint width.

**B** = drilled shaft diameter.

# Drilled Cast-in-place Shafts Bearing



# Drilled Cast-in-place Shafts friction

The allowable design load for a circular drilled shaft of radius (r) is computed by:

$$(Q_{\text{all}})_{\text{friction}} = \alpha \cdot \beta \cdot q_{\text{un}} \cdot \pi \cdot L_s \cdot B_s / \text{Safety Factor}$$

Where:

$\alpha$  = function (rock unconfined compressive strength).

$\beta$  = function (RQD).

$q_{\text{un}}$  = avg unconfined compressive strength of rock cores.

$L_s$  = penetration depth within the rock stratum.

$B_s$  = Diameter of rock socket.

Safety factor  $\geq 2$

# Drilled Cast-in-place Shafts friction

$q_{un}$ (kg/cm <sup>2</sup> )	$\alpha$
<10	0.30
10-20	0.25
20-50	0.18
50-100	0.13
100-200	0.10
> 200	0.05

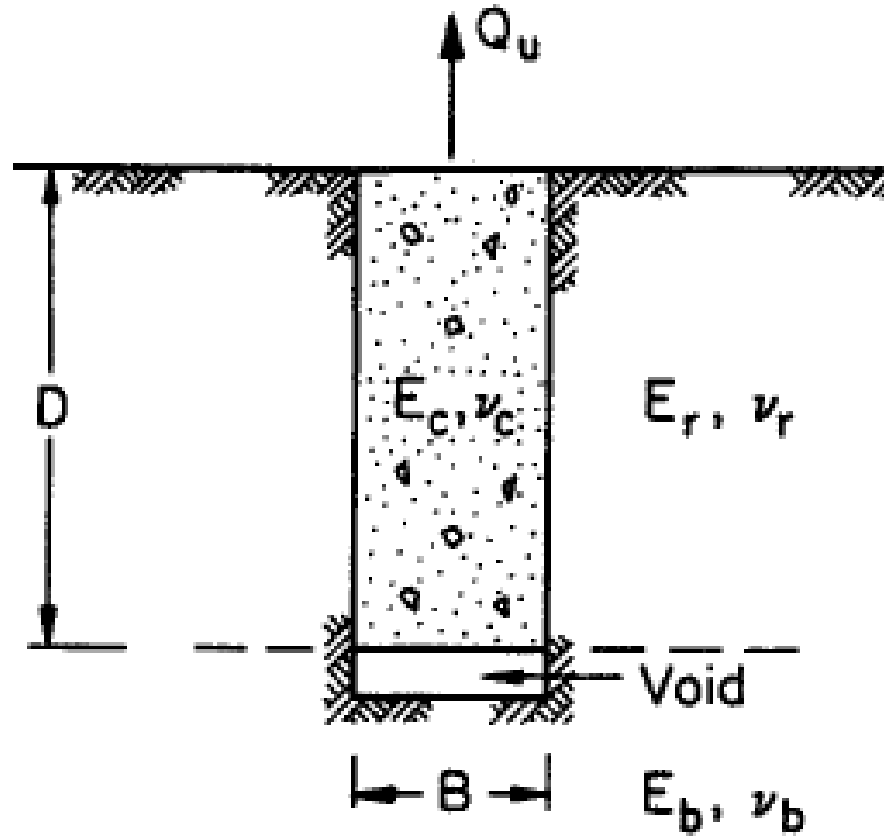
# Drilled Cast-in-place Shafts friction

RQD (%)	$\beta$
<50	0.65
50-75	0.73
75-90	0.88
90-100	1.00

# Piles under Tension

- In some cases, piles socketed in rock are subjected to uplift forces. The resistance to uplift is developed from both side friction and tip resistance.
- The tip resistance is developed from the concrete-rock tensile bond. However, it is usually ignored because of construction problems related to cleaning the bottom of the socket hole. Accordingly only friction is considered.

# Piles under Tension



# Piles under Tension

- For piles subjected to tensile forces, Poisson's effect is negative resulting the contraction of the pile.
- Accordingly, the shaft friction is reduced by 30%.

