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Purpose and Choice of Instrumentation

Notes

Purpose and Choice of Instrumentation

Purpose of Geotechnical Instrumentation

Site Investigation — Instruments are used to characterize initial site conditions. Common parameters of interest in a site investigation are pore-water pressure, permeability of the soil, and slope stability.

Design Verification — Instruments are used to verify design assumptions and to check that performance is as predicted. Instrument data from the initial phase of a project may reveal the need (or the opportunity) to modify the design in later phases.

Construction Control — Instruments are used to monitor the effects of construction. Instrument data can help the engineer determine how fast construction can proceed without the risk of failure.

Quality Control — Instrumentation can be used both to enforce the quality of workmanship on a project and to document that work was done to specifications.

Safety — Instruments can provide early warning of impending failures, allowing time for safe evacuation of the area and time to implement remedial action. Safety monitoring requires quick retrieval, processing, and presentation of data, so that decisions can be made promptly.

Legal Protection — Instrument data can provide evidence for a legal defense of designers and contractors should owners of adjacent properties claim that construction has caused damage.

Performance — Instruments are used to monitor the in-service performance of a structure. For example, monitoring parameters such as leakage, pore-water pressure, and deformation can provide an indication of the performance of a dam. Monitoring loads on tiebacks or rock bolts and movements within a slope can provide an indication of the performance of a drainage system installed in a stabilized slope.

Factors Affecting the Choice of Instruments

Critical Parameters

Each project presents a unique set of critical parameters. The designer must identify those parameters and then select instruments to measure them. What information is required for the initial design? What information is required for evaluating performance during and after construction? When the parameters are identified, the specification for instruments should include the required range, resolution, and precision of measurements.

Ground Conditions

Ground conditions often determine the choice of instrument. For example, a standpipe piezometer is a reliable indicator of pore-water pressure in soil with high permeability, but is much less reliable in soil with low permeability. A large volume of water must flow into the standpipe to indicate even a small change in pore-water pressure. In soils with low permeability, the flow of water into and out of the standpipe is too slow to provide a timely indication of pore-water pressure. A better choice in this case would be a diaphragm-type piezometer, which offers faster response since it is sensitive to much smaller changes in water volume.

Complementary Parameters & Redundant Measurements

The behavior of a soil or rock mass typically involves not one, but many parameters. In some cases, it may be sufficient to monitor only one parameter, but when the problem is more complex, it is useful to measure a number of parameters and to look for correlation between the measurements. Thus it is common practice to choose instruments that provide complementary measurements.

For example, inclinometer data indicating increased rate of movement may be correlated with piezometer data that shows increased pore pressures. The load on a strut, calculated from strain gauge data, should correlate with convergence data provided by inclinometers behind a retaining structure.

Another benefit of selecting instruments to monitor complementary parameters is that at least some data will always be available, even if one instrument fails.

Instrument Performance

Instrument performance is specified by range, resolution, accuracy, and precision. The economical designer will specify minimum performance requirements, since the cost of an instrument increases with resolution, accuracy, and precision.

Range is defined by the highest and lowest readings the instrument is expected to produce. The designer typically specifies the highest values required.

Resolution is the smallest change that can be displayed on a readout device. Resolution typically decreases as range increases. Sometimes the term “accuracy” is mistakenly substituted for resolution. Resolution is usually many times better than accuracy and is never expressed as a “±” value.

Accuracy is the degree to which readings match an absolute value. Accuracy is expressed as a ± value, such as ± 1 mm, ± 1 % of reading, or ± 1 % of full scale.

Precision or **repeatability** is often more important than accuracy, since what is usually of interest is a change rather than an absolute value. Every time a reading is repeated, the value returned by the instrument is slightly different. Precision is expressed as a ± value representing how close repeated readings approach a mean reading.

Cost-Effectiveness

The difference in cost between a high-quality instrument and a lesser-quality instrument is generally insignificant when compared to the total cost of installing and monitoring an instrument. For example, the cost of drilling and backfilling a borehole is typically 10 to 20 times greater than the cost of the piezometer that goes in it.

It is false economy to install a cheaper, less reliable instrument. It is expensive and sometimes impossible to replace a failed instrument. Even when it is possible to replace the instrument, the original baseline data is no longer useful.

Instrument Life

Are readings needed only during construction or will they be needed for years afterwards? Instruments, signal cables, and protective measures should be selected accordingly. Some instruments are excellent for short-term applications, but may exhibit excessive drift over the long term.

Environmental Conditions

Temperature and humidity also affect instrument choice. Instruments such as hydraulic piezometers and liquid settlement gauges have limited use in freezing weather. In tropical heat and humidity, simple mechanical devices may be more reliable than electrical instruments.

Personnel and Resources at the Site

Consider the personnel and resources at the site when choosing instruments. Do technicians have the skills required to install and read a particular type of instrument? Are adequate support facilities available for maintenance and calibration of the instrument?

Data Acquisition

An automatic data acquisition system may be required when: (1) there is a need for real-time monitoring and automatic alarms; (2) sensors are located at a remote site or in a location that prevents easy access; (3) there are too many sensors for timely manual readings; or (4) qualified technicians are not available.

If a data acquisition system is required, the choice of instruments should be narrowed to those that can be connected to the system easily and inexpensively.

2

Basic Soil Mechanics

Notes

Basic Soil Mechanics

What is Soil?

Soil is made up of mineral particles, water, and air. The mineral particles do not fit together perfectly, and the voids between them are filled with water or air. The water or air in the voids is called *pore-water* or *pore-air*.

A soil whose pores are filled entirely with water is called a *saturated soil.* Most soils below the water table are saturated.

A soil whose pores are filled with both water and air is called an *unsaturated* soil. The compacted fill material in embankments is an unsaturated soil.

Pressure in the Soil

Soil is always under pressure. The combined pressure of the weight of a soil and any applied load is called *total stress.* The pressure carried by the soil particles in contact with each other is called *effective stress.* The pressure of the water in the voids is called *pore-water pressure.*

When pore-water pressure increases, effective stress is reduced. When pore-water pressure decreases, effective stress is increased. This principle can be expressed as:

Effective Stress = Total Stress – Pore-Water Pressure

or, in symbolic form,

$$\sigma' = \sigma - u$$

where:
σ' is effective stress,
σ is total stress, and
u is pore-water pressure.

Note The terms “stress” and “pressure” refer to force per unit area and can generally be used interchangeably. Thus, “total stress” is the same as “total pressure” and “effective stress” is the same as “effective pressure.”

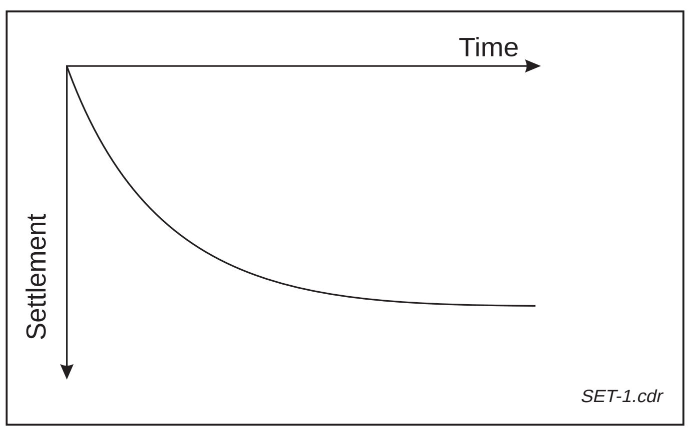
Consolidation of Soil

When a load is applied to a *dry soil,* the soil particles are forced closer together. In contrast, when a load is applied to a *saturated soil,* the soil particles cannot move closer together, since water fills the voids between them. Instead, the load is transferred to the pore-water. This creates excess pore-water pressure and causes the water to flow into soil where pore-water pressure is lower. As the water flows out of the voids, the soil particles are able to *consolidate,* to move closer together.

Consolidation occurs rapidly at first, because there is a high pressure-gradient between the loaded soil and the non-loaded soil. As the pressure-gradient decreases, consolidation slows.

The rate at which excess pore-water pressure dissipates and the soil consolidates depends on the permeability of the soil. In a granular soil such as sand, the pore-water flows away quickly and consolidation occurs quickly. In less permeable soils such as clays, dissipation of the excess pore-water pressure is much slower, and consolidation can take many months or even years.

As consolidation occurs, the volume occupied by the soil decreases and settlement occurs. By monitoring settlement, the engineer determines how far consolidation has progressed. Construction can begin when the degree of settlement has reached an acceptable level.



Shear Strength of Soil

A shear force in a soil tends to cause adjacent particles to slide relative to each other. The *shear strength* of a soil is a measure of its resistance to internal sliding.

There are several factors contributing to shear strength. One is effective stress, the pressure of contact between soil particles. Another is cohesion, the electro-chemical attraction between the particles. A third is the angle of friction between the particles.

Shear strength can be described symbolically as:

$$\tau_f = c' + \sigma' \tan\phi \qquad \text{(After Coulomb)}$$

Where:
τ_f is the shear stress at failure,
c' is the cohesive strength of the soil,
σ' is the effective stress at the shear surface,
ϕ is the angle of internal friction.

Values for the cohesive strength and angle of internal friction are found by laboratory analysis. Total stress can be calculated when the density of the soil and the elevation of the water table are known. It can also be measured with a total pressure cell.

Note that pore-water pressure has a negative effect on shear strength. As pore-water pressure increases, effective stress and shear strength are reduced.

$$\sigma' = \sigma - u$$

Where:
σ' is effective stress,
σ is total stress, and
u is pore-water pressure.

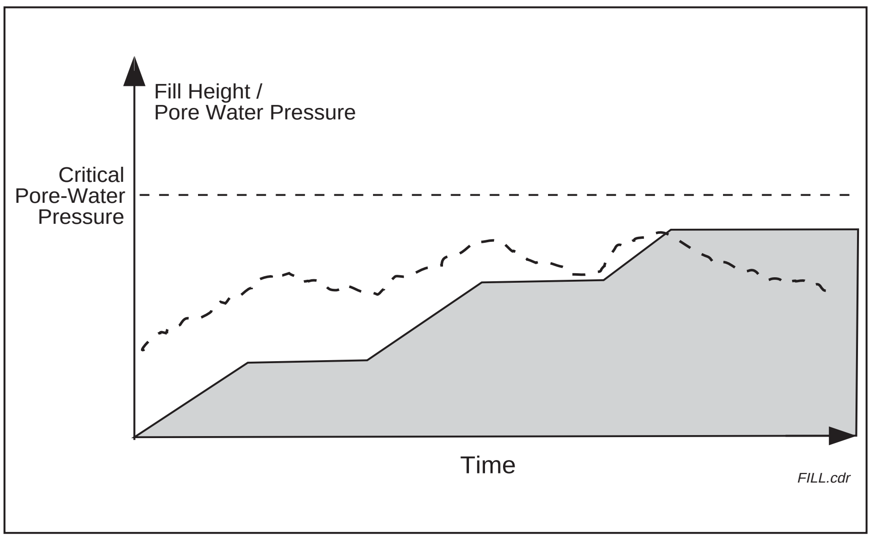
When σ and u are known, τ_f can be calculated. When τ_f is known, σ and u become predictors of foundation stability.

Control of Filling Operations

Engineers place "fill" to raise the ground to a higher level or to speed the consolidation of the soil (temporary surcharges). Projects involving fill include land reclamation and the construction of dams and embankments.

Dumping and compacting tons of fill increases the load on the foundation soil. The load is immediately transferred to the pore-water in the soil. The increased pore-water pressure reduces the effective stress in the soil, and thus its shear strength. If fill is placed too quickly, without allowing time for excess pore-water pressures to dissipate, the increased load on the weakened soil may cause failure.

Before construction starts, the project engineer determines the shear strength of the foundation soil and establishes a safe pore-water pressure. Piezometers are installed to monitor pore-water pressures at various distances from drainage boundaries. The engineer then slows or halts placement of fill to maintain pore-water pressure at safe levels.



Slope Stability

Natural slopes include hillsides and river banks. Man-made slopes include cuttings and embankments for highways or railroads, earth dams, river levees, dikes, landscaping, canals, waterways, and excavations.

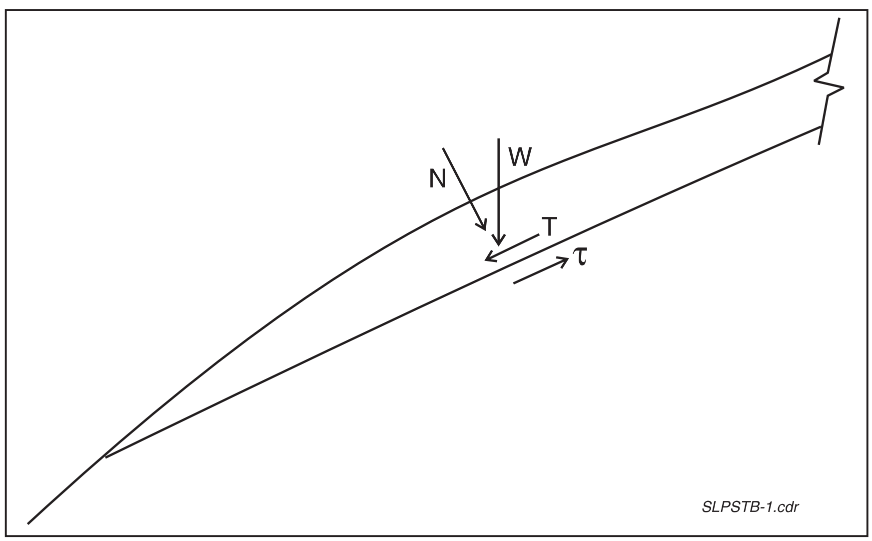
Slope failure occurs when the equilibrium of the slope is disturbed enough to overcome the shear-strength of the soil or rock. Factors affecting the stability of a slope are its stratigraphy, soil strength, and seepage. An in-flow of water affects the equilibrium of the slope in two ways. It increases shear forces by adding mass and it decreases shear strength by raising pore-water pressure.

Measurements of pore-water pressure can be used to predict slope failure and can assist the design of retention and drainage systems.

Plane Failure

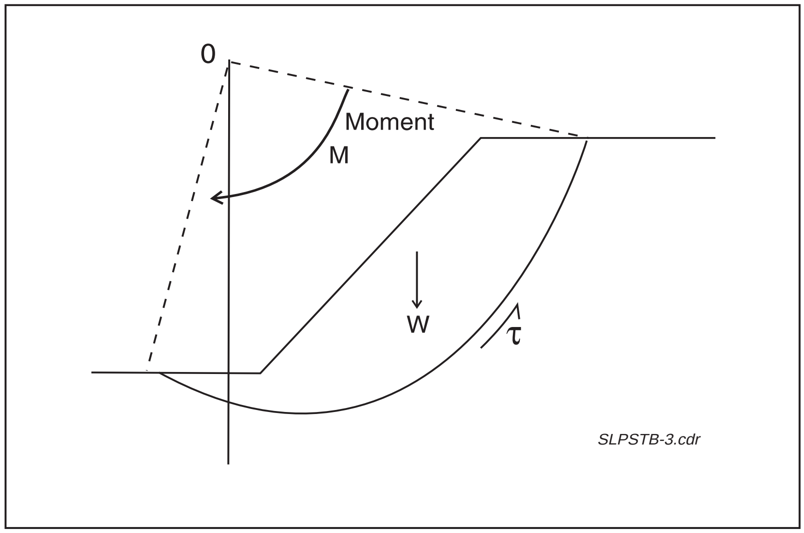
Plane failures tend to occur in layered soils or rock where one layer is weaker than the others. A simple stress diagram shows a soil block of weight W that exerts a normal force N and tangential force T on the shear plane. If the tangential force T of the block exceeds shear strength τ of the soil, the block will move. Ground water increases the chances of failure: it adds mass to the block and it decreases shear strength.

When soils are un-saturated, a basic analysis can be carried out using total stress. When soil is saturated, a more accurate analysis is obtained using effective stress.



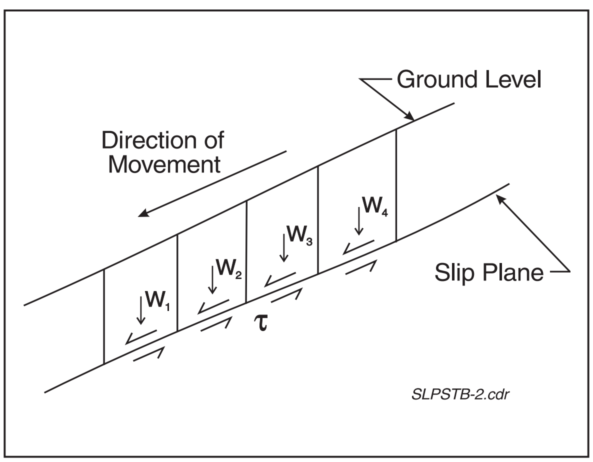
Circular Failure

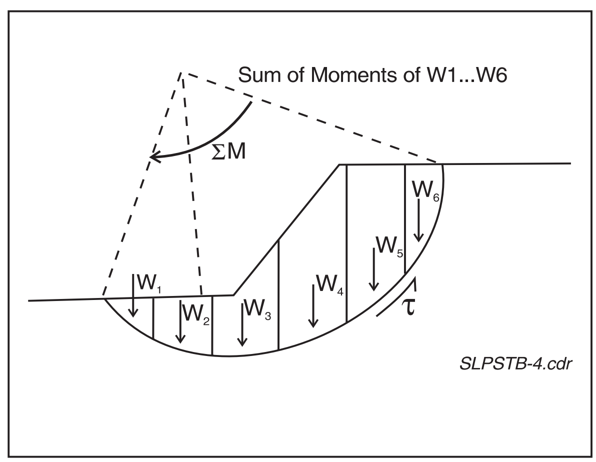
Circular failures tend to occur in homogeneous soils. In the illustration below, any forces eccentric to the center point O will generate a moment M. When M becomes greater than τ, failure occurs.



Typical Analyses

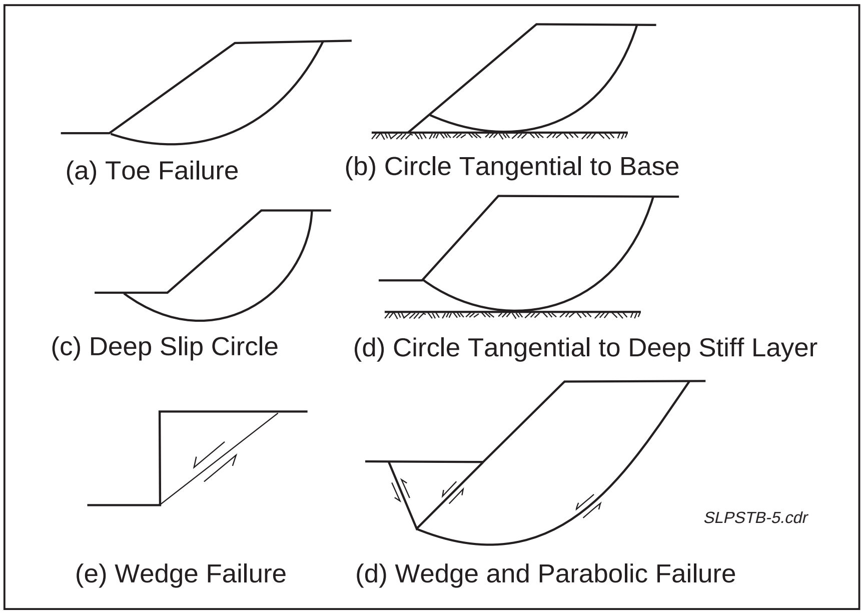
Most analysis techniques divide the slope into a number of “slices” to improve accuracy.





Multiple Failure Planes

There may be more than one potential failure plane. After considering a variety of scenarios, such as those illustrated below, the engineer determines the most probable mode of failure.



Lateral Earth Pressure

Active and Passive Pressures

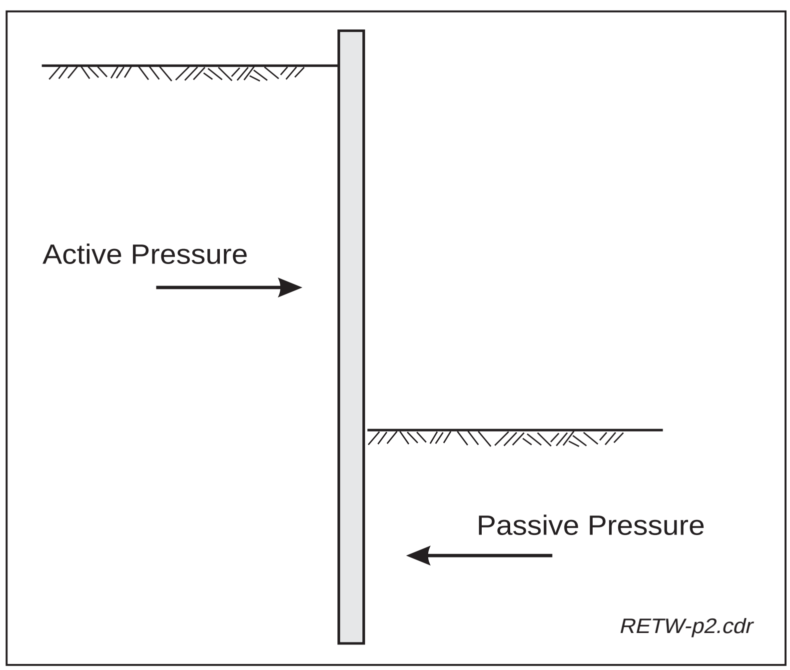
Retaining walls are designed to support soil masses that cannot support themselves. The pressure exerted by the soil mass on the wall is called “active pressure.” The soil on the other side of the retaining structure exerts a resisting “passive pressure” on the wall.

Active pressure on a retaining wall increases with pore-pressure and the depth of the soil being retained. Passive pressure increases with the depth of the soil on the other side of the wall.

If the water level behind the wall can be lowered, active pressure on the wall will be reduced and a lighter, less expensive wall can be built. If the water level cannot be lowered because the resulting settlement would damage adjacent buildings, a heavier, more expensive wall must be built.

Before construction of the wall, pore-water pressures are monitored to determine the existing water level and the permeability of the soil. With permeable soils, water can be directed to a sump and pumped out. In other soils, more elaborate dewatering systems must be devised.

After construction of the wall, pore-water pressures are monitored to detect any seepage that would increase active pressure on the wall and reduce its factor of safety.

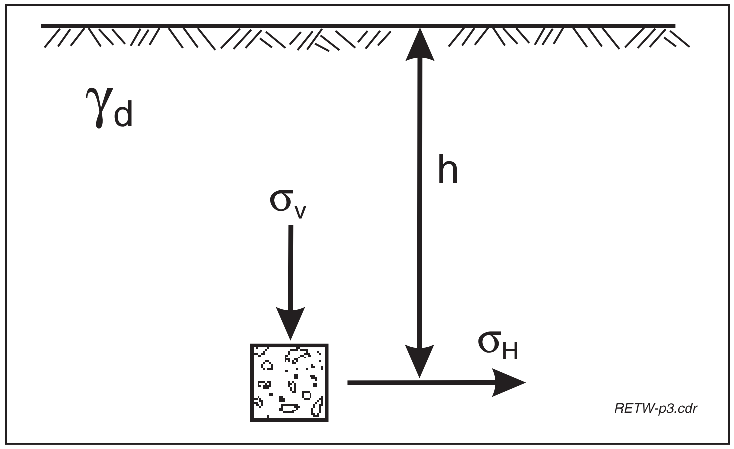


Typical Analysis

The object of the analysis is to quantify active and passive pressures so that a structure can be designed to withstand any imbalance between the two pressures. Typically, the analysis begins with dry conditions.

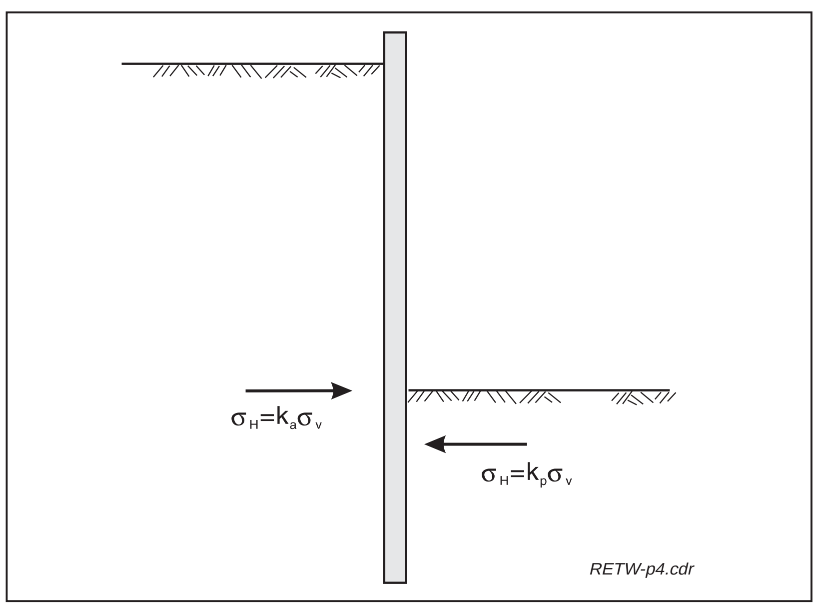
Dry conditions

In dry conditions, the total vertical stress is equal to the height of the soil times the density of the soil: $\sigma_V = \gamma_d h$.



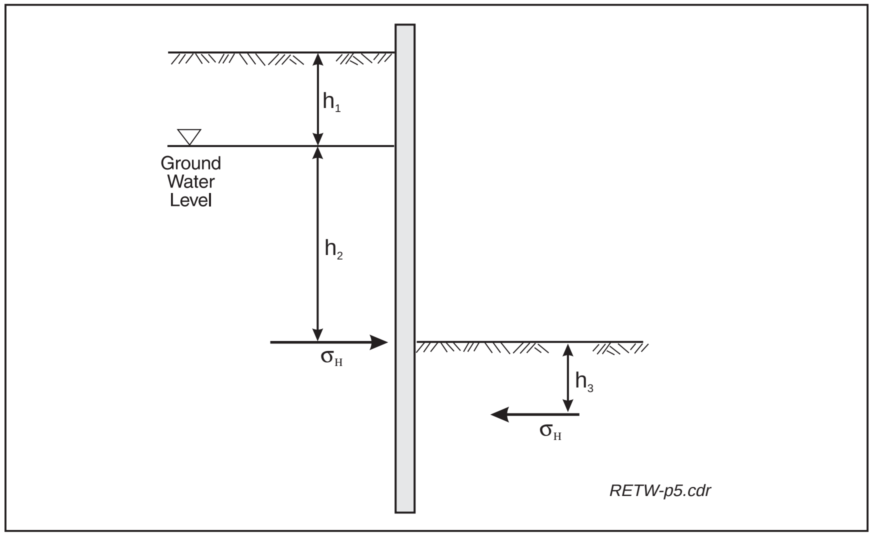
Total horizontal stress can be calculated from total vertical stress using Rankine's coefficient of earth pressure, K_a, for active pressure and K_p for passive pressure. K_a is always less than one, while K_p is always greater than one.

In symbolic form, the active horizontal stress is $\sigma_H = K_a \sigma_V$ and the passive horizontal stress is $\sigma_H = K_p \sigma_V$.



Wet Conditions

In wet conditions, the level of the water table enters into the calculation. As you may recall, total stress = effective stress + pore-water pressure. Also, the saturated soil below the water table has a different density than the dry soil above the water table.



On the active side, we have:

$$\sigma_H = K_a \, \sigma_V' + u$$

$$= K_a \, (\sigma_V - u) + u$$

$$= K_a \, (h_1 \gamma_d + h_2 \gamma_s - h_2 \gamma_w) + u$$

On the passive side, we have:

$$\sigma_H = K_p \, \sigma_V' + u$$

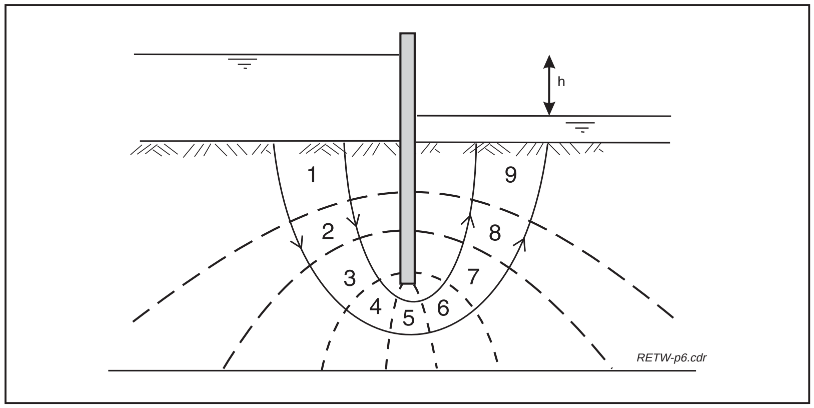
$$= K_p \, (\sigma_V - u) + u$$

$$= K_p \, (h_3 \gamma_s - h_3 \gamma_w) + u$$

Seepage

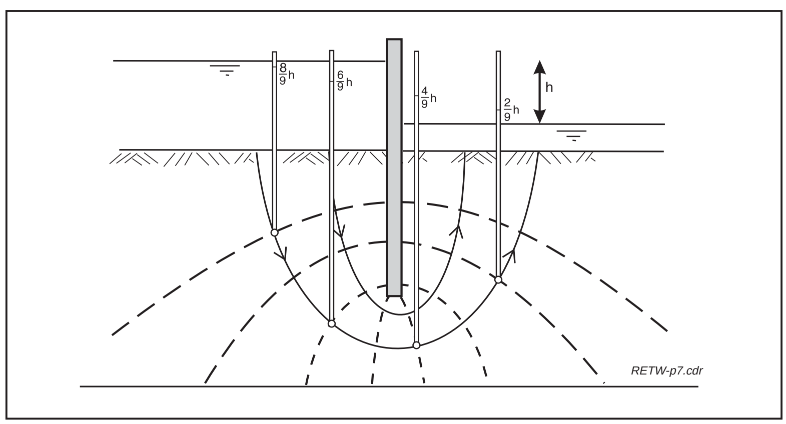
The voids of a soil and of most rocks are connected together to form continuous passageways for the movement of water. Water moving through these passageways is driven by a difference in water head and is called "seepage."

Engineers develop models of seepage called "flow nets." Such modeling helps in the design of de-watering and drainage systems and can also be used to help evaluate the effectiveness of dams and dikes that are already in place.



In the diagram above, the head of water on the left side of the barrier is greater than that on the right side. Water flows from the left to the right, following the flow lines shown.

To calculate the rate of flow, the engineer first draws equi-potential lines across the flow lines. The head of water is constant along each equi-potential line. The result is a system of "squares." The volume of water flowing through each square is the same. Total seepage can be calculated by adding up the squares.

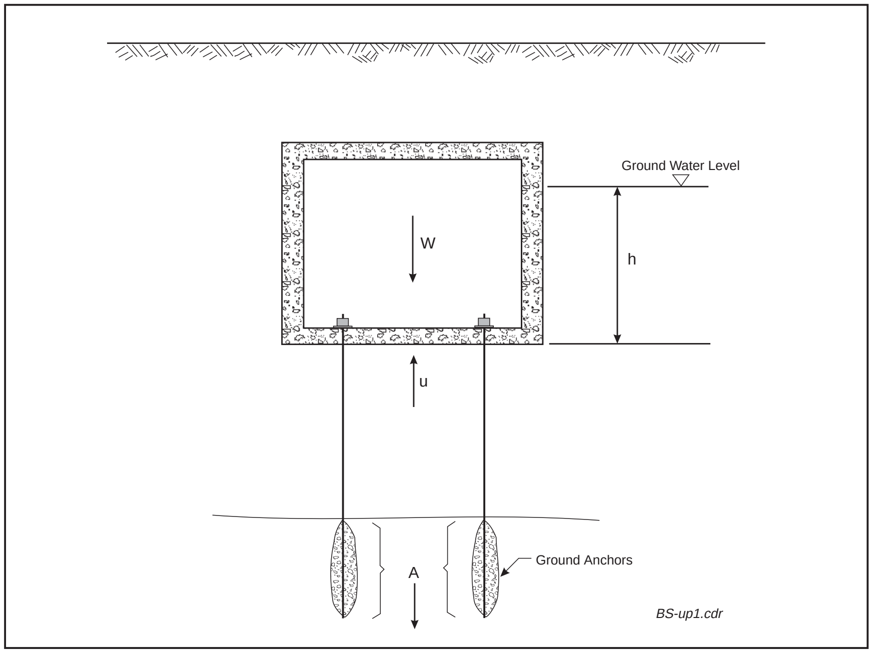


The idealized flow net shown above is correct only for a homogeneous soil or rock mass. In practice, seepage is much more complicated to analyze, and data from piezometers installed at selected depths is required to define flow patterns.

Uplift Pressure and Buoyancy

Water pressure exerts an uplift force on the underside of a structure whose base sits below the water table. If the uplift force is greater than the weight of the structure, the structure will float.

In the drawing below,
W = weight of structure
A = total anchor force
h = height of water table above base of structure
γ_w = density of water
$u = h\gamma_w$ = uplift water pressure



Uplift pressure increases with pore-water pressure. Monitoring pore-water pressure during the design stage can help in assessing the need for anchors to counter buoyancy.

Seepage under a concrete gravity dam can create uplift pressures that are destabilizing. Monitoring pore-water pressures under the dam provides input to stability calculations and may indicate the potential for failure and the need for remedial action.

3

Piezometers

Notes

Applications

Piezometers

Piezometers measure pore-water pressure and ground water levels. They are used in geotechnical, environmental, and hydrological applications.

Geotechnical Applications

Piezometer measurements help engineers to:

- Control placement of fill.
- Predict slope stability.
- Design and build for lateral earth pressures.
- Design and build for uplift pressures and buoyancy.
- Monitor seepage and verify models of flow.

Environmental Applications

Some of the applications listed above are also relevant to environmental remediation and containment systems. Other applications, not discussed in this guide, include the use of piezometers to:

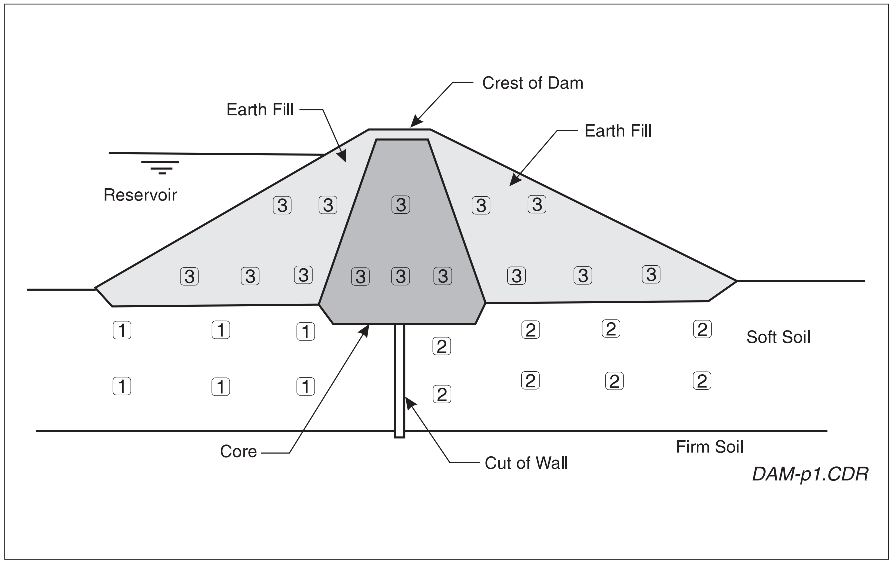
- Monitor surface water runoff.
- Monitor water levels at contaminated sites, to find the rate and direction of movement of the contamination plume.

Hydrological Applications

Hydrological applications not discussed in this guide include the use of piezometers to:

- Map subsurface water flow and to predict both the volume of water in an aquifer and its recharge rate.
- Monitor streams for forestry, agriculture, power companies, and metropolitan water districts.
- Monitor tidal effects on coastal soils.
- Monitor the encroachment of salt water into fresh water aquifers.

Earth Fill Dam



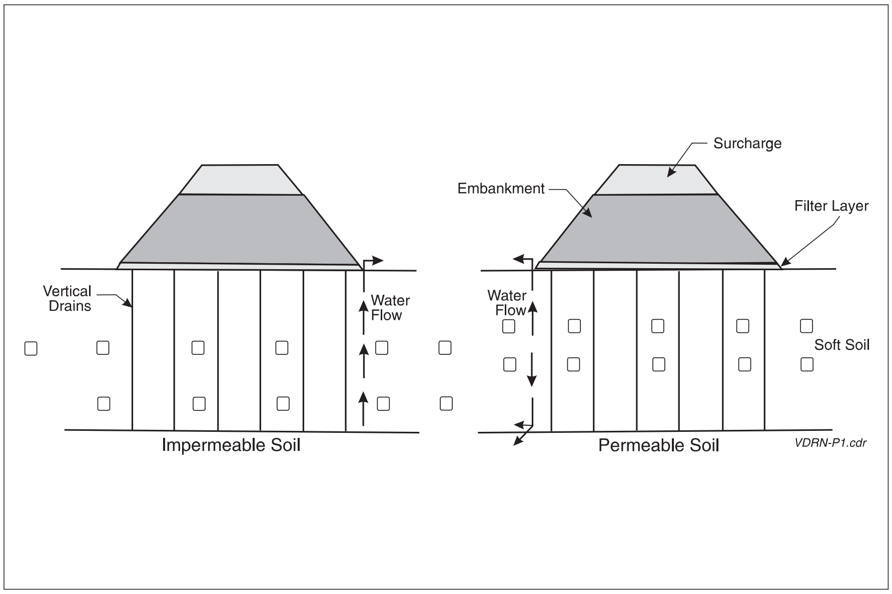
Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Control placement of fill.
Monitor pore-water pressures to determine shear strength.
Measure uplift pressures.

2 Control placement of fill.
Monitor pore-water pressures to determine shear strength.
Monitor seepage.
Measure uplift.

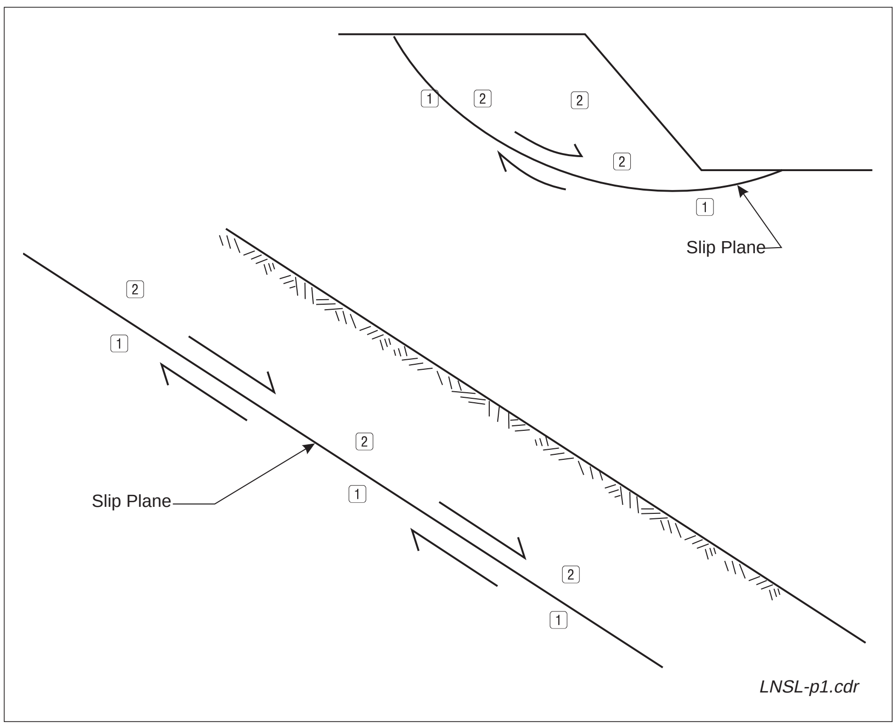
3 Control placement of fill.
Monitor seepage.

Embankment on Soft Soils (Vertical Drains)



- ❑ Control placement of fill.
- ❑ Monitor consolidation before further construction.

Potential Landslide

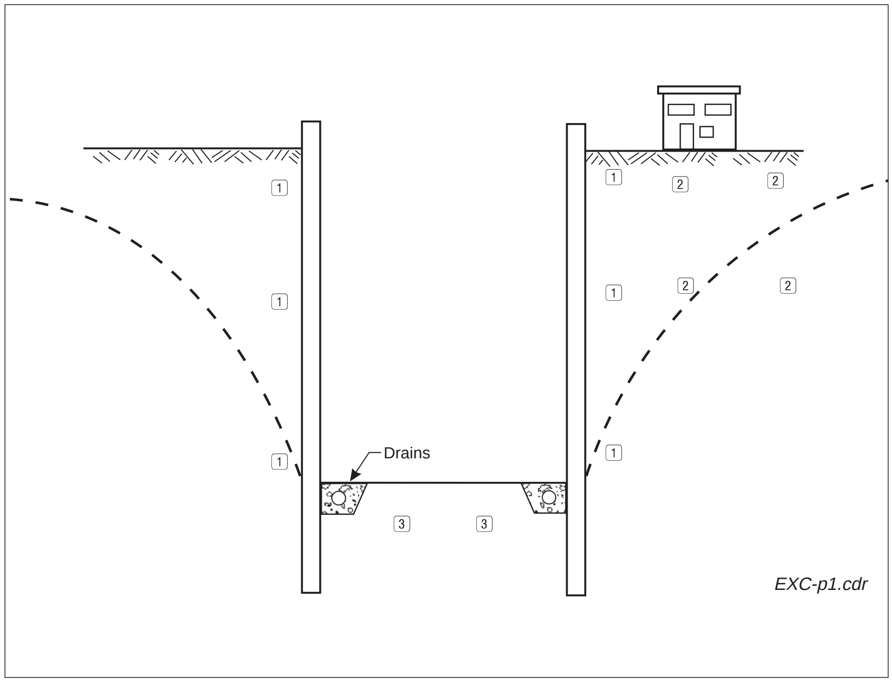


Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Monitor pore-pressure to calculate shear strength of soil.

2 Monitor ground water level to calculate soil mass.

Diaphragm Wall or Sheet Pile Wall



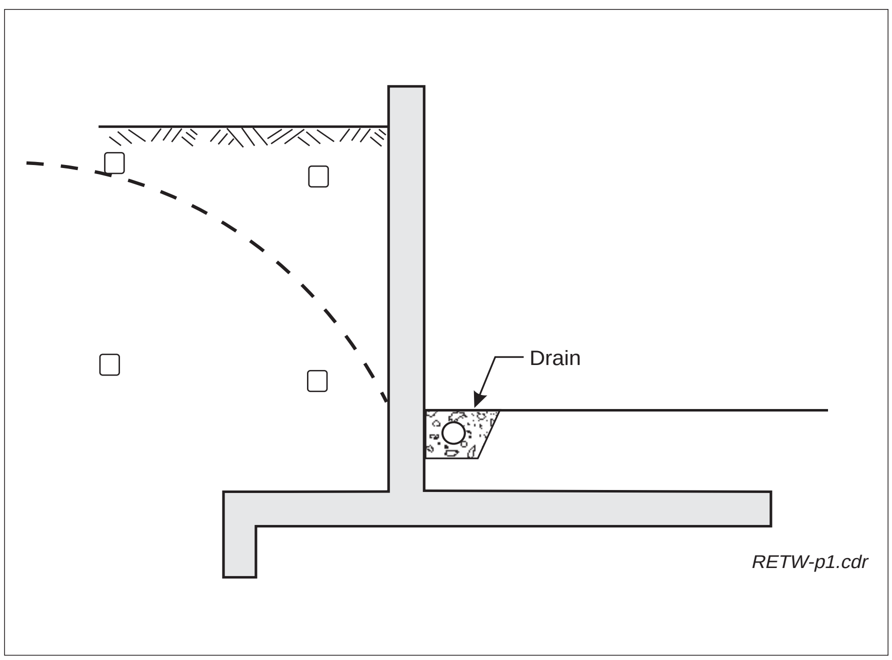
Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Monitor load applied to wall.

2 Monitor draw-down due to seepage or dewatering to predict settlement of adjacent structures.

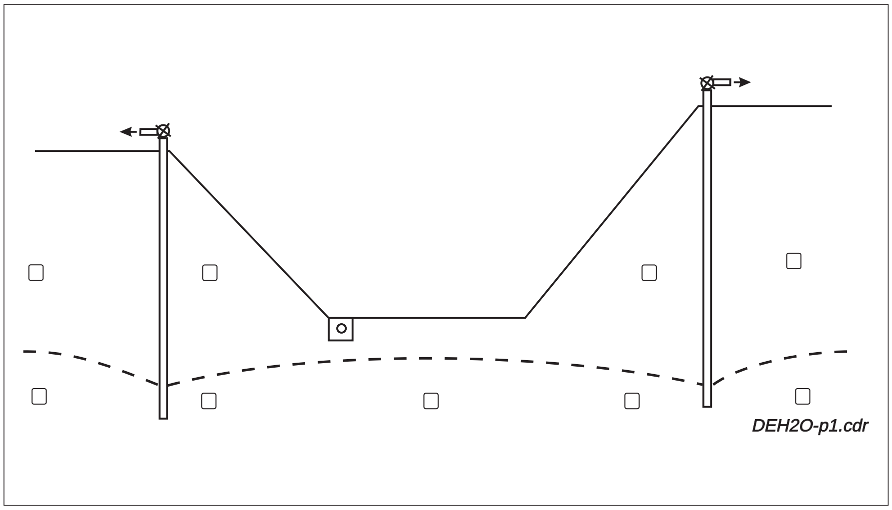
3 Measure uplift to determine stability of base.