# Drilled Cast-in-place Shafts

## General

- Typical socket length = 1-3 pile diameter. Larger lengths may be used to obtain the required allowable load.
- Fill any cavities with plain concrete.
- Avoid concrete shrinkage that may cause a gap between rock-concrete.

# Integrity Testing of Piles

Modified from Dr Amr Elhakim  
lecture notes

# What is a defective pile?

- Traditionally, the pile integrity was determined from pile load tests either on trial or working piles.
- The Engineer decides upon the pile suitability based on settlement-load data from the pile load test.
- Most structural elements may be inspected superficially, whereas piles may contain hidden cracks, voids or inclusions.

# Pile Load Test

- Best way for determining axial pile capacity.
- Time-consuming.
- Expensive.

Egyptian Code of practice specifies performing a minimum of 1 pile load tests/100-200 working piles, with a minimum of 1 pile.

# Integrity Testing of Piles

- Crosshole sonic logging (CSL),
- Sonic echo (SE)

# Crosshole sonic logging (CSL)

- Developed for integrity testing of concrete foundations, such as drilled shafts, and auger cast piles.
- The purpose of the test is to assess the homogeneity and integrity of concrete between access tubes in a deep foundation.
- Steel or PVC access tubes must be attached to the inside of the reinforcing rebar cage prior to the concrete placement and be filled with water.

# Crosshole sonic logging (CSL)



InfraSeis, Inc.



Olson Instruments, Inc.



GeoSciences Testing and Research, Inc.

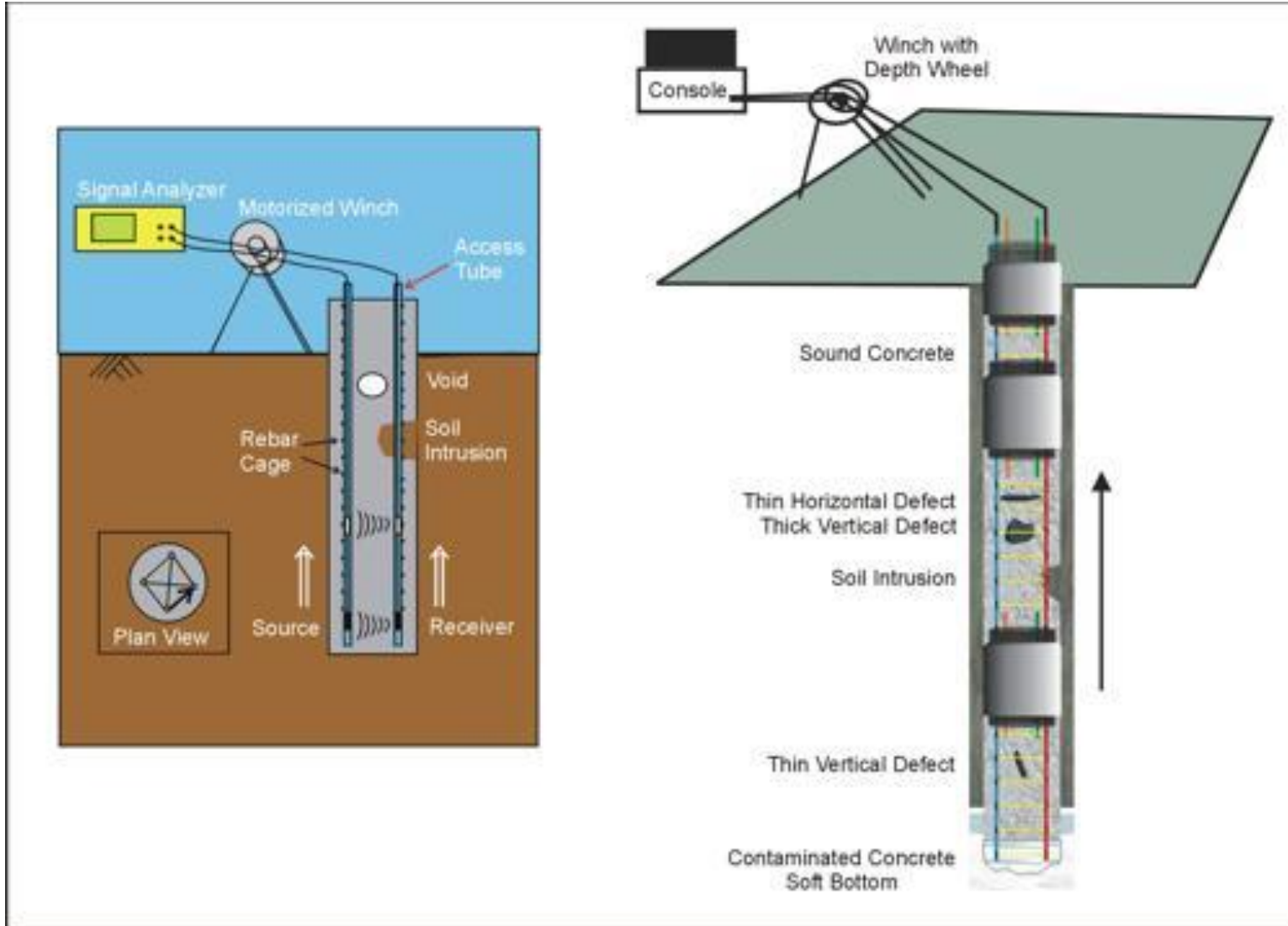
# Crosshole sonic logging (CSL)