Retaining Wall



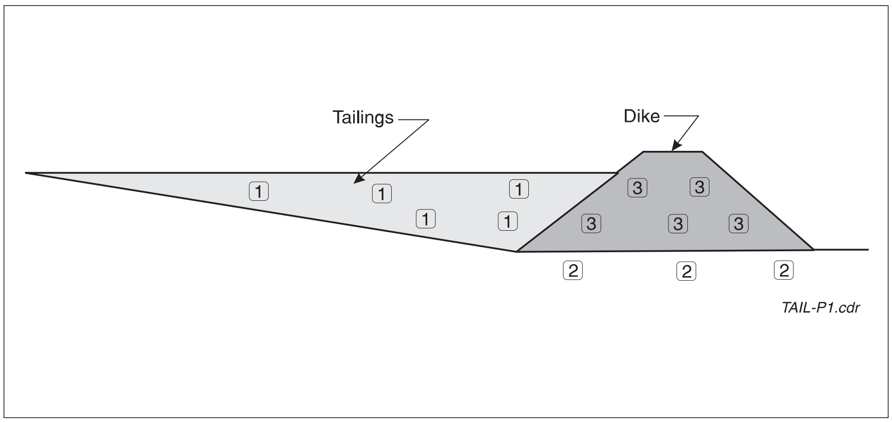
- ❑ Monitor load applied to wall.

Dewatering an Excavation



- Assist design of pumping scheme.
- Determine efficiency of pumping scheme.
- Provide early warning of flooding.

Tailings Pond



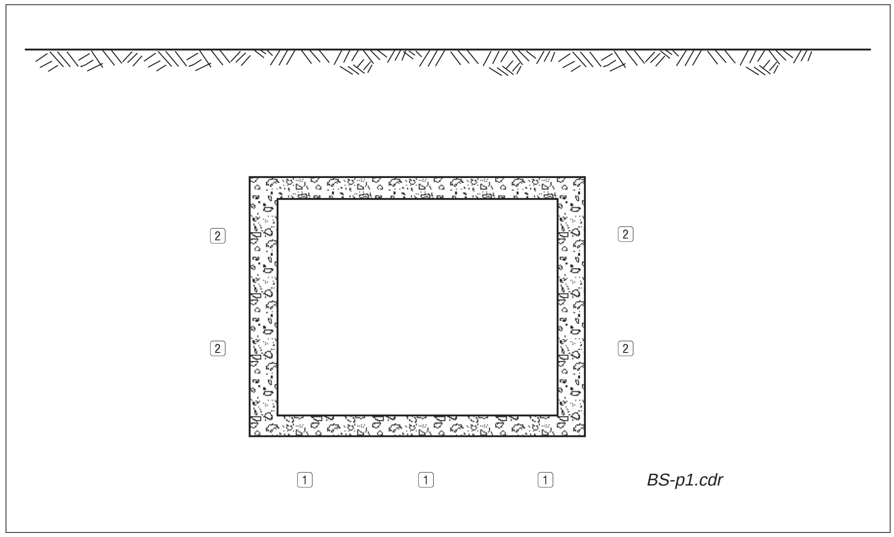
Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Measure pore-water pressure during placement of tailings to determine shear strength and degree of consolidation.

2 Control placement of fill.
Monitor pore-water pressures and determine shear strength.
Measure uplift.

3 Control placement of fill.
Monitor seepage.

Buried Structures

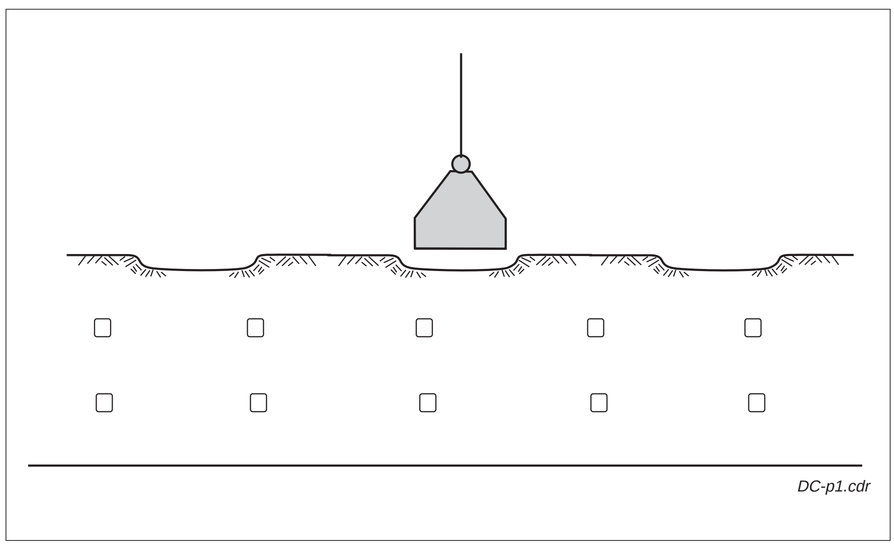


Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Determine uplift pressures (buoyancy).

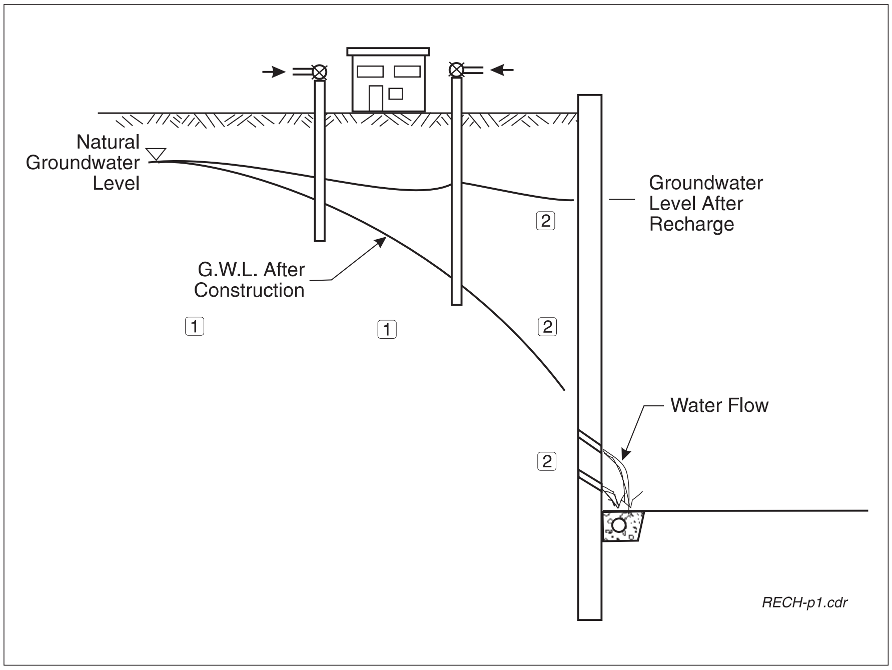
2 Measure pressure of water acting on construction joints, etc.

Dynamic Compaction



- ❑ Determine degree of consolidation prior to construction.

Recharge Systems

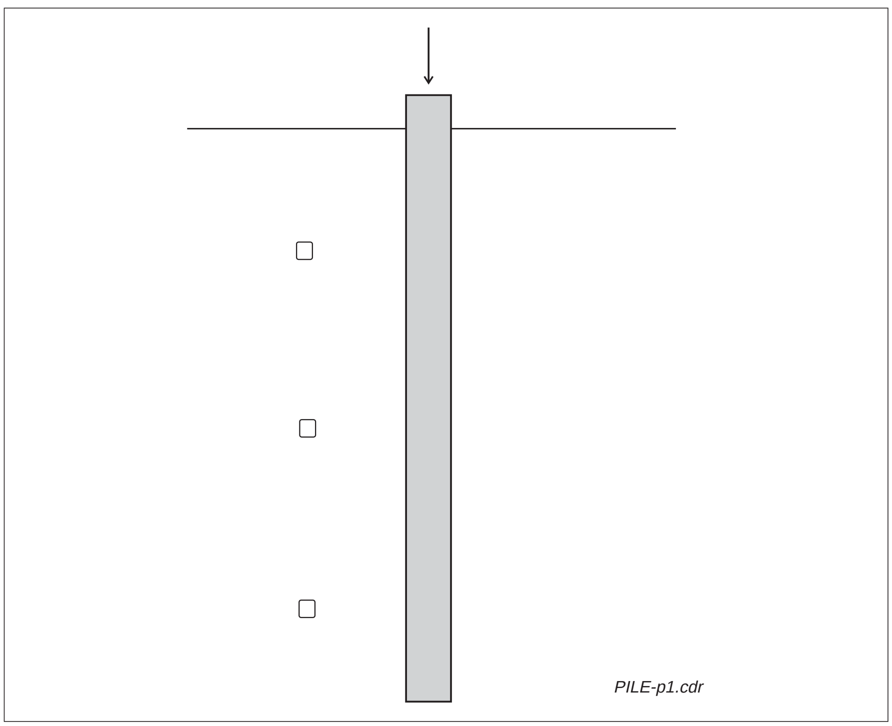


Boxes indicate typical locations for piezometers. Numbers refer to functions listed below.

1 Measure effectiveness of recharge system.

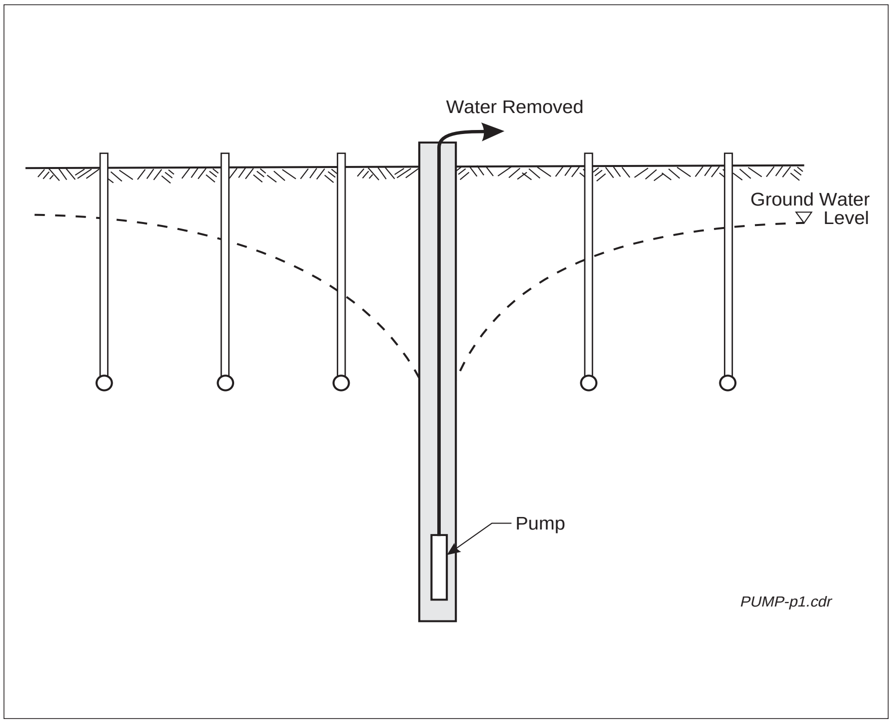
2 Monitor load applied to wall.

Pile Test



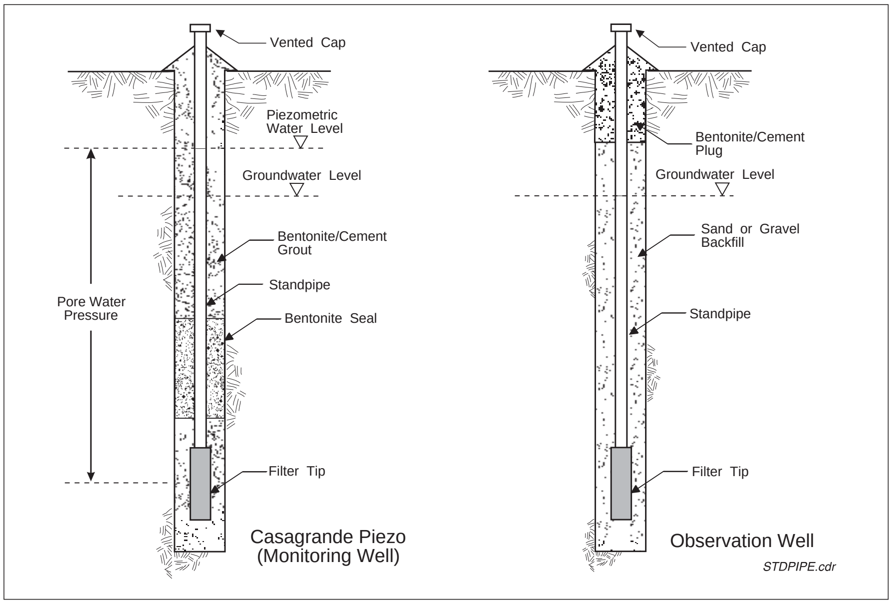
- Monitor excess pore-water pressures generated by pile driving. After excess pore-water pressure dissipates, pile loading can begin.

Pumping Test



- ❑ Monitor draw-down of water table.

Standpipe Piezometer
“Casagrande" Piezometer



Slope Indicator’s standpipe piezometer consists of a filter tip joined to a riser pipe that communicates with the surface. The low air entry filter has 60-micron pores and a permeability of 3 x 10^{-4} m/sec.

A sand cell is formed around the filter tip at the bottom of the borehole. A bentonite seal is placed above the sand to isolate the pore-water pressure at the tip. As pore-water pressure increases or decreases, the water level inside the standpipe rises or falls. The height of the water above the filter tip is equal to the pore-water pressure.

“Observation wells” use the same components as the standpipe piezometer, but are installed differently. The tip is not sealed off and the borehole is backfilled with gravel or sand. Unlike the standpipe piezometer, the observation well can collect water from any elevation above the filter tip. The water level inside the pipe rises or falls with the ground water level.

Advantages

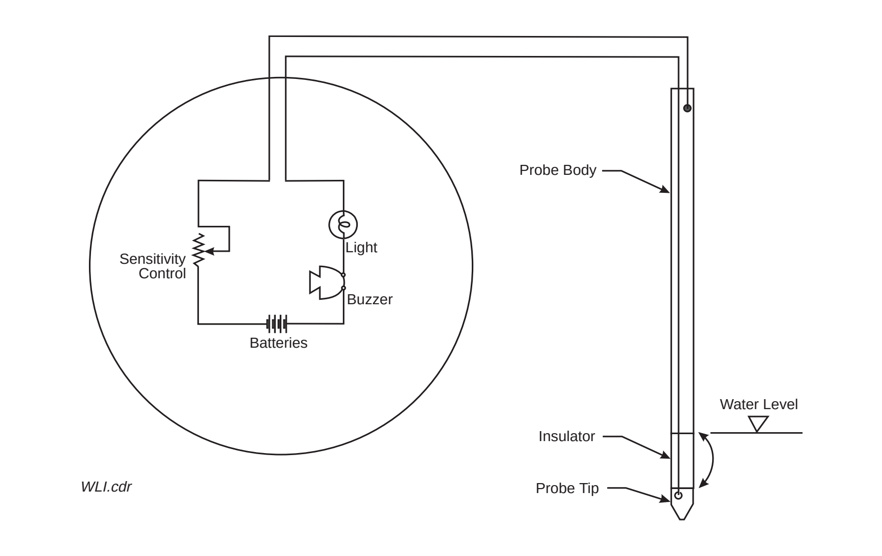
- Simple and reliable.
- Low cost.
- Can be used in permeability tests.

Limitations

- Slow response in low permeability soils.
- Cannot measure negative pore pressure.
- Expensive to automate – requires transducer or bubbler.
- On construction site, top of standpipe interferes with construction activity and may be damaged.

Standpipe continued

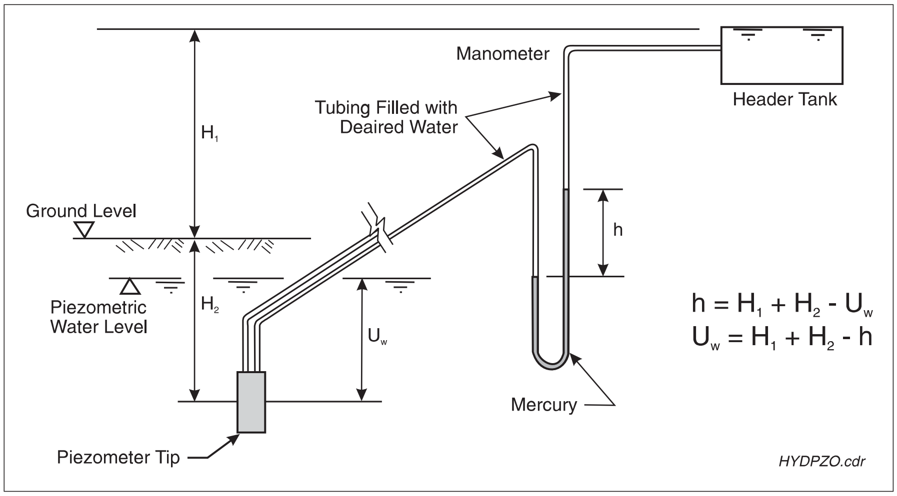
Water Level Indicator



Water levels in either the standpipe piezometer or the observation well are generally measured with a water level indicator, sometimes called a dipmeter. The water level indicator consists of a probe, a cable or tape marked in millimeters or hundredths of a foot, and a cable reel with built-in electronics. The probe is lowered down the standpipe until a light and buzzer indicate contact with water. Depth markings on the cable show the water level.

Slope Indicator's Water Level Indicator offers a sensitivity adjustment to accommodate variations in water conductivity and well conditions.

Hydraulic Piezometer



The hydraulic piezometer system includes a piezometer tip, tubing filled with a de-aired liquid, and a readout unit such as a manometer, Bourdon pressure gauge, or a pressure transducer.

Pore-water pressure acts on the piezometer tip and the liquid-filled tubes transmit the pressure to the readout device.

A low air-entry tip with 60-micron pores and a permeability of 3×10^{-4} m/s is used in saturated soils. A high air-entry tip with 1-micron pores and a permeability of 3×10^{-8} m/s is used in unsaturated soils and where negative pore-pressures are anticipated.

The twin-tube configuration makes it possible to replace the de-aired liquid, provides redundant readings (one from each tube), and provides a way to measure soil permeability.

The fluid in the tubing must be de-aired. Air bubbles in the system can create reading errors and slow response time. The system should be flushed when the reading from one tube does not match the reading from the other.

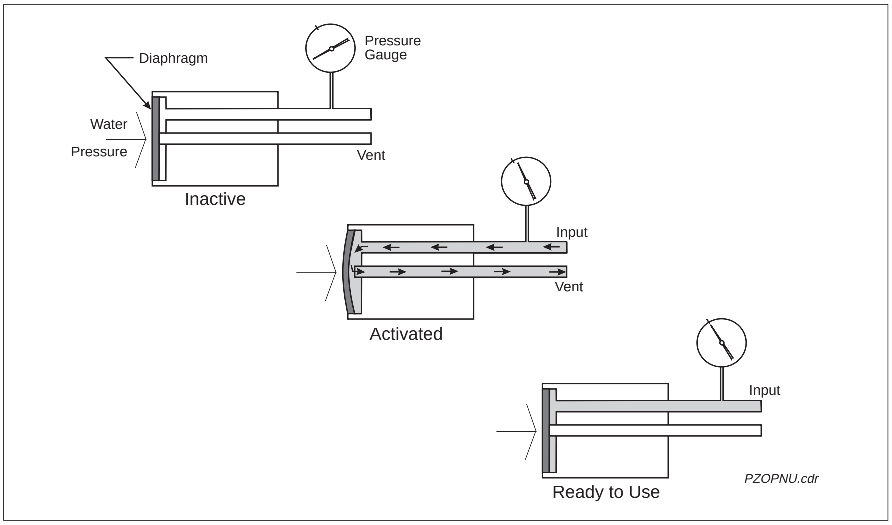
Advantages

- Simple, reliable mechanism.
- Good response time even in soils with low permeability.
- Can be used in permeability tests.
- Capable of reading negative pore-pressures.
- Reading station is remote from work area and does not interfere with construction activity.

Limitations

- Must be de-aired periodically. De-airing process requires special equipment and is time-consuming.
- Cabinet or gauge house required for readout device and de-airing equipment.
- Elevation difference between readout or tubing and piezometric level is limited to 5 meters.
- Cannot be operated in freezing temperatures and can be damaged by freezing.

Pneumatic Piezometer



Slope Indicator's pneumatic piezometer can be sealed in a borehole, embedded in fill, or fixed in a standpipe. Twin tubing runs from the piezometer to a terminal at the surface.

Water pressure and gas pressure act on opposite sides of a diaphragm inside the piezometer body. The diaphragm acts as a valve. In its "closed" position, it seals off the vent tube, preventing the escape of gas.

When a reading is required, a pneumatic indicator with a supply of nitrogen gas is connected to the tubing at the surface. The indicator sends gas down the input tube. Gas pressure on the diaphragm increases. Gas pressure becomes greater than the water pressure and forces the diaphragm away from the vent tube. Gas then escapes through the vent tube to the surface.

At the surface, the operator observes a return flow of gas and shuts off the gas supply. Gas pressure in the piezometer tip decreases until the diaphragm is again forced against the vent tube, preventing further escape of gas.

At this point, gas pressure in the piezometer and tubing equals the water pressure on the other side of the diaphragm. The operator obtains a reading from the indicator's pressure gauge, which is connected to the input tube.

Pneumatic Piezometer continued

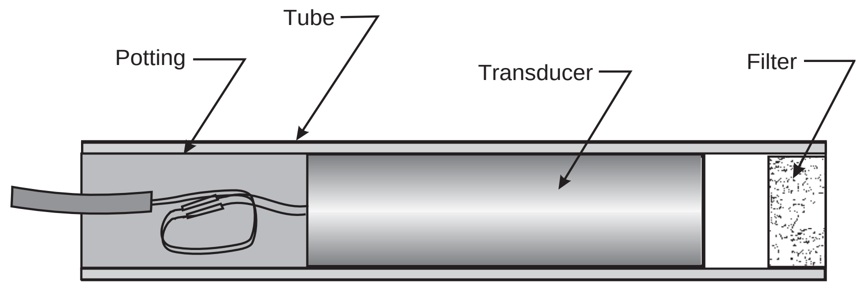
Advantages

- Simple, reliable mechanism is free from long-term drift.
- Reading station is remote from work area and does not interfere with construction activity.
- Less expensive than other types of diaphragm piezometers.
- Not damaged by freezing.
- Good response time even in soils with low permeability.

Limitations

- Time required to take reading increases with tubing length.
- Complicated and expensive to automate readings.
- Requires supply of nitrogen gas.

Electrical Piezometer



The electrical piezometer employs strain gauges to sense the pressure of water on a diaphragm. The strain gauges are mounted on or etched into the diaphragm. A reading is obtained by passing a current of precise voltage through the strain gauges. The resistance of the strain gauges varies with pressure on the diaphragm. The readout device converts the voltage returned from the piezometer to units of pressure or water head.

Electrical piezometers are typically used for short-term water level monitoring, such as draw-down tests.

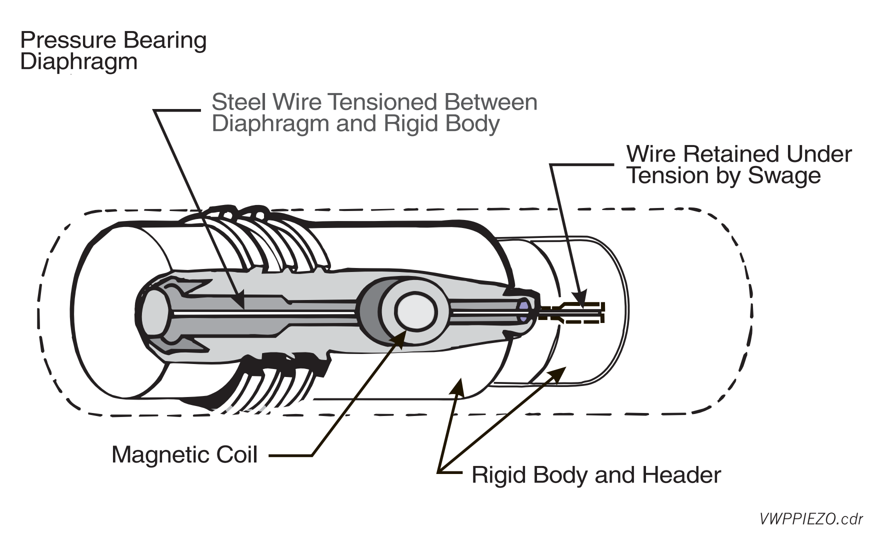
Advantages

- Easy to automate.
- Available in vented form for monitoring wells.
- Rapid reading rate (12 times per second) for dynamic conditions.
- Reading station is remote from work area and does not interfere with construction activity.

Limitations

- Calibrated components are buried.
- More expensive than some other types of piezometers.

Vibrating Wire Piezometers



Slope Indicator's VWP piezometer is a pressure transducer that can be sealed in a borehole or embedded in fill. Its sensing mechanism consists of a tensioned steel wire, a diaphragm, and an electromagnetic coil. One end of the wire is connected to the diaphragm. Pressure causes the diaphragm to deflect, reducing tension in the wire. The magnetic coil is used to "pluck" the wire, causing it to vibrate. The vibration of the wire near the coil generates a frequency signal that is transmitted via a signal cable to the readout device.

Some readout devices display a simple frequency reading. Other readouts, such as Slope Indicator's DataMate series, convert the frequency reading to units of pressure or water head.

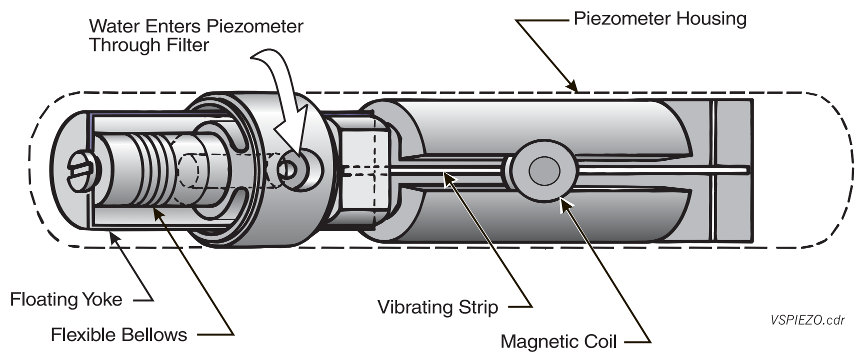
Advantages

- Reading station is remote from work area and does not interfere with construction activity.
- Very good response time even in soils with low permeability.
- Easy to automate.

Limitations

- Calibrated components are buried.
- Resolution worst at low pressures.
- Temperature corrections may be required for highest accuracy.

VS Piezometer



Slope Indicator's VS piezometer is a pressure transducer that can be sealed in a borehole or embedded in fill. Its sensing mechanism consists of a tensioned steel strip, a bellows, and an electro-magnetic coil. The mechanism is configured so that increased water pressure directly increases the tensional load on the steel strip, eliminating the deflecting diaphragm used in other vibrating-wire transducers. When excited by the magnetic coil, the strip vibrates. The vibration of the strip in the fields of the magnetic coil generates a frequency signal that is transmitted via signal cable to the readout device.

Some readout devices simply display a frequency reading. Other readouts, such as Slope Indicator's DataMate series, convert the frequency reading to units of pressure or water head.

Advantages

- Provides highest resolution at low pressures.
- Very stable, negligible long term drift or temperature sensitivity.
- Reading station is remote from work area and does not interfere with construction activity.
- Very good response time even in soils with low permeability.
- Easy to automate.
- Available in vented form for monitoring wells.

Limitations

- More expensive than some other types of piezometers.
- Calibrated components are buried.

General Considerations

Handling and Storage

- Piezometers should be handled with same care given to other precision measuring instruments. They should not be dropped on the ground or thrown into trucks.
- Do not allow a water-filled piezometer or saturated filter to freeze.

Tubing & Signal Cable

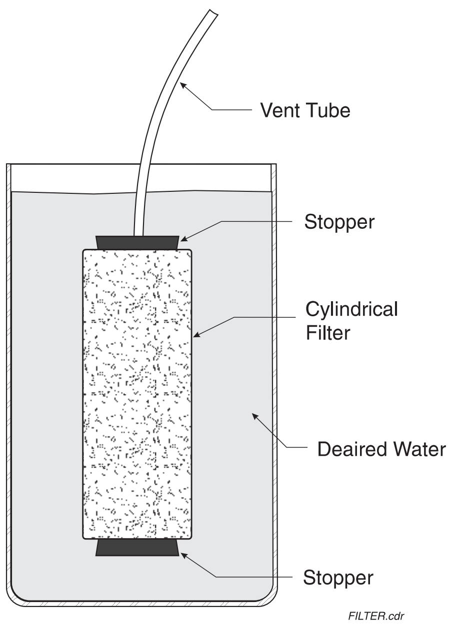
- Store tubing and signal cable in a sheltered, dry place, safe from rodents or other damage.
- Keep tubing and signal cable free from cuts or abrasions. Do not lay tubing or cable across roads with traffic.
- Do not make small-radius bends and do not pull on obstructed tubing or cable in an attempt to free it.
- Mark tubing carefully for positive identification later. Use an appropriate coding system. Mark tubing at frequent intervals, not just at ends.
- Borehole installation: Check borehole depth using a weighted survey tape. Use colored tape to mark intended ground level on tubing or cable. This will indicate when piezometer has been positioned at proper depth in borehole. Put another tape mark on tubing or cable to indicate height of drill casing above ground level.
- Embankment installation: Specifications sometimes require that cable be snaked in trenches to accommodate settlement. Up to 5% extra length may be required. There is some question whether this practice is necessary, however. This view holds that normal forces acting on snaked cable prevent it from slipping and therefore snaking does nothing to accommodate settlement.

Saturating Low Air Entry Filters

Immerse the filter in clean water for approximately 15 minutes. Gently tap the filter to remove air bubbles. If the piezometer is supplied with a non-removable sintered filter, immerse the entire piezometer and follow same procedure.

Saturating High Air Entry Filters

Immersion Method: Prepare deaired water. Stopper the ends of the filter so that water can act only on the outside of the filter. Allow air to vent through the stopper at the top of the filter, as shown in the drawing. Immerse filter for approximately 24 hours.



Vacuum Method: This method probably provides the most complete saturation. The filter is placed in a chamber and a vacuum is applied. The chamber is then slowly flooded with deaired water. As the water level rises, any remaining air is driven out of the filter.

Once saturated, the filter should be attached to the piezometer under water, and the assembled piezometer should be bagged in deaired water to maintain saturation until installation.

Preparing Deaired Water

Water can be deaired by boiling it with heat or by applying a vacuum at room temperature. The Nold DeAerator from the Walter Nold Company combines propeller cavitation with a vacuum to deair water rapidly. No heat is applied, so the deaired water is immediately usable.

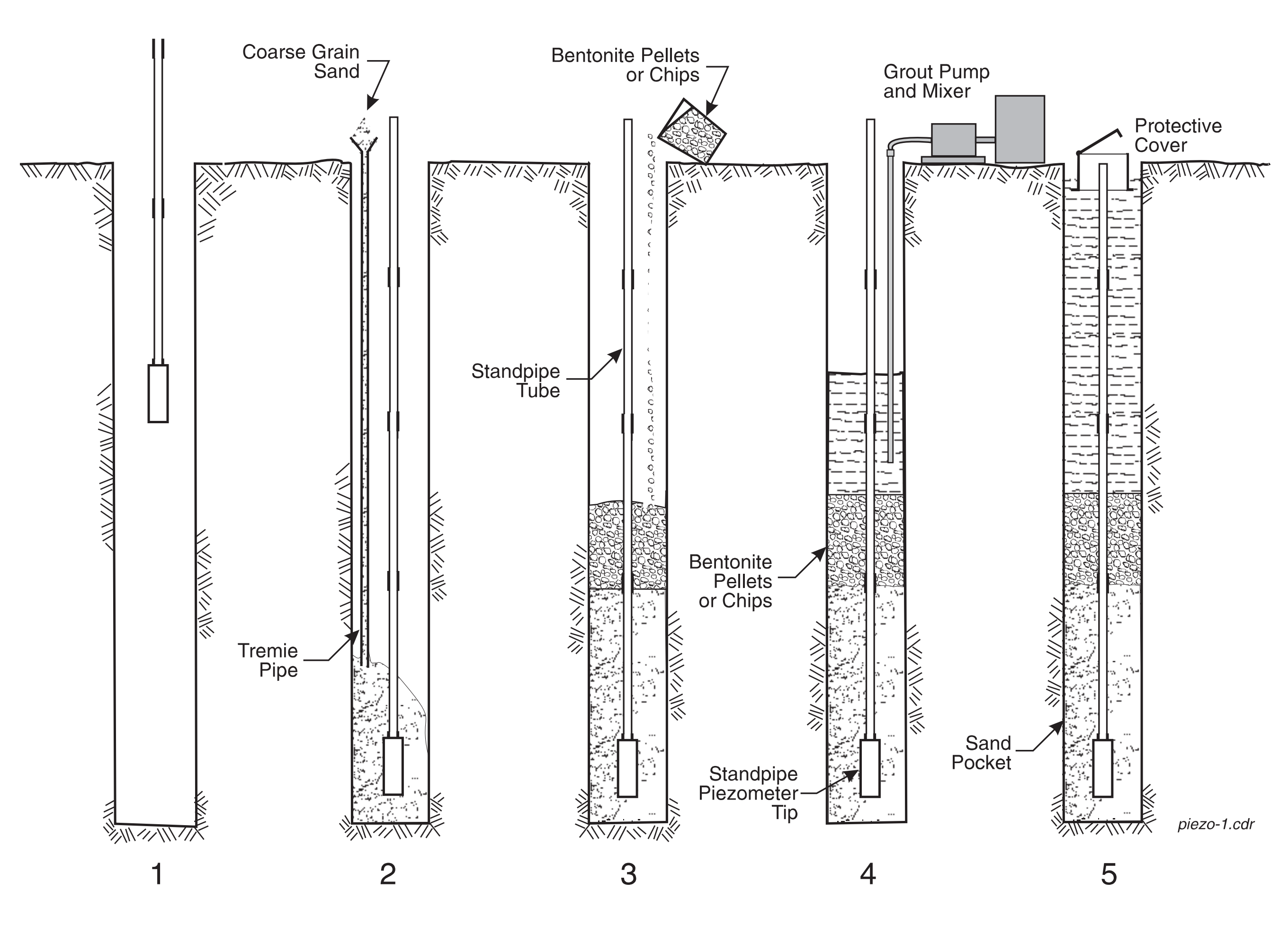
Other Preparations

- Remove dust caps from piezometer tips before installation.
- Piezometers are sometimes placed in sand-filled canvas bags. The bag centralizes the piezometer in borehole and acts as a sand filter. Additional sand should be tremied around bag before bentonite seal is placed.

Backfilling the Borehole

- A bentonite seal must be placed above the piezometer tip. The seal isolates pore-water pressure at the tip, and prevents grout from displacing the sand around the piezometer and blocking the entry of water. Be sure to supply enough water and allow enough time for sufficient hydration (swelling) of bentonite chips or pellets. Follow instructions supplied by manufacturer of bentonite.
- Remainder of borehole is backfilled with bentonite or bentonite-cement grout to prevent unwanted migration of water through borehole. Strength of grout should match strength of surrounding ground as closely as possible.
- If drill casing is used to hold borehole open, it must be pulled out as sand is tremied around piezometer.
- Drill casing must also be pulled slightly ahead of settling bentonite pellets or chips.
- Installation is not complete until it is tested and initial readings have been taken. Because ground and pore-water are disturbed during installation, it is necessary to take series of readings to determine when ground has “recovered” and repeatable readings are obtainable. In impermeable soils this can take several weeks.

Installing Standpipe Piezometer in Borehole



1 Flush borehole with clean water. Attach filter tip to pipe. Add additional lengths of pipe as standpipe is lowered into borehole, sealing joints with tape or glue. Continue adding pipe until tip has reached required depth.

2 Place sand around tip using tremie pipe. Sand must be wet to tremie successfully.

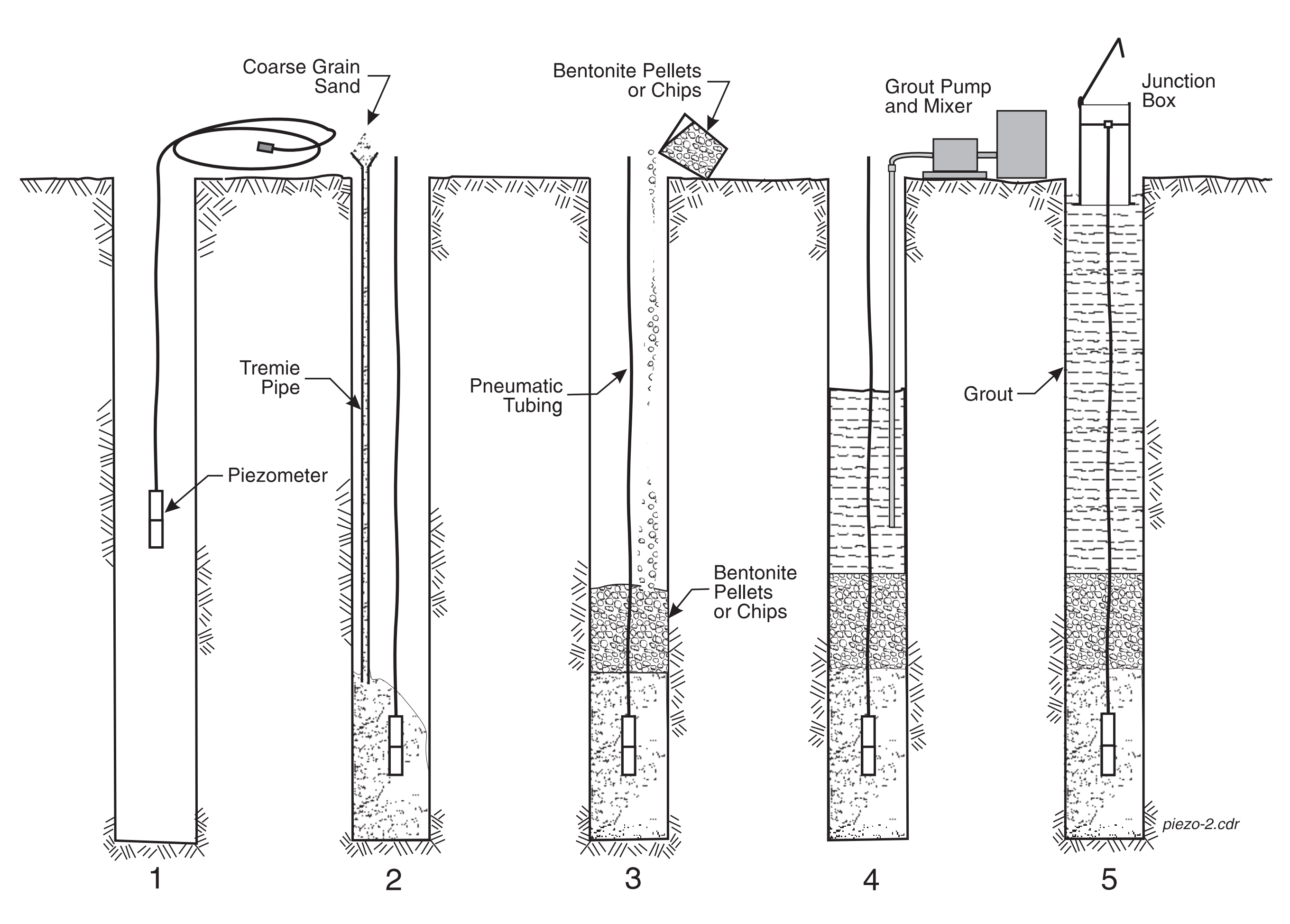
3 Place bentonite seal. Drop pellets or chips into borehole slowly to avoid bridging. Use of flush coupled pipe also helps to prevent bridging. Add water as needed for hydration of bentonite. Allow time for bentonite to swell.

4 Fill remainder of borehole with bentonite or bentonite-cement grout.

5 Cut standpipe to length. Top off borehole with grout and install protective cover. Hand over to client after proving installation.

Installing Piezometer in Borehole

Pneumatic, VWP, and VS piezometers



1 Saturate filter and piezometer. Flush borehole with clean water. Check that piezometer functions correctly and note “zero” readings of VWP and VS piezometers. Lower piezometer into borehole to required depth.

2 Place sand around tip using tremie pipe. Sand must be wet to tremie successfully. Check that piezometer functions.

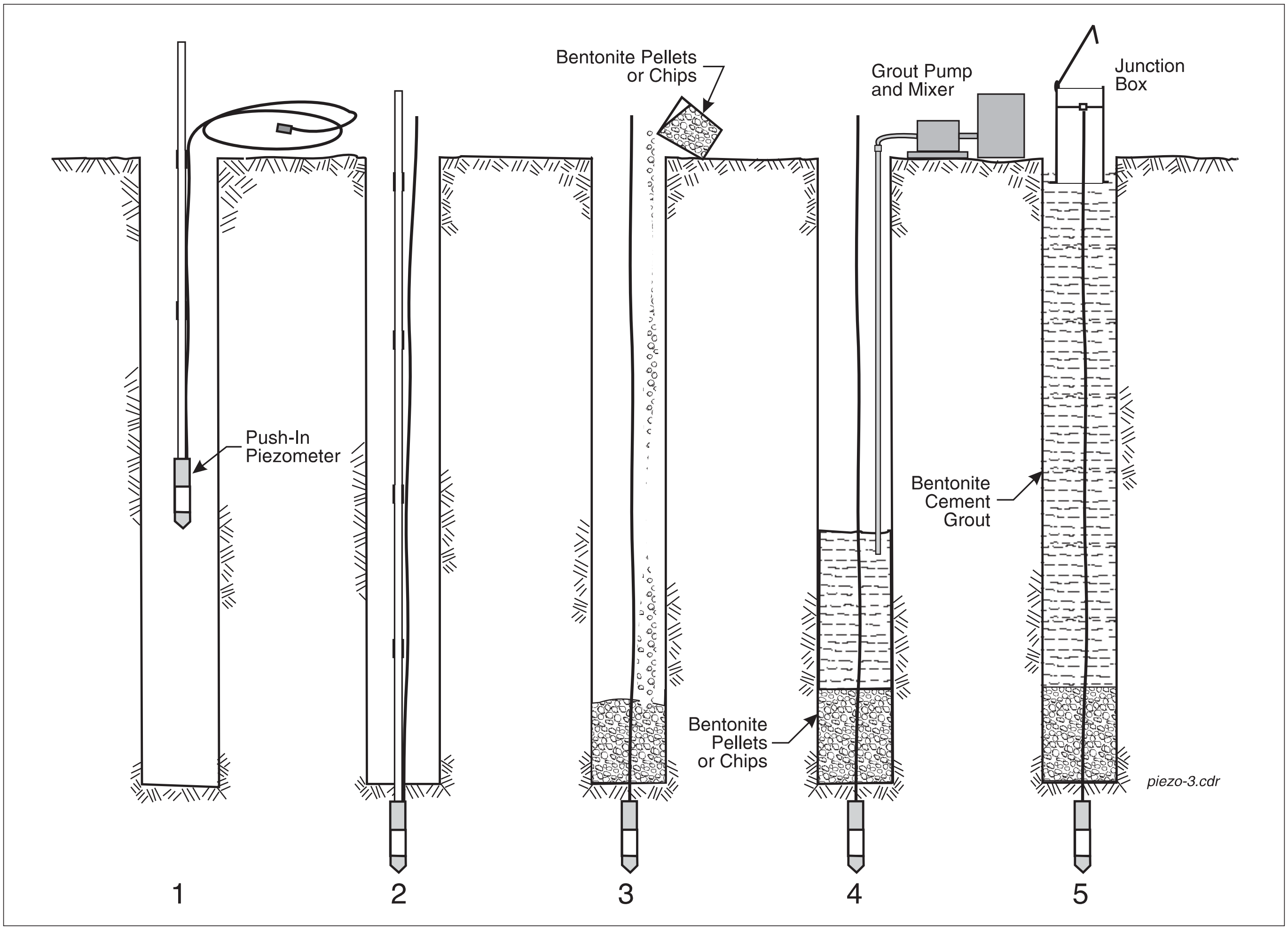
3 Place bentonite seal. Drop pellets or chips into borehole slowly to avoid bridging. Add water as needed for hydration of bentonite. Allow time for bentonite to swell.

4 Fill remainder of borehole with bentonite or bentonite-cement grout.

5 Terminate tubing or cable to prevent entry of water. Top off borehole with grout and install protective cover. Prove installation and obtain initial reading, then hand over to client.

Installing Push-In Piezometer in Borehole

Pneumatic, VWP, or VS Piezometers



1 Saturate filter and piezometer. Flush borehole with clean water. Check that piezometer functions correctly and obtain “zero” readings of VS and VWP piezometers. Attach push-rod to piezometer. Lower piezometer to bottom of hole, adding rods as necessary.

2 Hand-push piezometer into ground at bottom of borehole. Read piezometer continuously to check that pressure generated by pushing does not exceed instrument maximum. Retrieve rods.