- Special care must be taken when installing access tubes to avoid debonding between the concrete and the tubes. Poor bonding between access tubes and concrete can cause complete signal loss.
- One of the tubes is used for the transmitter and the other for the receiver probe. The transmitter and receiver probes can be oriented such that the path between them is horizontal.

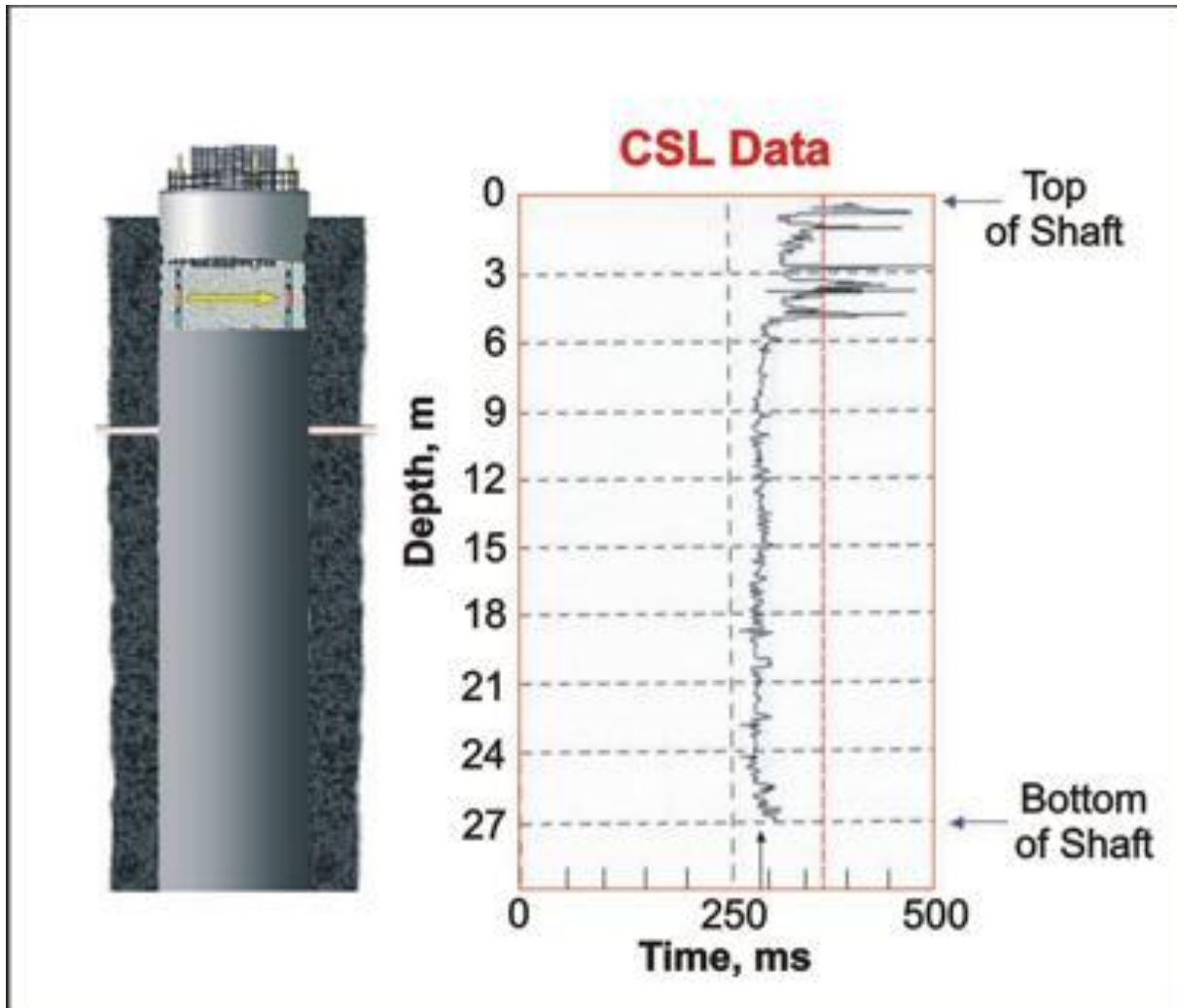
# Crosshole sonic logging (CSL)