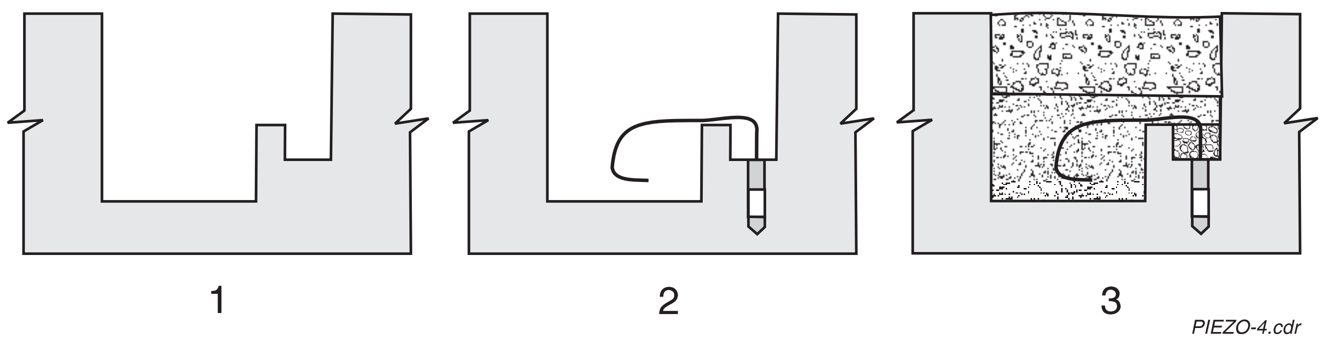
3 Check that piezometer functions, then place bentonite seal. Drop pellets or chips into borehole slowly to avoid bridging. Add water as needed for hydration of bentonite. Allow time for bentonite to swell.

4 Fill remainder of hole with bentonite or bentonite-cement grout.

5 Terminate tubing or cable to prevent entry of water. Top off borehole with grout and install protective cover. Prove installation and take initial reading, then hand over to client.

Installing Piezometer in Embankment

Pneumatic, VWP, VS, Hydraulic



1 Excavate main cable trench. Make a pit for each piezometer.

2 Saturate filter and piezometer. Form hole for piezometer with drill and mandrel. Push piezometer into hole. Check that piezometer functions and take “zero” readings of VS & VWP piezometers.

3 Fill pit with bentonite pellets. Pour water onto pellets. Use enough water to ensure full hydration. Place layer of selected fill in trench. Lay out tubing or cable as specified. Cover cable or tubing with selected fill. Fill remainder of trench with stone-free material. Build water stops in trenches as specified. Terminate tubing or cable to prevent entry of water. Prove installation, take initial readings, then hand over to client.

Notes

4

Inclinometers

Notes

Inclinometers

Inclinometers are used to monitor lateral earth movements in landslide areas and embankments. They are also used to monitor the deflection of retaining walls and piles under load. Horizontal inclinometers, which are discussed in a separate section, are used to monitor settlement in foundations and embankments.

Reasons for installing inclinometers include:

Site Investigations

Geotechnical site investigations involve evaluations of soil strength and stability. Inclinometers monitor movement, a direct measure of stability, so they are often used in site investigations. Installed at the proposed site for a dam, an inclinometer might detect movement at a sub-surface shear plane. The shear plane could cause problems later when the reservoir behind the dam is filled and pore-water pressure along the shear plane increases.

Verification of Design Assumptions

Inclinometers may be installed to check that actual movements of a structure correlate to those predicted during the design phase. For example, an inclinometer may be installed behind a retaining wall to check that it deflects no more than 7.5 cm when fully loaded. If the inclinometer detects deflections greater than that, the designer may modify the design for future sections of the wall.

Determining the Need for Corrective Measures

Inclinometers are installed to monitor the magnitude, direction, and rate of movement. This information helps engineers determine the need for corrective measures. For example, a highway department may know of many landslides that put highways at risk, but may not have the funds or the manpower to stabilize all of them. By monitoring the landslides with inclinometers, engineers can identify the worst threats and prioritize stabilization measures.

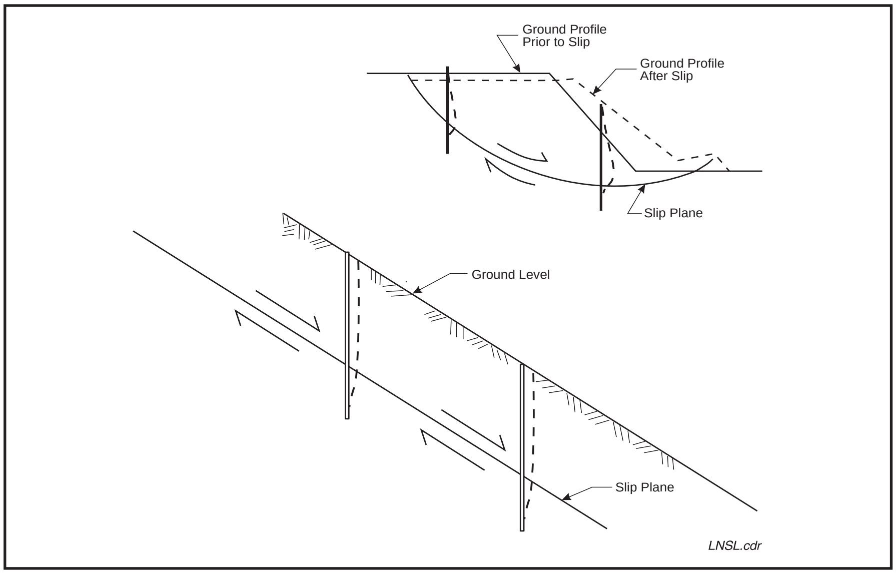
Monitoring Long-Term Performance

Inclinometers are installed for long term monitoring to detect changes in ground conditions or in the structure itself. For example, a contractor refurbishing a highway retaining wall may inadvertently block its drainage system, causing pore-water pressure behind the wall to rise. A routinely monitored inclinometer may detect movement in the ground behind the wall before it is visible in the wall itself.

Safety Monitoring

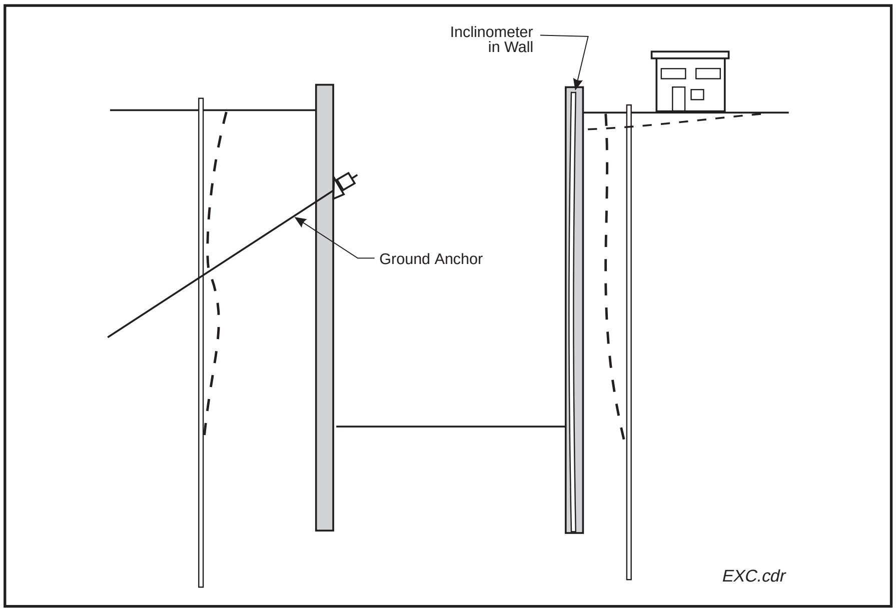
Inclinometers, particularly in-place inclinometers that are monitored continuously, can provide early warning of catastrophic failure. Such systems may be installed near highways, railroads, and pipelines that pass through landslide areas.

Slopes and Landslides



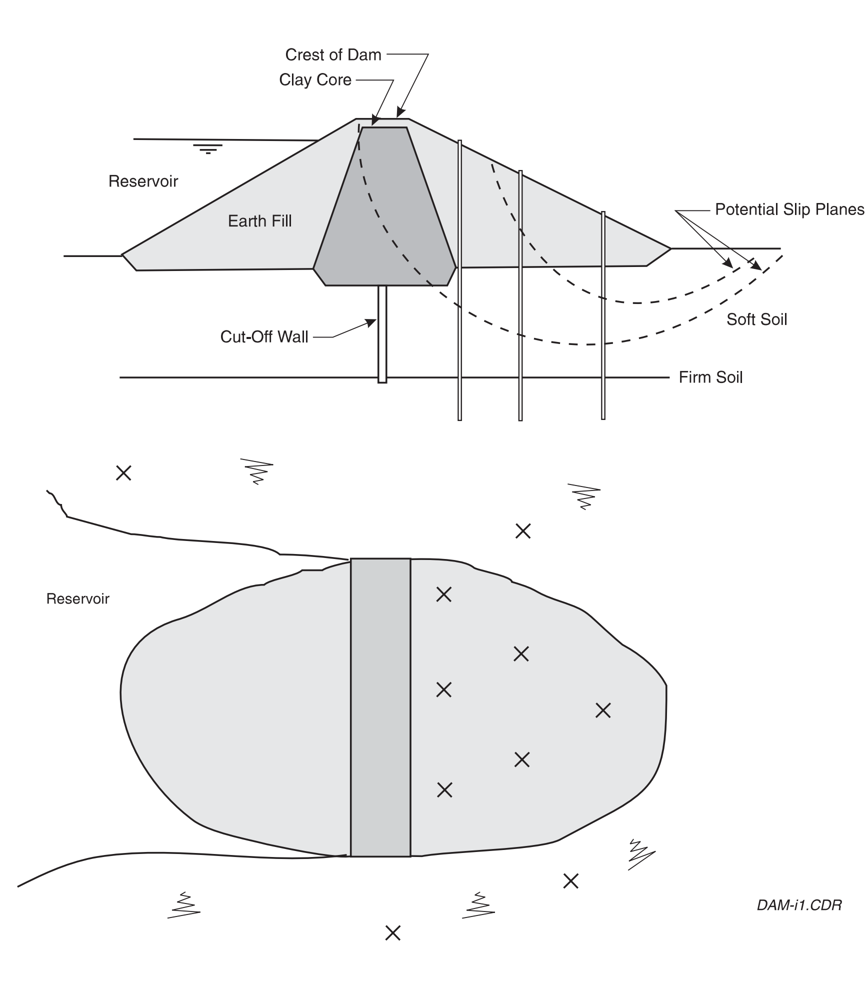
- Locate shear zones. Help determine whether shear is planar or circular.
- Measure movement at shear zone. Determine whether movement is constant, accelerating, or slowing.

Diaphragm Wall or Sheet-Pile Wall



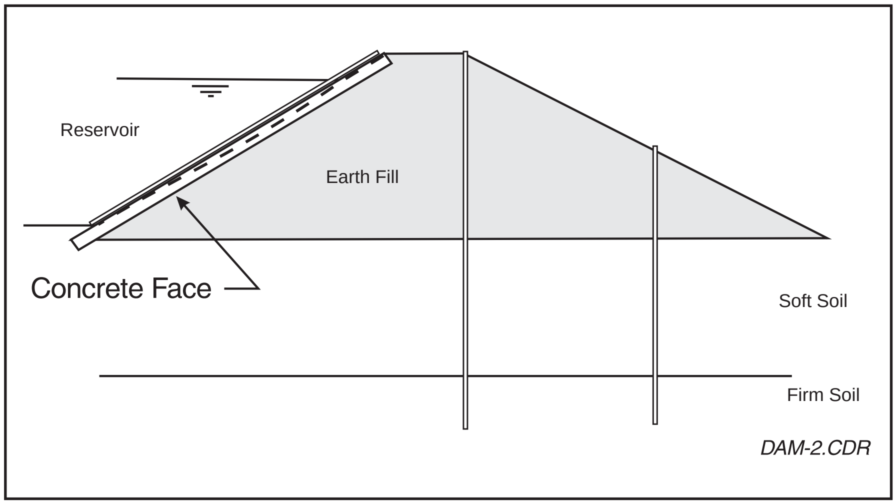
- Check stability of retaining wall. Check that deflections in retaining wall are within design limits.
- Check for ground movement that may affect adjacent buildings.
- Check performance of struts and ground anchors.

Earthfill Dams



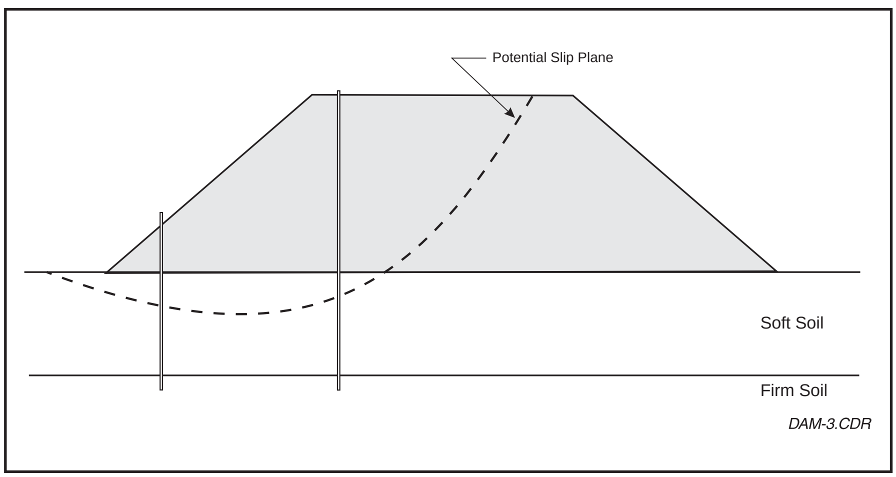
- Detect movement in downstream side of dam, particularly during impounding. Help define any shear zones in foundation.
- Monitor stability of upstream slopes during and after impounding. Failure of slopes could result in wave that over-tops dam.
- Determine type of shear and depth, direction, magnitude, and rate of movement (constant, accelerating, or decelerating).
- Inclinometers not installed in clay core unless critical to monitoring program.

Concrete-Faced Dams



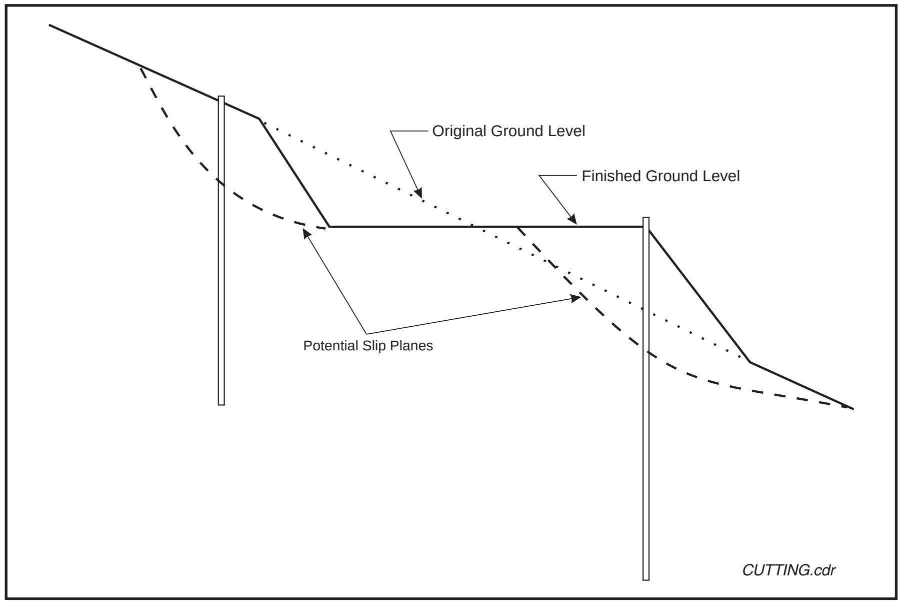
- ❑ Detect movement in downstream side of dam, particularly during impounding. Help define any shear zones in foundation.
- ❑ Monitor stability of upstream slopes during and after impounding. Failure of slopes could result in wave that over-tops dam.
- ❑ Determine type of shear and depth, direction, magnitude, and rate of movement (constant, accelerating, or decelerating).
- ❑ Monitor deformation of concrete face slab. Deformation can lead to cracks in slab that allow water to seep through dam.

Embankments



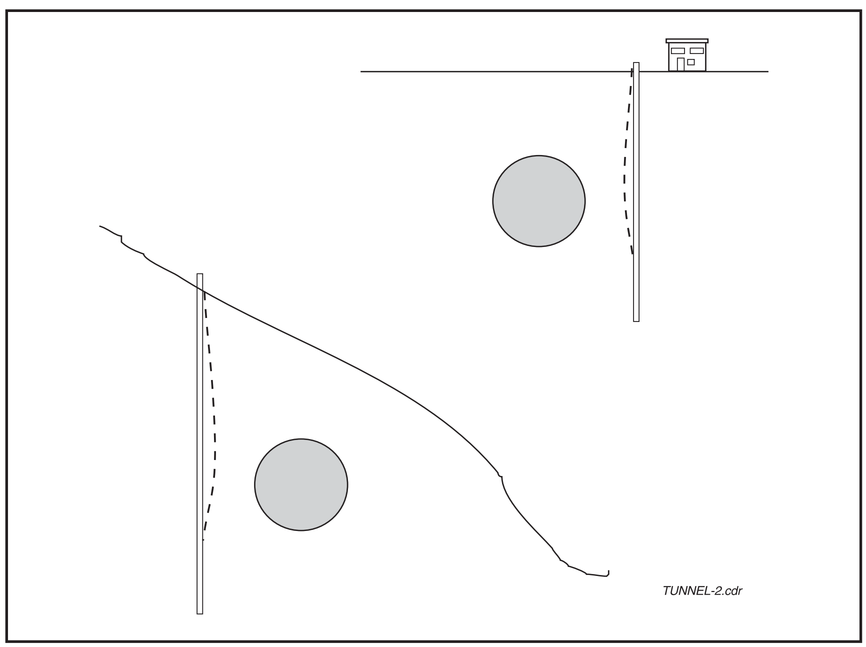
- ❑ Locate shear zones and help identify whether shear is planar or circular.
- ❑ Measure the movement at the shear zone. Determine whether movement is constant, accelerating, or slowing.

Cutting



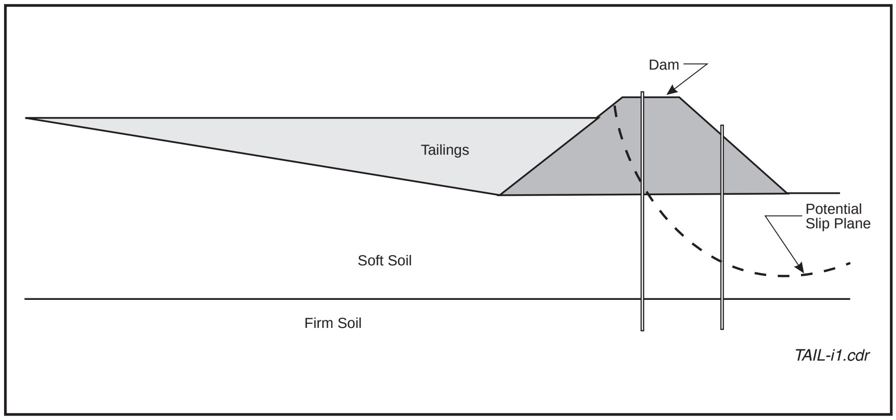
- ❑ Locate shear zones. Help identify whether shear is planar or circular.
- ❑ Measure movement at shear zone and indicate whether movement is constant, accelerating, or slowing.

Tunnels



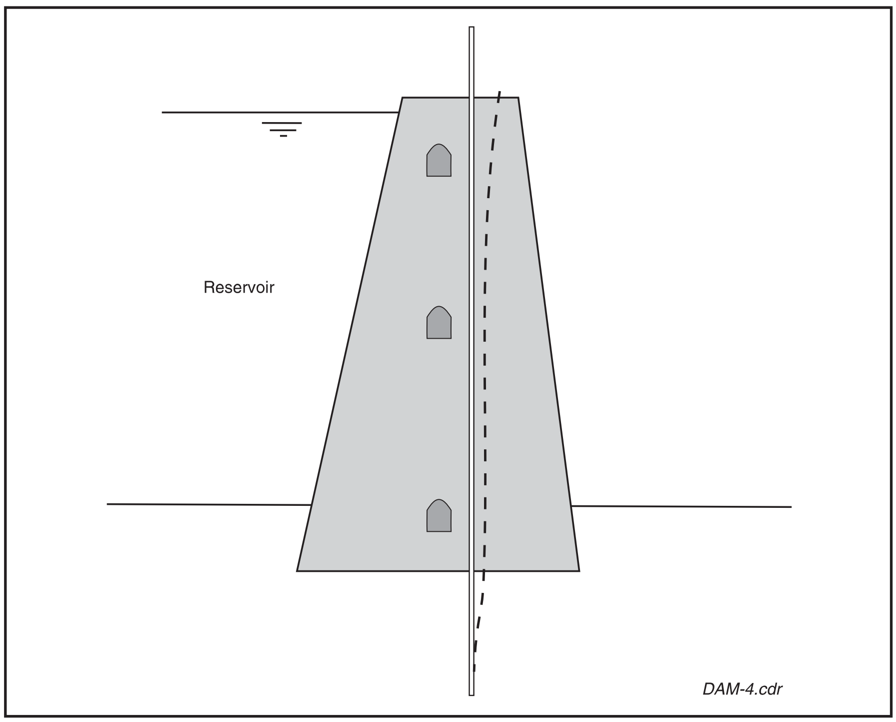
- ❑ Monitor soil movement due to tunneling operations. Such movements may damage tunnel or nearby structures.
- ❑ Check design assumptions. Verify finite element analysis. If actual conditions are different from assumed conditions, inclinometer data can be used to modify soil model.

Tailings Dam



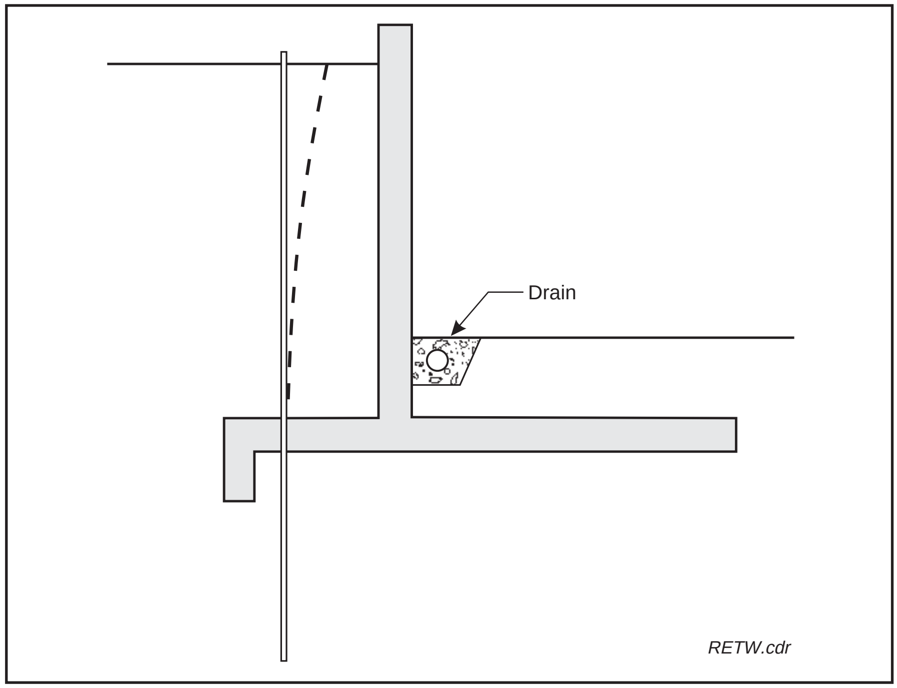
- ❑ Check stability of dam.
- ❑ Check stability of upstream slopes.
- ❑ Locate shear zones.
- ❑ Measure movement at shear zone. Determine whether movement is constant, accelerating, or slowing.