- The sonic source produces an impulse whose frequency content is usually 30 to 40 kHz.
- Sonic waves passing through concrete are influenced by the density and elastic modulus of the concrete.
- Fractured or "weak" concrete zones lower the velocity of the sonic waves and, therefore, can be detected.

# Crosshole sonic logging (CSL)



# Crosshole sonic logging



Travel Time vs  
Depth

# Crosshole sonic logging (CSL)

## Advantages

- Accurate characterization of pile anomalies inside the shaft between the rebars.
- Defining the geometry and location of the anomaly.

## Disadvantages

- Detection tubes are installed prior to placing the concrete.
- Problems with debonding may result in “no signal” zones.
- Detects only anomalies between the rebar.
- Detects only anomalies along wave path.
- Can not detect changes pile diameter.

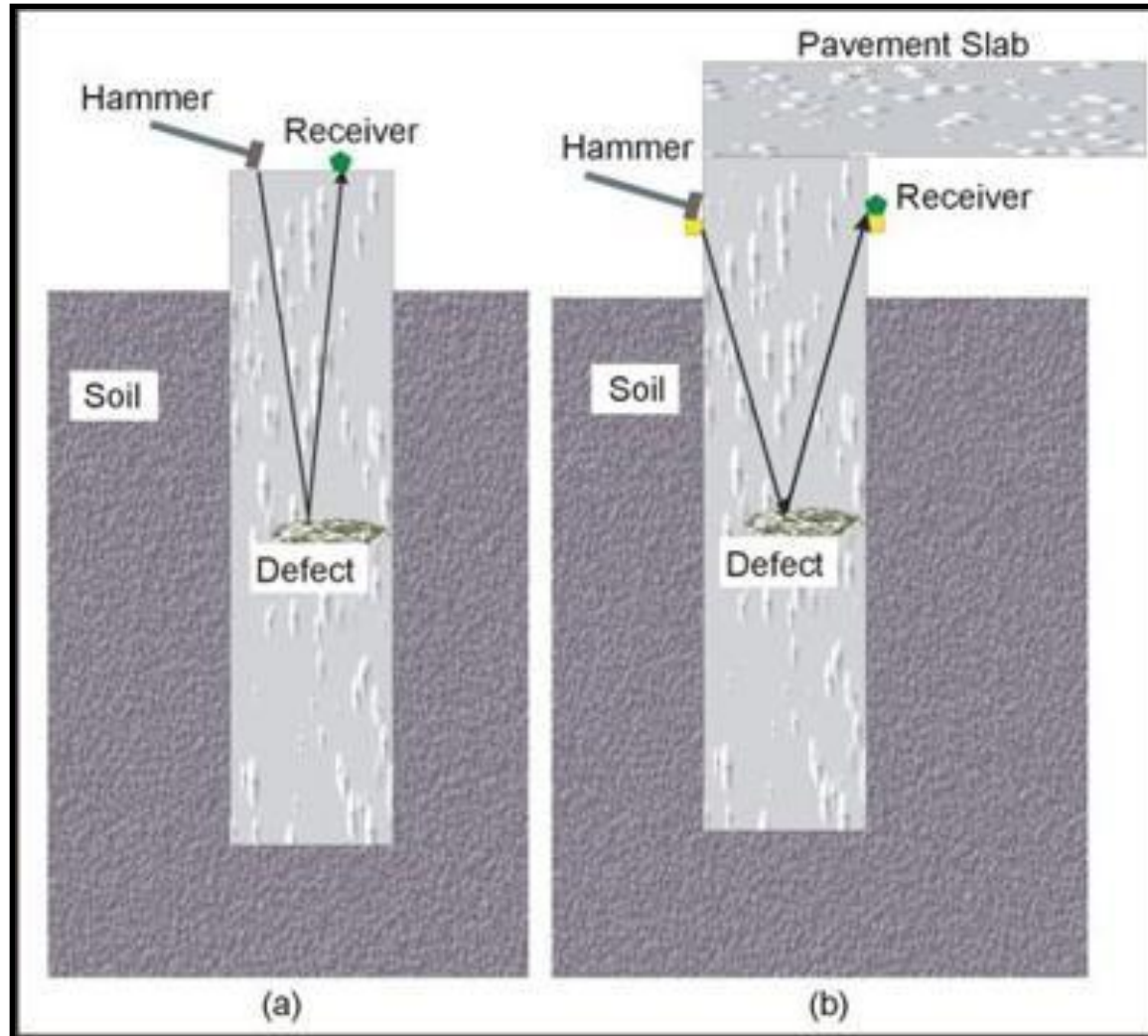
# Sonic Echo (SE)

- Determine approximate pile length.
- Detect pile necking (decrease in pile diameter).
- Detect pile bulging (increase in pile diameter).
- Detect pile defects and soil inclusions.

# Sonic Echo (SE)

- The test involves the measurement of the travel time of seismic waves.
- Compression waves are reflected either at the bottom of the pile or at any discontinuity (crack or soil inclusion).
- The reflected waves are detected by a receiver placed next the source (transmitter).

# Sonic Echo (SE)



# Sonic Echo (SE)

- A hammer strikes the foundation top, and a receiver monitors the response of the foundation.
- A digital analyzer records the hammer input and the receiver output.
- Special techniques may be used to enhance weak echoes.
- For best results, it is important to know the compression wave velocity in the structure being tested.