Concrete Gravity Dam



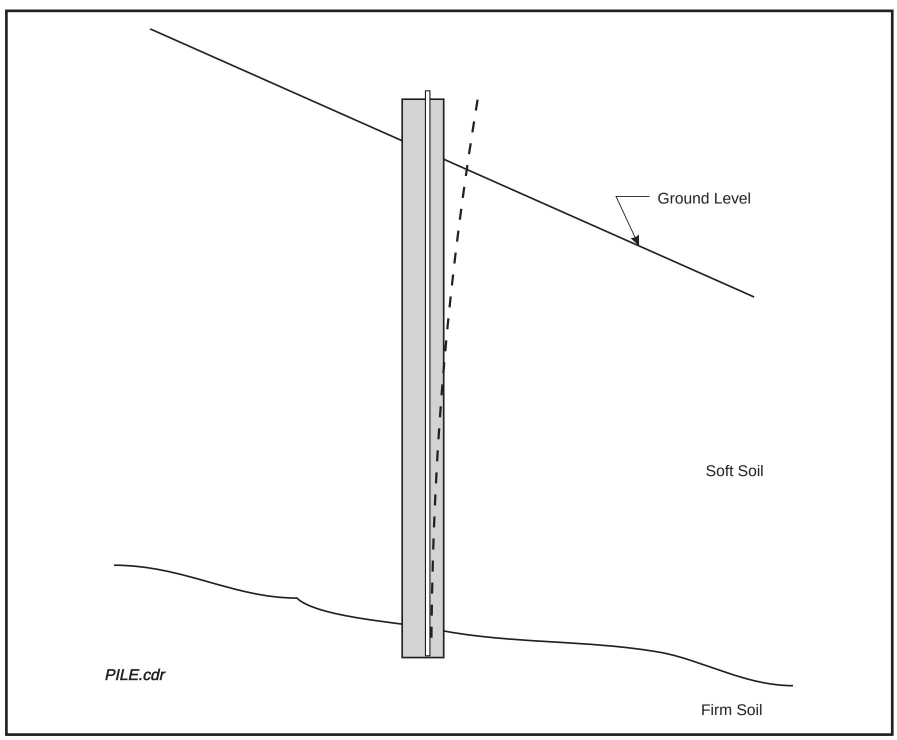
- ❑ Monitor deflection of dam, rotation (overturning) of dam, and possible downstream movement of dam, especially during impounding.

Retaining Wall



- Measure bending in the retaining wall.
- Check for rotation (overturning) of retaining wall.

Laterally-Loaded Pile



- Monitor bending of pile (indicates slope stability).
- Warn of impending failure (in-place inclinometer).

Components and Operation

Inclinometer Casing

Inclinometer casing is a special-purpose, grooved pipe used in inclinometer installations. It performs three functions:
(1) it provides access for the inclinometer probe, allowing it to obtain subsurface measurements; (2) it deforms with the adjacent ground or structure, so that inclination measurements of the casing accurately represent ground movements; and (3) its internal grooves control the orientation of the wheeled inclinometer probe.

Casing is installed in a near-vertical borehole that is drilled through suspected zones of movement. Casing can also be embedded in fill, cast into concrete, or attached to structures.

The initial position of the casing is established in a survey taken with the inclinometer probe. Ground movement causes the casing to move from its initial position. The rate, depth, and magnitude of this displacement is calculated by comparing data from the initial survey to data from subsequent surveys.

Inclinometer Probe

The wheeled inclinometer probe tracks the longitudinal grooves in the casing. It contains two force-balanced servo-accelerometers. One accelerometer measures tilt in the plane of the inclinometer wheels. This plane is known as the A axis. The other accelerometer measures tilt in a plane perpendicular to that of the wheels. This plane is known as the B axis. Tilt readings are typically obtained at two-meter intervals as the probe is drawn from the bottom to the top of the casing. Two-foot intervals are used with English probes.

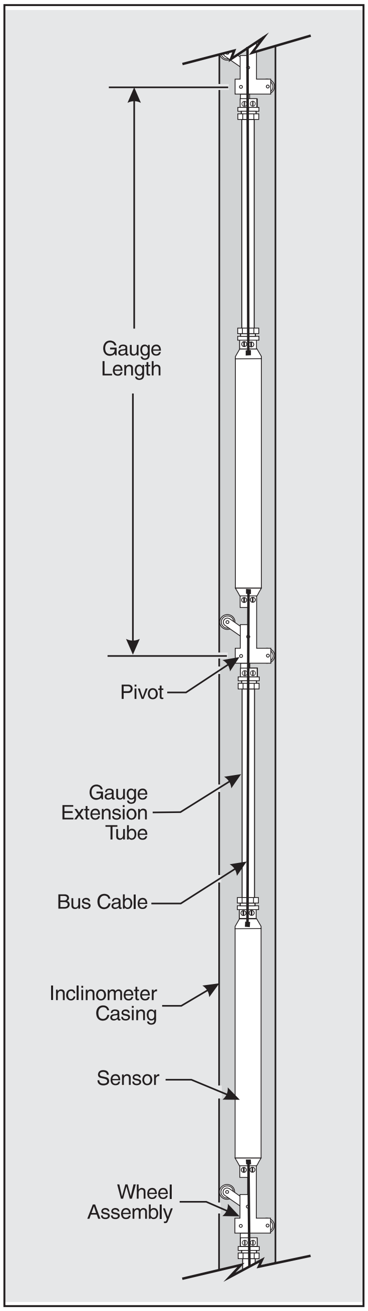
Control Cable

Control cable is used to control the depth of the inclinometer probe. It also conducts power and signals between the probe and the readout. Metric control cables are graduated at 0.5-meter intervals. English control cables are graduated at 1-foot intervals.

Digitilt Readout Unit

The readout unit displays the inclination measurement obtained from the inclinometer probe. Sophisticated readout units, such as the Digitilt DataMate, store readings in solid state memory, eliminating the need for recording readings with pencil and paper.

In-Place Inclinometer Sensors



The *in-place* inclinometer system is designed for data logging and remote monitoring. The in-place system consists of a string of inclinometer sensors permanently deployed in the casing.

Slope Indicator manufactures two types of in-place sensors. The accelerometer-based sensors are similar to those used in the inclinometer probe. The electrolytic sensors are similar to those used in EL beam sensors.

The string of inclinometer sensors is positioned inside the casing to span the zone where movement is anticipated. The sensors are generally spaced at one-meter or larger intervals.

In most applications, the sensors are connected to a data acquisition system that continuously monitors movements and can trigger an alarm when it detects a change or rate of change that exceeds a preset value.

Data Reduction

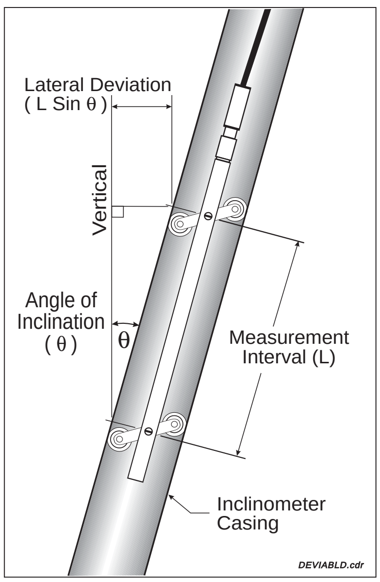
Inclination Measurements

The inclinometer probe and the in-place sensor measure the tilt of the casing. With the probe, inclination measurements are typically taken at half-meter or 2-foot intervals from the bottom to the top of the casing. In-place sensors are installed at fixed positions in the casing at one-meter or larger intervals. In either case, the tilt reading is associated with a depth or elevation.

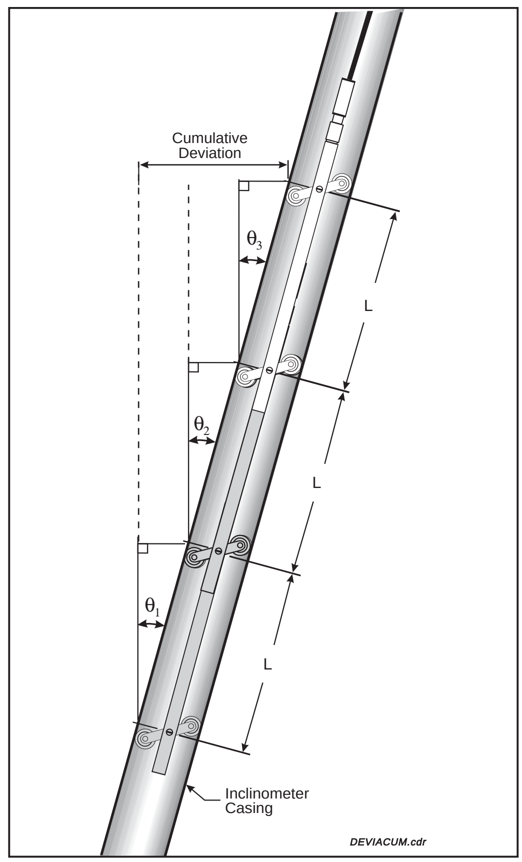
Lateral Deviation

When inclinometer readings are processed, tilt is converted to a lateral distance, as shown below. Deviation at each interval is called *incremental* deviation. The sum of incremental deviations is called *cumulative* deviation.

Deviations represent the position of the casing. A plot of cumulative deviations shows the profile of the casing.



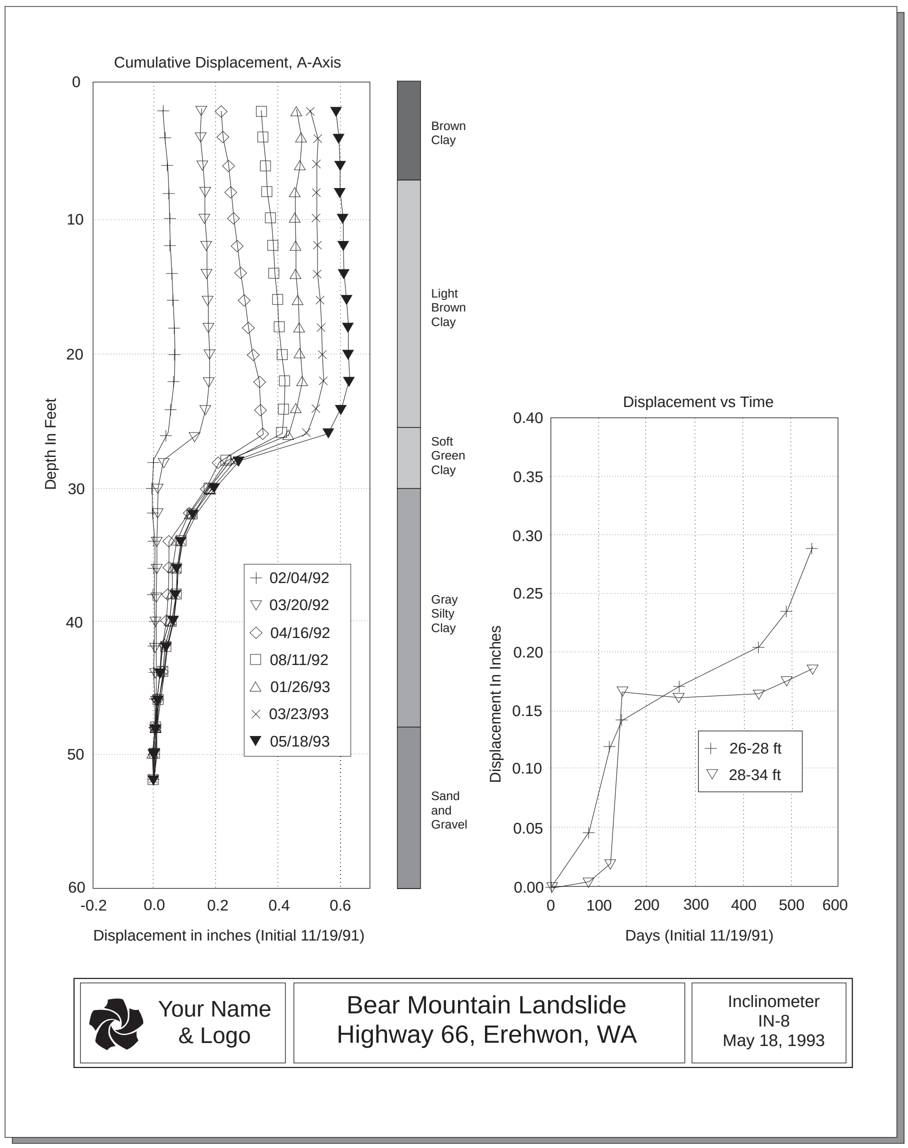
Cumulative Deviation



Lateral Displacement

Displacement represents a change in the position of the casing, i.e. a change in deviation. Displacement is calculated by subtracting initial deviation from current deviation. *Incremental* displacement is the change at one interval. *Cumulative* displacement is the sum of incremental displacements.

In the graph below, displacements are referenced to a fixed point at near the bottom of the casing. When the bottom of the casing is not in stable ground, displacements are referenced to the top of the casing, which must be optically surveyed.



Incremental Deviation

Inclinometer Surveys

General Concerns

- When possible, use the same probe and control cable for each survey. If you must use different probes, be sure to note the serial number of the probe used for each data set so any necessary corrections can be made during data processing.

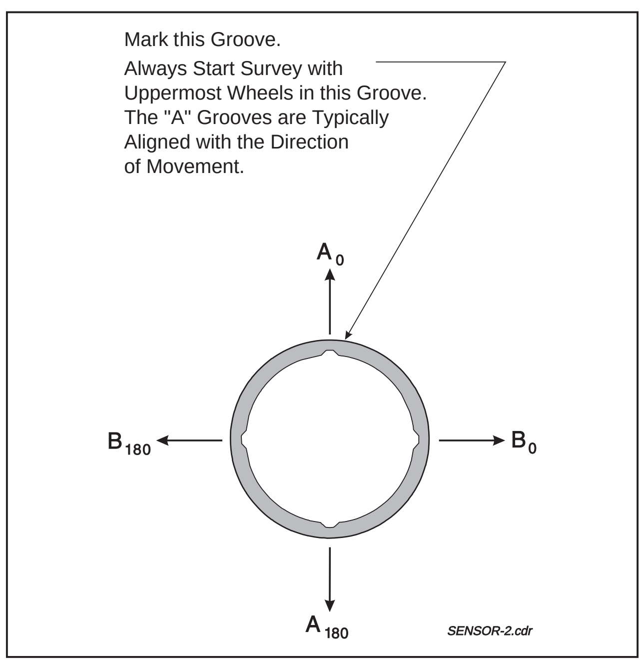
- Mark the A0 casing groove with paint or a notch in the casing. Train technicians to start the survey with the uppermost wheels of the probe in this groove. See drawing below.

- A new installation should be surveyed several times and a representative data set chosen for use as the initial (datum) set. All subsequent data sets will be compared with this set.

- Determine the standard deviation of checksums (explained later) for the initial data set. Record this value and use it for quick validation of subsequent data sets.

- Always use the same reference for depth control. If one technician uses the top of the pulley assembly as reference and another technician uses the top of the casing as reference, there will be a 300 mm difference in probe position from survey to survey. Accurate results require placement repeatability of 6 mm (0.25 inch) or better.

- If you accidentally draw the probe past a reading depth, lower the probe at least one depth below the intended depth. Then draw the probe up to the intended depth a second time. This technique ensures the probe will be positioned correctly.



Survey Instructions

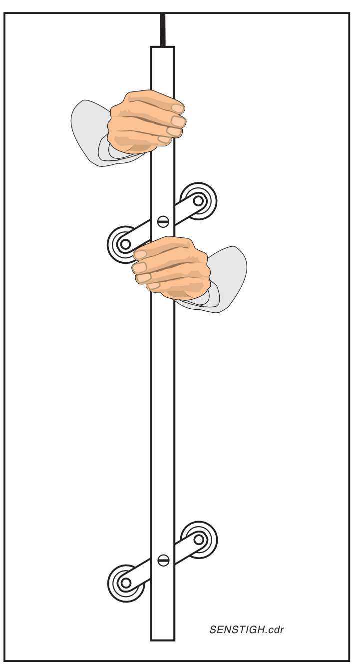
Check Probe

1. Check that probe wheels turn smoothly. If necessary, clean wheels and apply spray lubricant or small amount of oil to each bearing.
2. Check that wheel yokes move freely. Push yoke into probe body, then release slowly. Yoke should return to fully-extended position.
3. Check for excess play in wheels and yokes.
4. Check that no screws are loose.
5. Check connectors and O-rings for wear and corrosion.
6. Connect probe to readout. Switch on. Readings should be greater than zero (positive) when probe is tilted in A0 and B0 directions.
7. Place probe in its protective box for transport.

Set Up on Site

1. Spread plastic sheet or tarp near casing installation. Tarp keeps equipment clean. During survey, keep control cable on tarp rather than on bare ground. A box or basket may be useful to hold control cable.
2. Remove cap from casing. Attach pulley assembly.

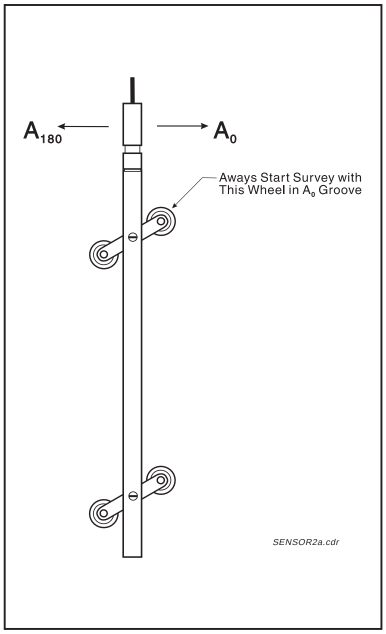
Connect Control Cable



1. Remove protective caps from probe and control cable.
2. Hold probe just below upper wheel yoke as shown in illustration. Do not hold probe by wheels.
3. Align connector key with keyway in probe, then press together. Do not “hunt” for keyway by rotating connector.
4. Tighten nut to secure connection. Do not over-tighten, since O-ring will be deformed and its effectiveness reduced.

Survey Instructions continued

Position Probe



1. Switch on indicator to energize accelerometers. When energized, accelerometers are less susceptible to damage should probe be dropped or accidentally struck.

2. Align upper wheels of probe with A0 groove, then insert probe in casing. If using pulley assembly, remove pulley wheel, insert probe, and then replace wheel.

3. Lower probe slowly to bottom. Do not allow it to fall to bottom. Allow five to ten minutes for probe to adjust to temperature inside casing.

Record Data

1. Raise probe to starting depth. Wait for numbers on readout to stabilize. If using the DataMate, press button of hand switch to record both A- and B-axis readings. If using manual indicator, write down A-axis reading, then switch to B-axis and record that reading, too.

2. Raise probe to next depth. Wait for stable reading, then record. Repeat process until probe is at top of casing.

3. Remove probe and rotate 180 degrees. Align upper wheels with A180 groove and insert into casing.

4. Lower probe to bottom, then raise to starting depth. Take readings at each depth until probe is at top of casing.

5. Remove probe from casing.

6. If using the DataMate, run “Validate Data” command (See the next section for an explanation).

Survey Instructions continued

Clean Up

1. Wipe probe and cable.
2. Replace end-caps on probe and cable.
3. Store probe in protective case.
4. Insert plugs into indicator sockets.
5. Coil cable.
6. Remove pulley assembly.
7. Replace cap on casing.

Maintenance

1. Wipe off indicator and recharge batteries.
2. Oil probe wheels.
3. If storage place is dry, remove protective caps from probe and control cable to allow all connectors to dry.

Checksums and Data Validation

Checksums

A checksum is the sum of a 0- and a 180-degree reading at the same depth. Ideally, the sum should be zero since the readings have opposite signs. In practice, variations in casing grooves, the positioning of the probe, and the zero-offset of the probe itself contribute to non-zero checksums.

You can use checksum *statistics* to evaluate the quality of your data. Slope Indicator's Digitilt DataMate generates checksum statistics to help you detect possible reading errors while you are still on site and able to make corrections. If on-site validation is not possible, checksum statistics can be generated on your PC using inclinometer data reduction software such as Slope Indicator's "DigiPro" program, which provides a graph of checksums as well as a full set of statistics.

Standard Deviation of Checksums

The standard deviation provides the surest and easiest way of validating the data set. You can compare the standard deviation for the current data set to a typical standard deviation established for that installation.

It is good practice to make several surveys of the casing to establish a good initial (datum) data set. The standard deviation of checksums for the initial set can be used as "typical" for the installation. Note that the "typical" is likely to be different for each installation.

After a survey, generate the standard deviation for checksums. (With the DataMate, use the "Validate" command.) If the standard deviation is within 3 to 5 units of typical, the data is probably good. For example, if the typical standard deviation is 4, then acceptable standard deviations for subsequent data sets could range as high as 7 or 9. Narrower limits may be appropriate for deeper installations and critical measurements. Wider limits may be appropriate for shallower installations or for poorly-installed casing.

The DataMate also calculates checksum statistics for groups (zones) of ten depths. This is especially useful in deeper installations, where the large number of readings may make a single bad reading statistically "invisible."

Checksums and Data Validation continued

Individual Checksums

If you find a zone that is suspect, you can isolate the bad reading depth by examining the checksums produced at each depth. As a rule of thumb, checksums for the A axis should be within 10 units of the mean checksum for that axis. For example, if the mean checksum is 5, A-axis checksums as large as -5 or +15 would be acceptable. The checksums for the B axis should within 20 units of the mean checksum for the B axis.

Larger checksums may indicate that the probe was not positioned correctly, that the reading was recorded before it stabilized, or that there is an obstruction in the inclinometer casing that affects the position of the probe.

Installation of Inclinometer Casing

General Concerns

Casing Size and Material

- Casing diameter affects the useful life of the installation. Ground movement causes the casing to deform and prevents the probe from passing through the casing. Larger diameter casing accommodates more ground movement and provides access longer than smaller diameter casing. Always use the largest diameter casing that drilling equipment and borehole size can accommodate.

- Casing materials also affect the useful life of the installation. ABS plastic casing is suitable for long-term contact with all types of soils, grouts, and groundwater. It does not corrode and provides excellent conformance to ground movements. Aluminum casing can corrode. When installing aluminum casing, be careful not to scratch its protective epoxy or anodized surface.