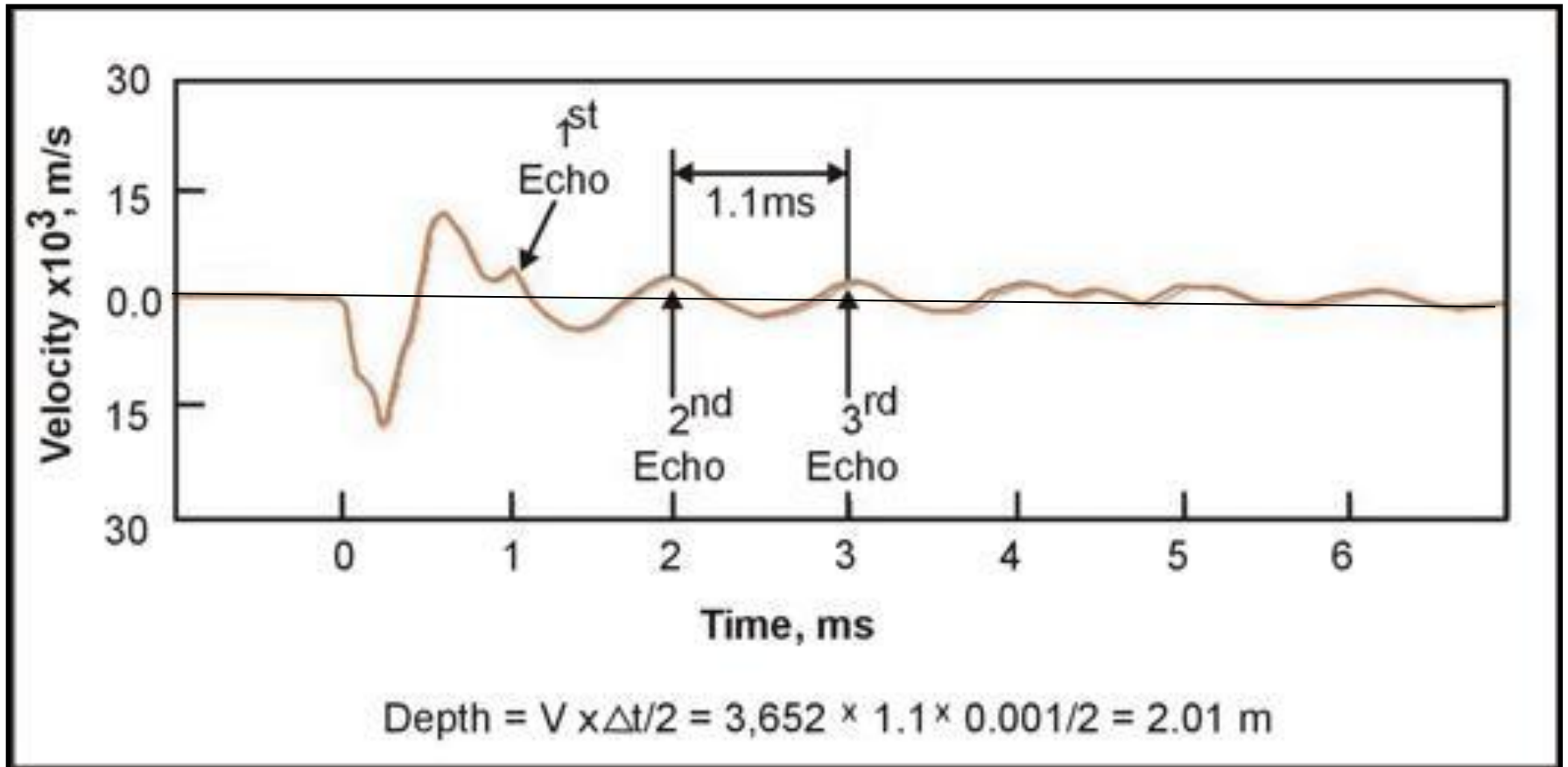
# Sonic Echo (SE)

- Sonic Echo data are used to determine the depth of the foundation based on the time separation between the first arrival and the first reflection events or between any two consecutive reflection events ( $\Delta t$ ) according to the following equation:

$$D = V \cdot \Delta t / 2$$

where  $D$  is the reflector depth, and  $V$  is the velocity of compressional waves.

# Sonic Echo (SE)



# Sonic Echo (SE)

- The multiple echoes are all interpreted as coming from the same reflector since they are an equal time apart. Any pair can be used to calculate the 2-way travel time between the source and the reflector.
- In this example, the clearest pair of echoes were the second and third, which were used to calculate the depth using the formula above.
- A reflector can be the bottom of the foundation or any discontinuity along the embedded part of the foundation.
- Sonic Echo data can also be used to determine the existence of a bulb or a neck in a shaft or the end conditions of the shaft.

# Sonic Echo (SE)

## Advantages

- Quick causing minimal delays to construction.
- Econominc.
- Does not require any special tubing.

## Disadvantages

- Detects discontinuities at least 5% of the pile area.
- No toe reflection for piles socketed in rock.