- A protective cover is usually installed at the top of the casing. The cover should be large enough to allow attachment of the pulley assembly to the top of the casing. Also, the cover should be positioned to allow easy access to the casing when settlement occurs.

Casing Orientation

- The borehole should be as close to vertical as possible. Errors in inclinometer surveys increase with tilt of the casing.

- Install casing with one pair of grooves oriented in the expected direction of movement. Maintain the proper orientation during the installation process. Attempts to correct casing orientation after installation will result in twisted casing.

General Concerns continued

Couplings

- The ABS cement used on couplings requires up to 24 hours to achieve full strength. Casing is usually assembled and installed much faster than that. In water filled holes, buoyancy reduces the effective weight of the casing, so less strength is required from the coupling. However, when casing is installed in dry boreholes, the coupling must hold the full weight of the casing. In this case, secure the coupling with rivets. A suspension cable attached to the bottom section of casing can also reduce the load on the couplings.

- Couplings should be sealed against grout. Grout that enters the casing may cause blockages, unreliable tracking, and damage to the wheels of the inclinometer probe.

Grout Backfill

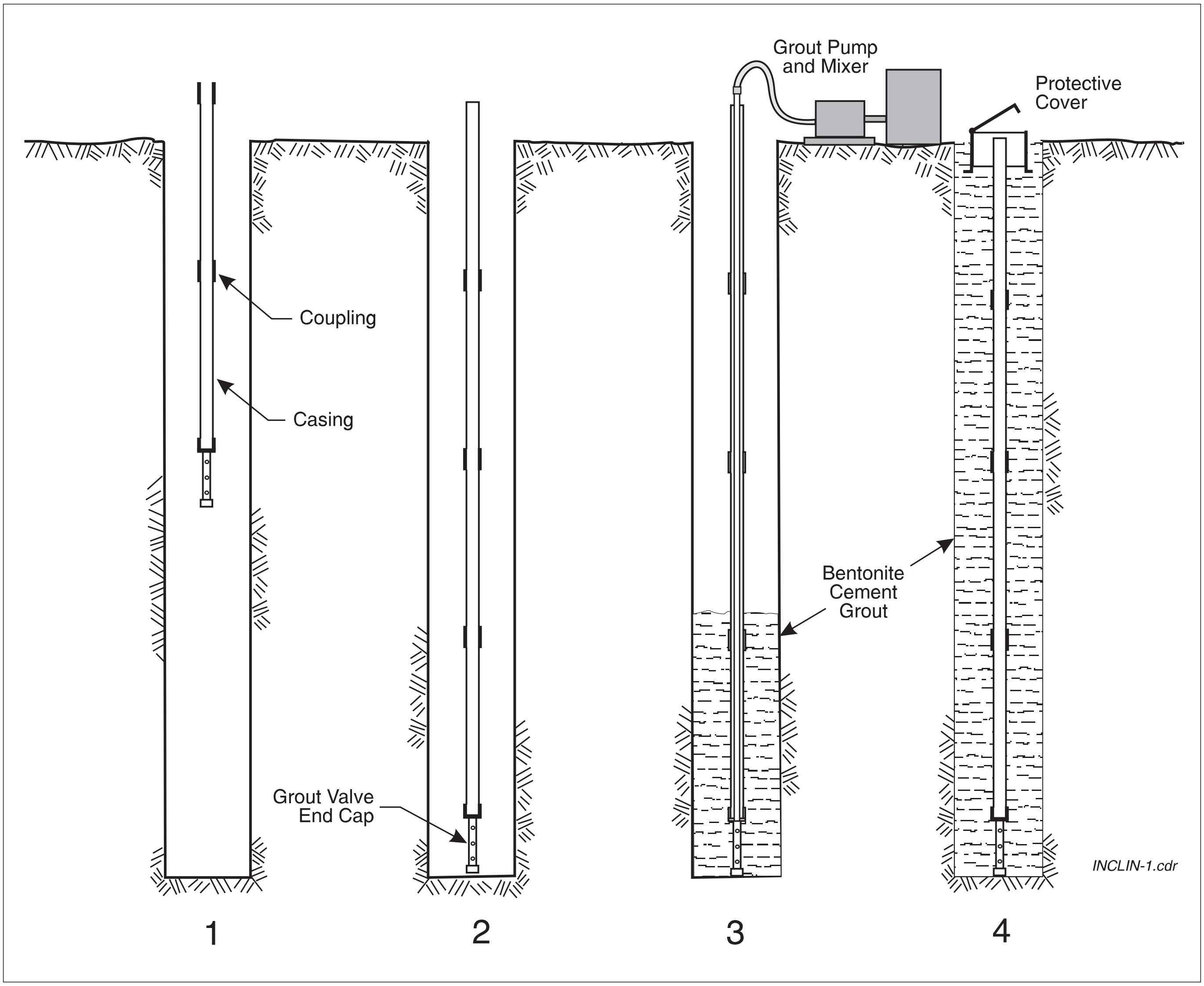
- Grout should be mixed to have a strength similar to that of the soil.

- The density of grout generates a buoyant force, so extra weight may be necessary keep the casing in the borehole after installation. A steel pipe can be lowered inside the casing to rest on the bottom cap. An external weight can be attached to the bottom of the casing, but this requires a deeper borehole and a suspension cable to prevent the weight from pulling apart newly assembled sections of casing.

- Do not hold casing down with the drill rig, since this practice can cause the casing to cork-screw within the borehole.

- After the grout sets, it is usually necessary to “top-off” the borehole with more grout before a protective cover is installed.

Using Grout Valve



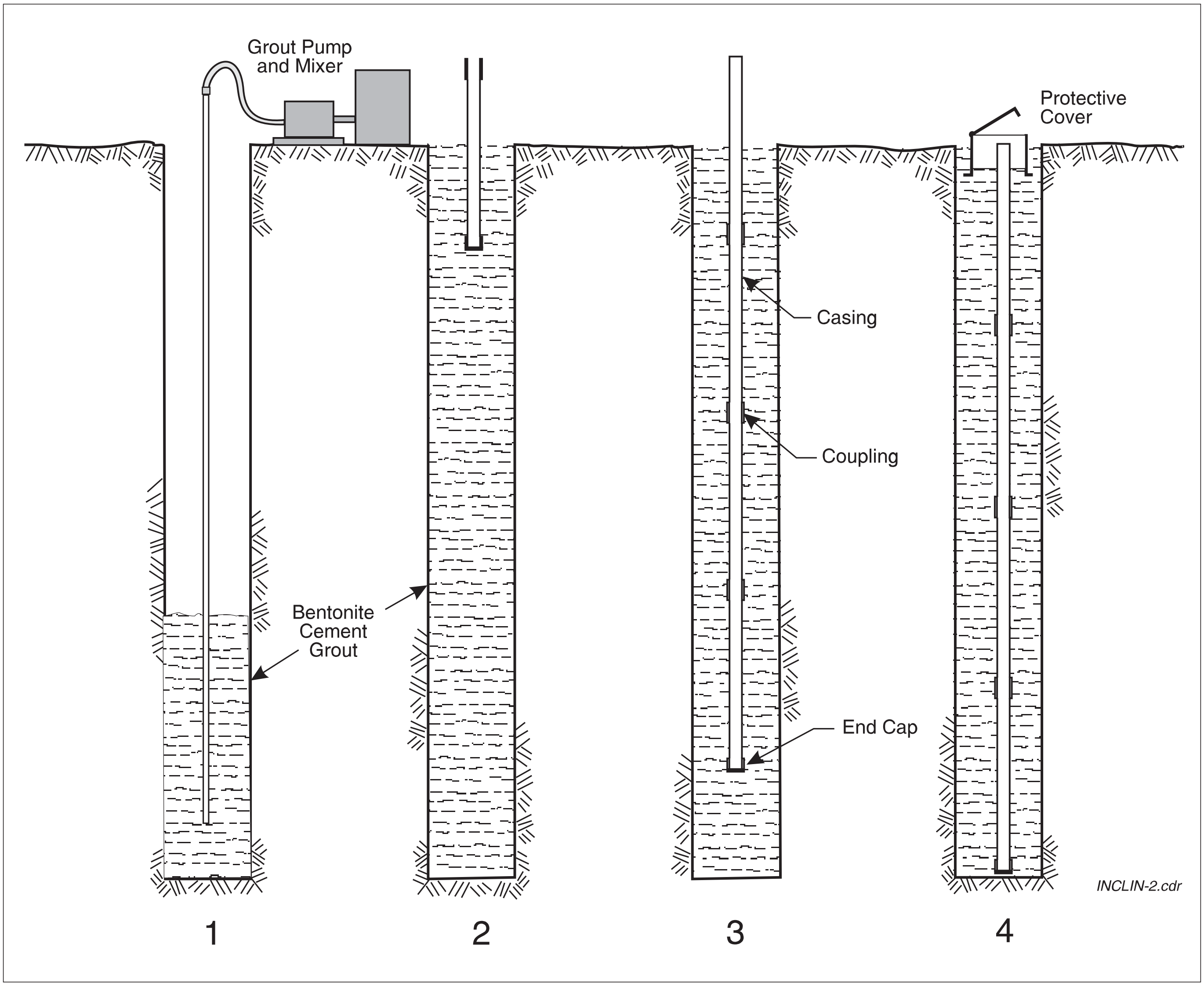
1 Clear drilling mud and debris from borehole. Attach grout valve to bottom section of casing.

2 Install casing in borehole, adding casing sections as necessary until casing reaches specified depth. In water-filled boreholes, fill casing with water to counter buoyancy. In dry boreholes, install dry casing. Fill casing with water to counter buoyancy when grouting begins. Keep water at same level as grout to avoid disturbing sealed couplings.

3 Lower grout pipe into casing to connect with grout valve. Start pumping grout. Water level in borehole should rise if grout pipe is properly connected to grout valve.

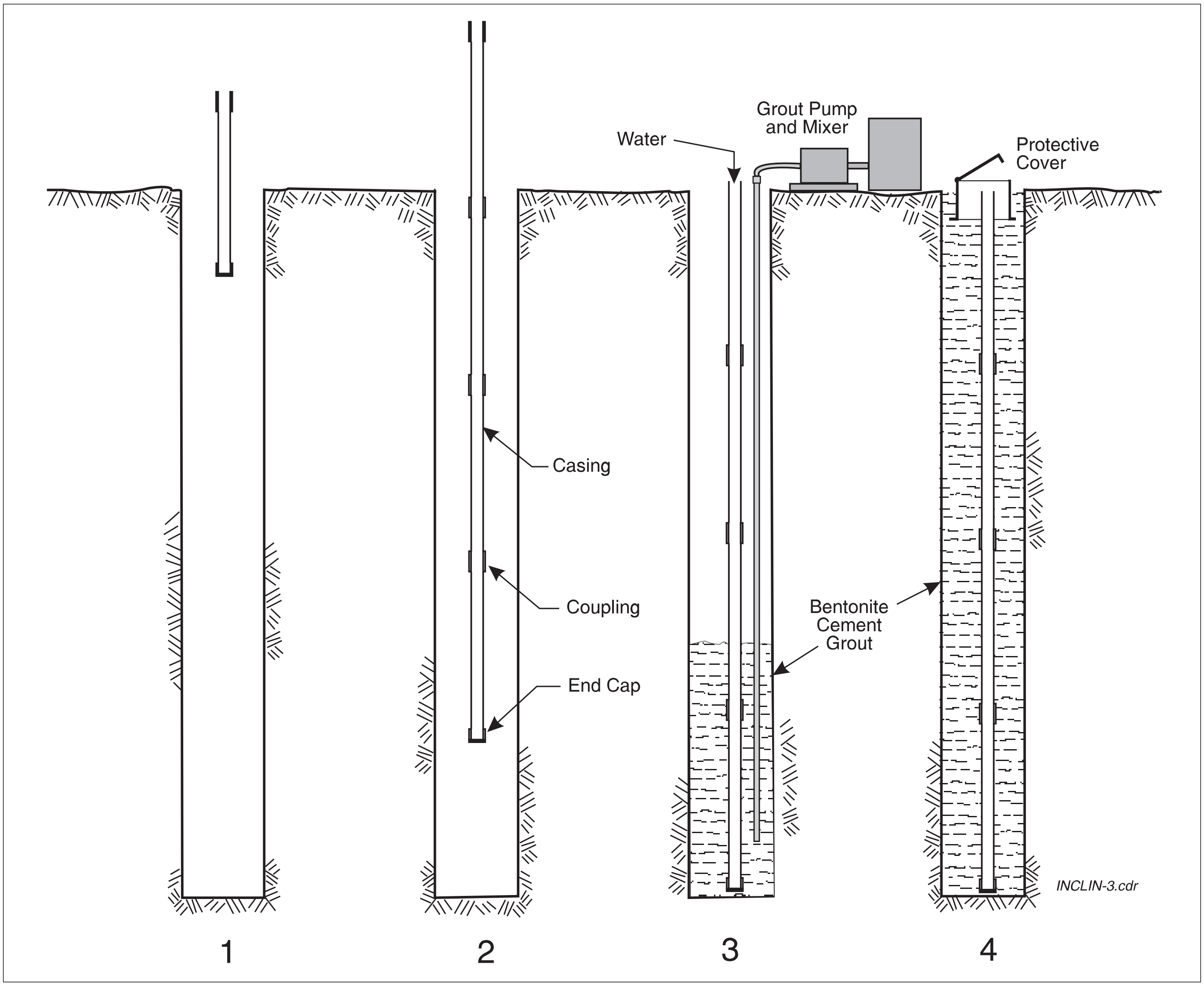
4 Halt pump when grout appears at top of borehole. Hold casing down and disconnect grout pipe. Flush casing with clean water. With quick-connect grout valves, retrieve grout pipe, then flush casing. Lower steel bar or drill pipe to bottom of casing to counter buoyancy while grout sets. Top off borehole with grout and install protective cover. Later, take initial readings, then hand over to client.

Using Pre-Grouted Borehole



1. Clear borehole of drilling mud and debris. Lower grout pipe to bottom of borehole. Pump grout, then retrieve grout pipe.
2. Attach bottom cap to bottom section of casing. Install casing in borehole.
3. Add casing sections as necessary until casing reaches specified depth. Keep casing filled with water to counteract buoyancy and inhibit entry of grout.
4. Lower steel bar or drill pipe to bottom of casing to counteract buoyancy while grout sets. Top off borehole with grout and install protective cover. Later, take initial readings, then hand over to client.

Using Tremied Grout



1 Clear drilling mud and debris from borehole. Attach bottom cap to bottom section of casing.

2 Install casing in borehole, adding casing sections as necessary until casing reaches specified depth. In water-filled boreholes, fill casing with water to counter buoyancy. In dry boreholes, install dry casing. Fill casing with water to counter buoyancy when grouting begins. Keep water at same level as grout to avoid disturbing sealed couplings.

3 Lower steel bar or pipe to bottom of casing to counteract buoyancy while grout sets. Then lower grout pipe to bottom of borehole and pump in grout.

4 Top off borehole with grout and install protective cover. Take initial readings, then hand over to client.

5

Beam Sensors and Tiltmeters

Notes

Applications

Introduction

Beam sensors and tiltmeters are used to monitor changes in the tilt of a structure.

Changes in tilt can occur when nearby construction activity affects the ground that supports the structure. Activities such as excavation, tunneling, or dewatering may cause settlement or lateral deformation. Placement of surcharges and pressure grouting may cause heave.

Changes in tilt are also caused when a load is applied to a structure. Dam impoundment, excavation behind a diaphragm wall, or wind and traffic on a bridge deck are examples of this.

Application Overview

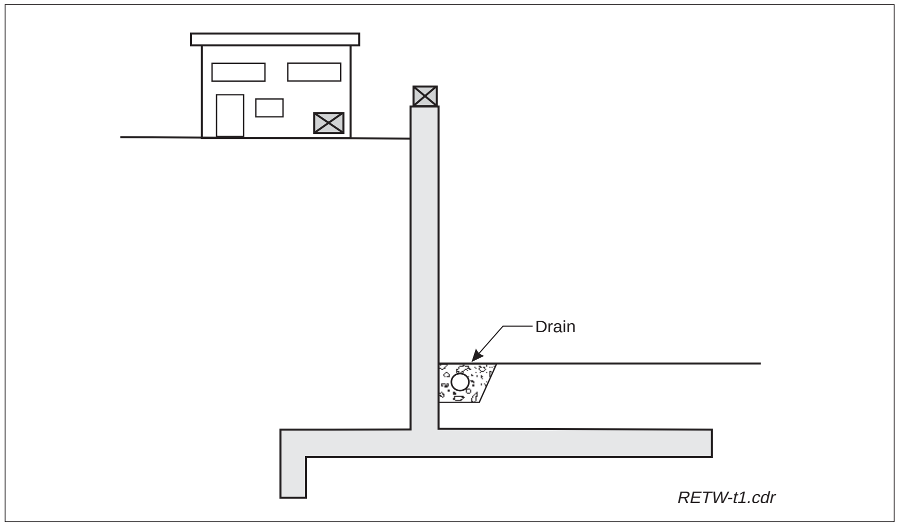
Beam sensors differ from tiltmeters in two important respects: First, the beam sensor has a defined gauge length, typically 1 to 3 meters, so changes in tilt can be converted simply and accurately to millimeters of movement (settlement, heave, convergence, or lateral displacement). Second, beam sensors can be linked end-to-end to monitor differential movements and provide absolute displacement and settlement profiles.

Tiltmeters typically have a more limited function, that of monitoring rotation. A tiltmeter can be used with a large number of tilt plates to detect differential movement in a structure, but the resulting data cannot provide absolute displacement and settlement profiles.

In general, however, both types of sensors can be used to:

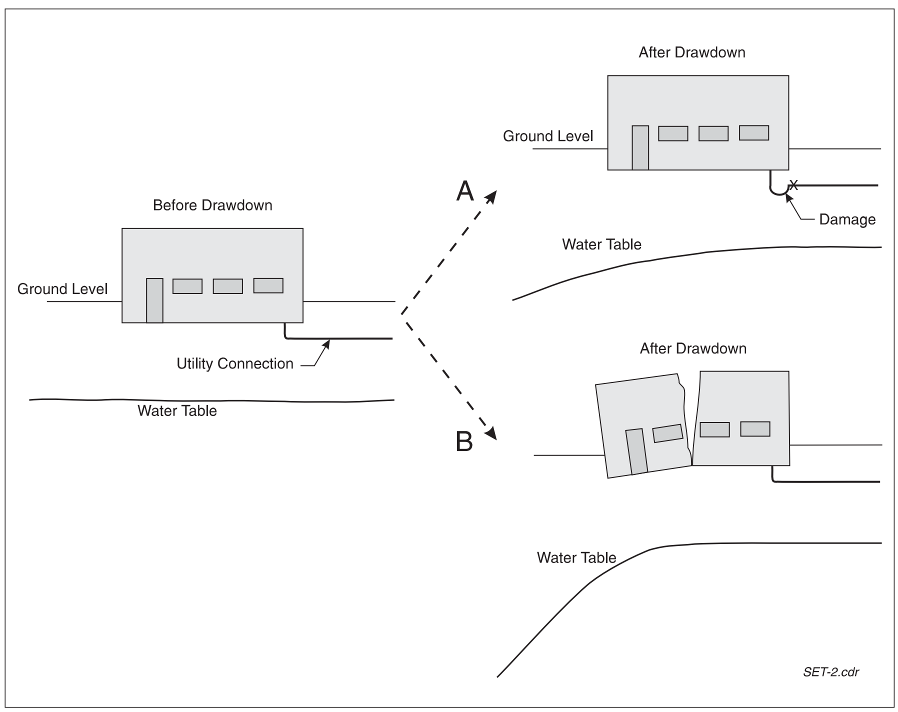
- Monitor stabilization measures, such as pressure grouting and underpinning.
- Monitor structures for the effects of tunneling and excavating.
- Evaluate the performance of bridges, beams, and dams under load.
- Monitor the stability of structures in landslide areas.
- Monitor the deflection and deformation of retaining walls.
- Monitor convergence and other movements in tunnels.
- Provide early warning of threatening deformations, allowing time for corrective action to be taken or, if necessary, for safe evacuation of the area.
- Provide an accurate record of movement in the structure for legal purposes.

Retaining Wall



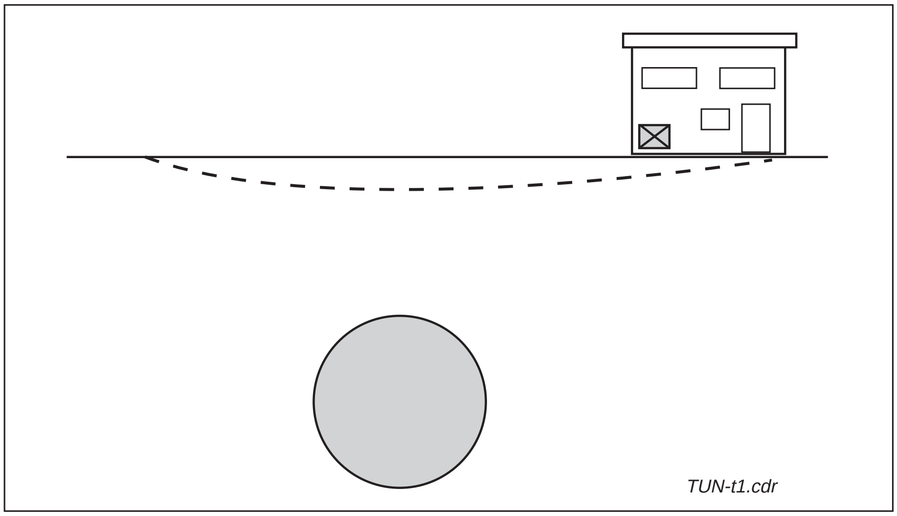
- Monitor rotation in wall to verify stability.
- Monitor rotation or differential movements in structure.

Dewatering



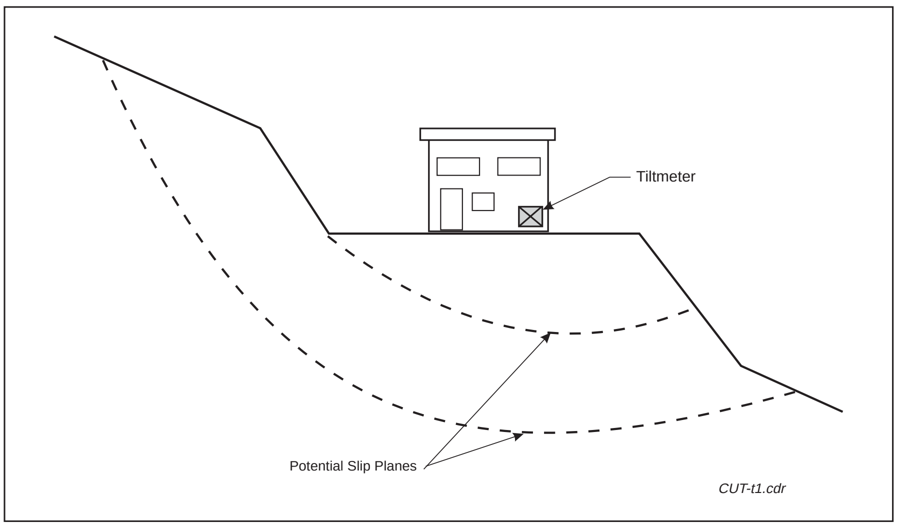
- Monitor for differential settlement that may damage the structure (EL beam sensors).

Tunneling



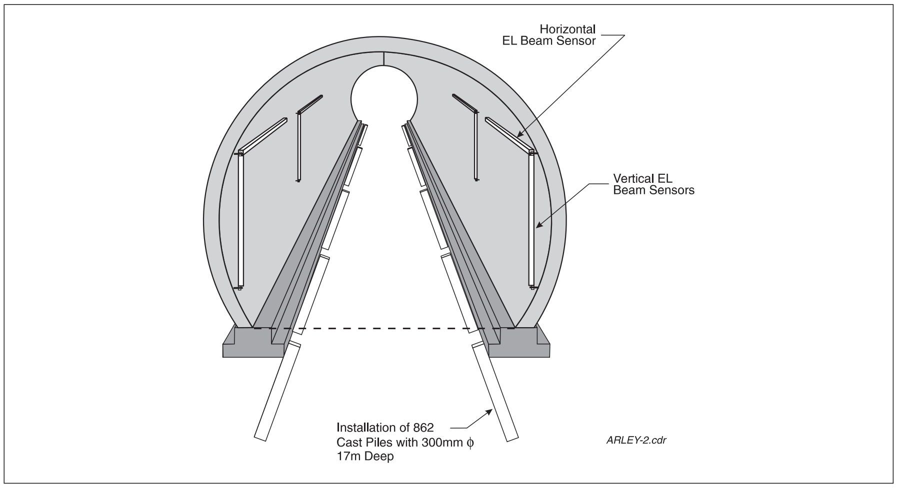
- Monitor for movement caused by tunneling or excavation.

Cutting



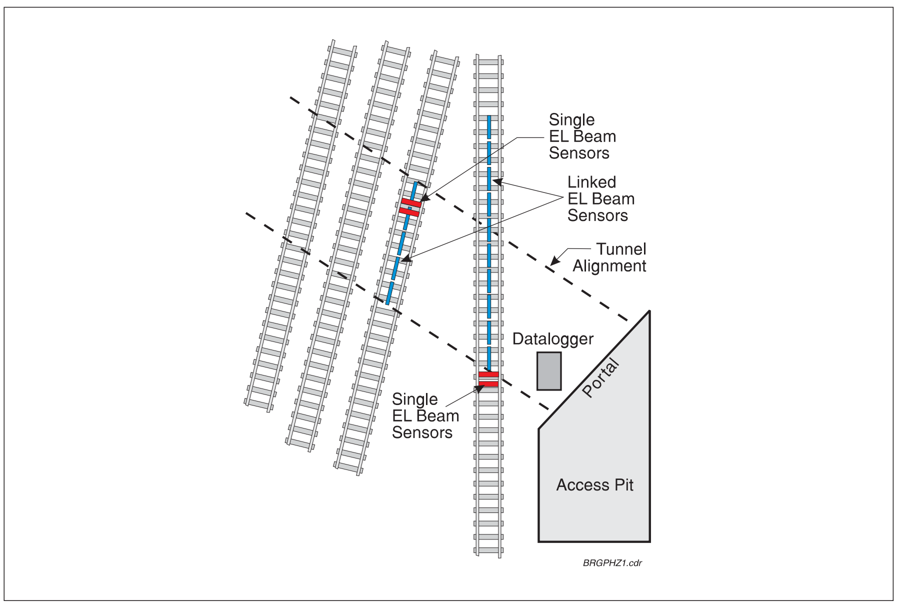
- Provide indication of slope stability.
- Monitor effects of stabilization measures.

Tunnel Construction or Renovation



- Horizontal EL beams monitor settlement.
- Vertical beams monitor convergence.

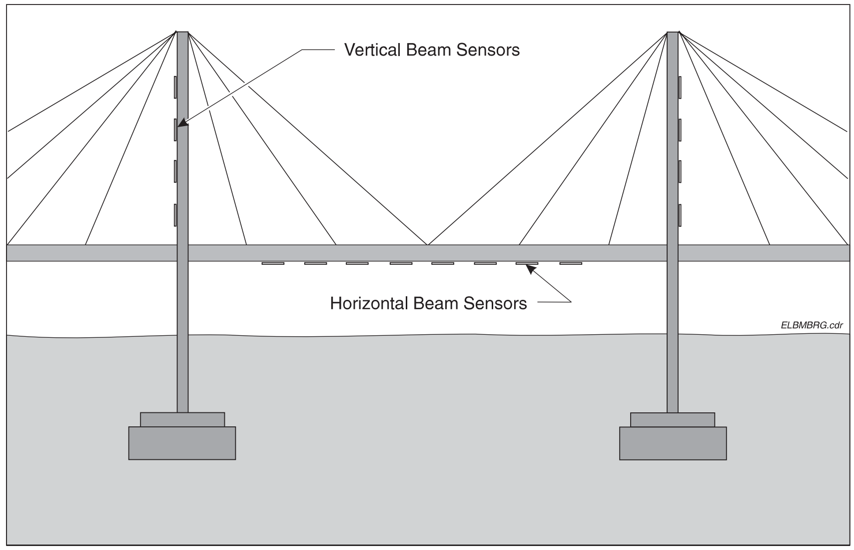
Heave & Settlement in Track Bed



A highway tunnel is being constructed under railway tracks. A supporting concrete arch will be jet-grouted, then remainder of material will be excavated. Construction may cause heave or settlement in the track bed, delaying train traffic or possibly causing derailment.

- Monitor for heave created by jet-grouting.
- Monitor for settlement created by excavation.
- Monitor for tilt across tracks.

Loads and Deflections



- Monitor deflection of bridge masts.
- Monitor deflection of bridge deck.

Operation

EL Beam Sensor

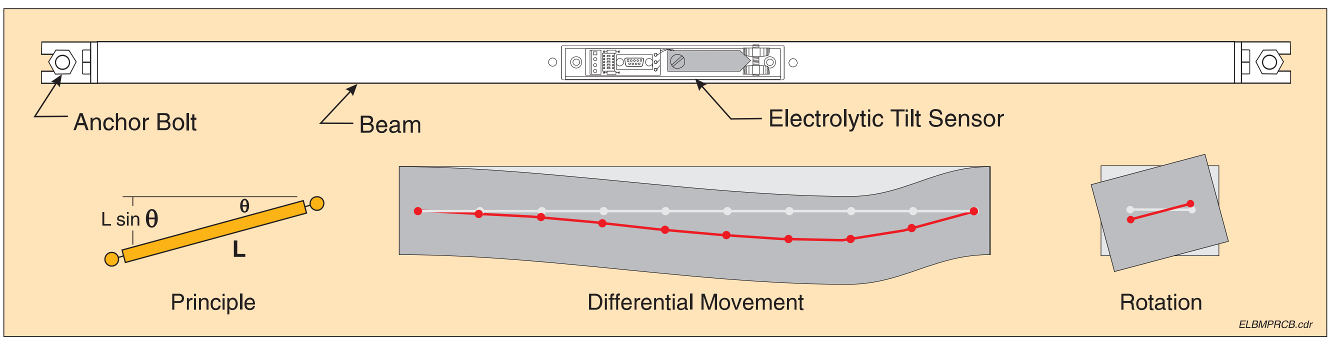
EL beam sensors detect rotation and differential movement in structures. Two versions of the beam sensor are available: a *horizontal* version for monitoring settlement and heave, and a *vertical* version for monitoring lateral displacement and convergence.

Operation

The beam sensor consists of an electrolytic tilt sensor attached to a rigid metal beam. The tilt sensor is a precision bubble-level that is sensed electrically as a resistance bridge. The bridge circuit outputs a voltage proportional to the tilt of the sensor.

The beam, which is typically one to three meters long, is mounted on anchor bolts that are set into the structure. The tilt sensor is then zero-adjusted and locked in position.

Movement in the structure changes the tilt of the beam. Displacement, the distance the structure has moved, is calculated as L ($\sin \theta_1 - \sin \theta_0$), where L is the gauge length of the sensor, θ_1 is the current tilt of the beam, and θ_0 is the initial tilt.



Advantages

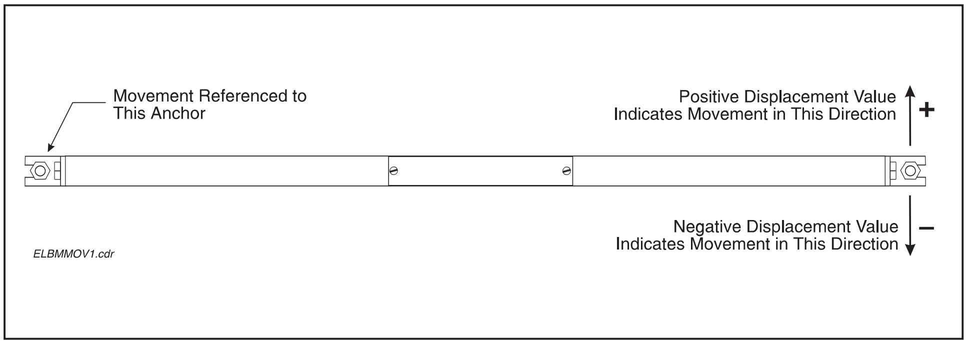
- ❑ Beam sensor detects changes in tilt as small as one second of arc, equivalent to 0.005 mm per meter of beam.
- ❑ Changes in tilt can be converted simply and accurately to millimeters of movement since beam sensor has a defined gauge length.
- ❑ Beam sensors can be linked end to end to provide absolute displacement and settlement profiles.
- ❑ Low-profile design is practical for tunnels and other locations where clearance is important.
- ❑ Reading station is remote from work area and does not interfere with construction activity.

Limitations

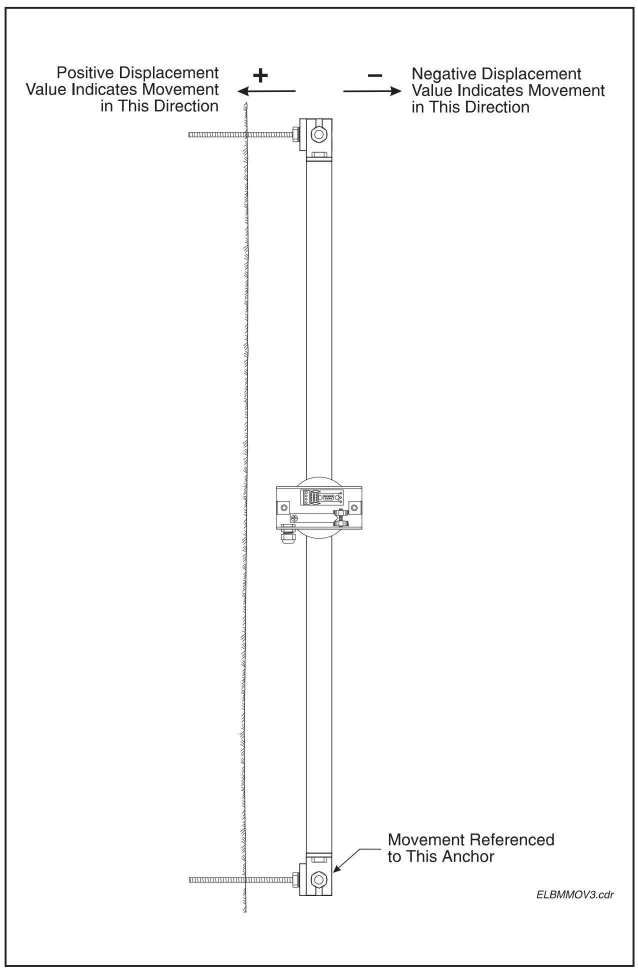
- ❑ Range is typically limited to (40 arc minutes, equivalent to 23 mm of movement per meter. When movement exceeds this range, sensor must be rezeroed. Zero-adjust mechanism permits adjustment of (4 ⊃ without moving beam.
- ❑ Requires AC excitation, so some data loggers not compatible.
- ❑ Cannot be buried or used underwater.

Direction of Displacement

Horizontal Beams: A positive displacement value indicates a counter-clockwise rotation as shown below. A negative value indicates a clockwise rotation.



Vertical Beams: A positive displacement value indicates a counter-clockwise rotation as shown below. A negative value indicates a clockwise rotation.

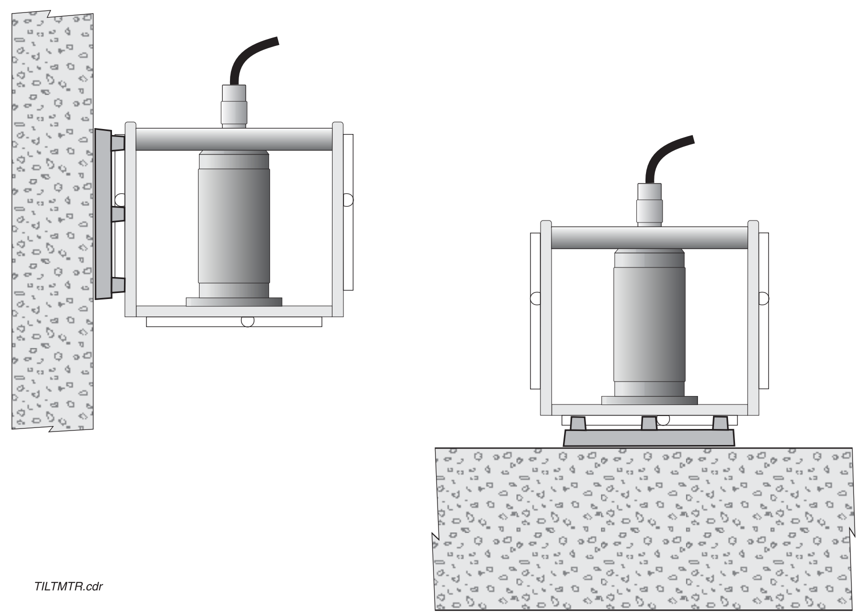


Tiltmeter

The tiltmeter system includes a number of tilt plates, the portable tiltmeter, and a readout unit.

The portable tiltmeter uses a force-balanced servo-accelerometer to measure inclination. The accelerometer is housed in a rugged frame with precisely machined surfaces that facilitate accurate positioning on the tilt plate. The bottom surface is used with horizontally-mounted tilt plates and the side surfaces are used with vertically-mounted tilt plates.

Tilt plates are mounted on the structure in specified locations. They are typically cemented in place, but may also be screwed to the surface.

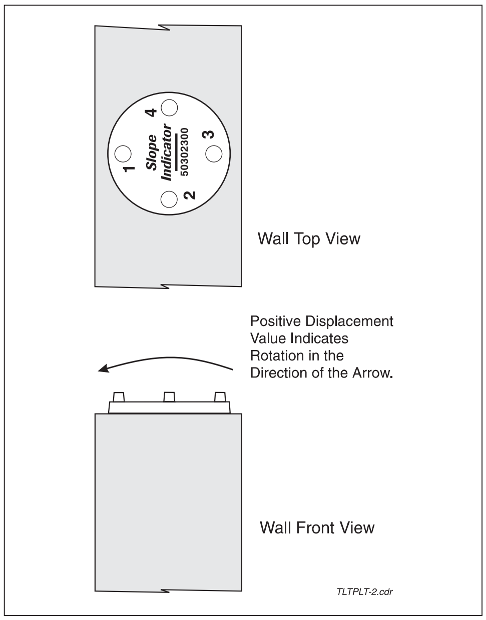


Tiltmeter (continued)

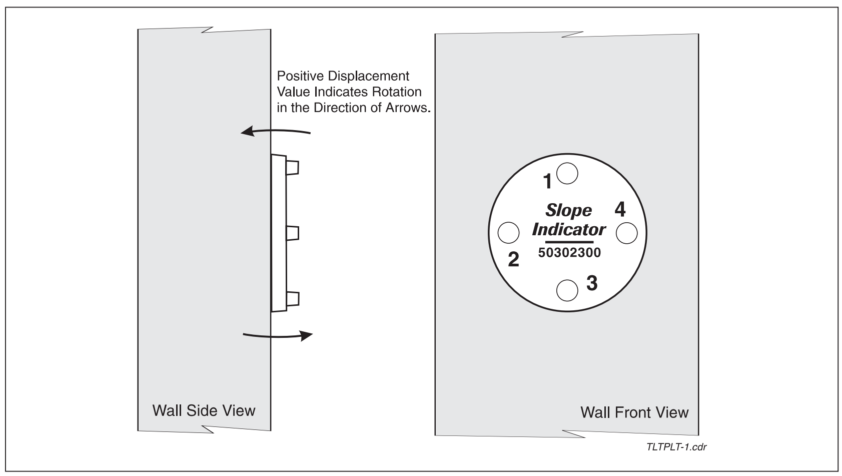
To obtain tilt readings, the operator connects the tiltmeter to the readout unit and positions the tiltmeter on the tilt plate, with the (+) marking on the sensor base plate aligned with peg 1. The operator then notes the displayed reading, rotates the tiltmeter 180⊃, and obtains a second reading. Later, the two readings are averaged to cancel sensor offset.

Changes in tilt are found by comparing the current reading to the initial reading. A positive value indicates tilt in the direction of peg 1 (peg 1 down, peg 3 up). A negative value indicates tilt in the direction of peg 3.

The metric tiltmeter and indicator deliver a resolution of 8 arc seconds or 0.004 mm of movement over the 101 mm base of the tilt plate. The English tiltmeter and indicator deliver a resolution of 10 arc seconds or 200 micro-inches of movement.



Orientation for Horizontal Mounting



Orientation for Vertical Mounting

Only one tiltmeter is required for many tilt plates.

Advantages

- Tilt plates can be glued or bolted to convenient surfaces of the structure.

Limitations

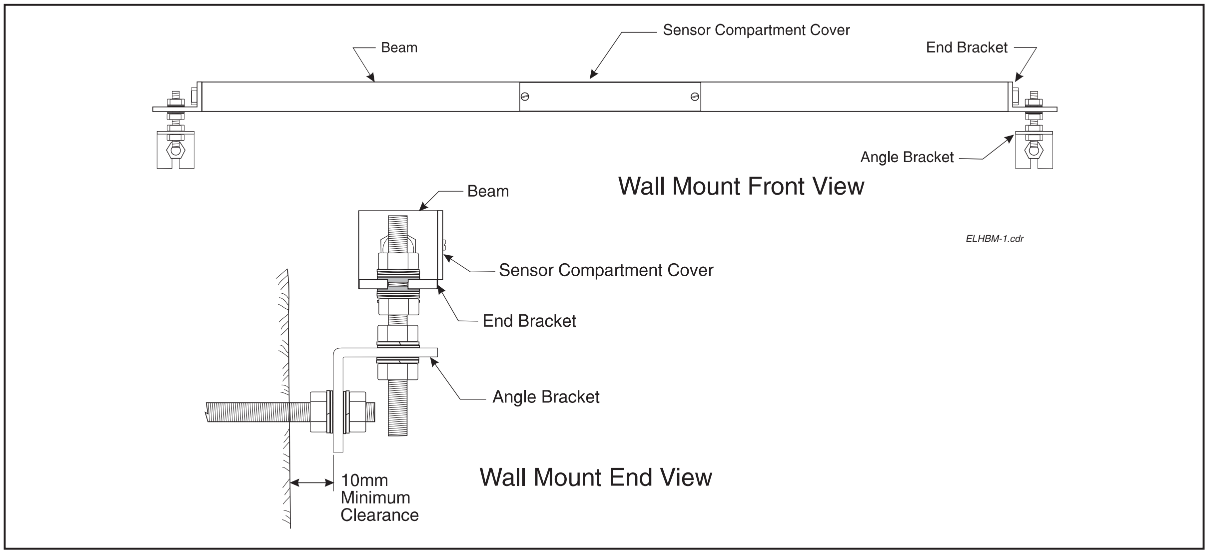
- Tilt measurements are local to the tilt plate. Extrapolating tilt in larger portions of the structure or interpolating rotation between a number of survey points involves assumptions about the rigidity and behavior of the structure.
- Tilt plates must be protected from accidental damage and vandalism.
- Remote reading is not available.

Installation

EL Beam Sensors

General Concerns

- Anchor studs should be installed exactly parallel to each other if beam is to be mounted directly onto studs.
- Angle brackets, supplied in the anchor kit, can compensate for studs that are not parallel. They also accommodate flexing in the wall or floor, so that lateral deviation does not affect the reading for tilt.
- It is important to install the washers and bushings in the correct order. The bushings help maintain free movement of the brackets and prevent galvanic corrosion. Spring washers should be partially compressed, not flattened.

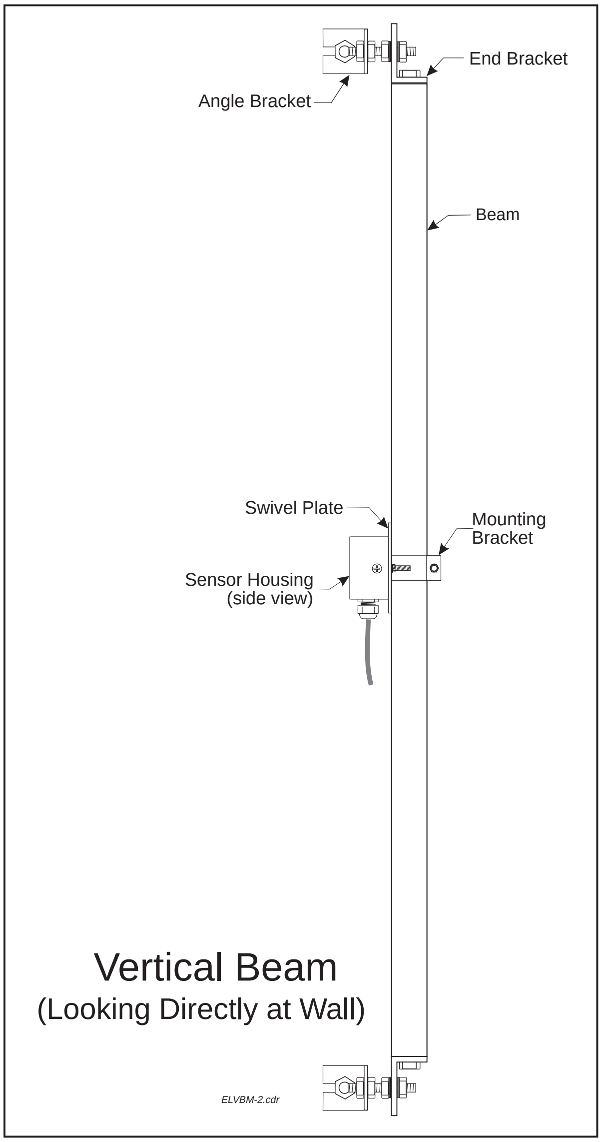


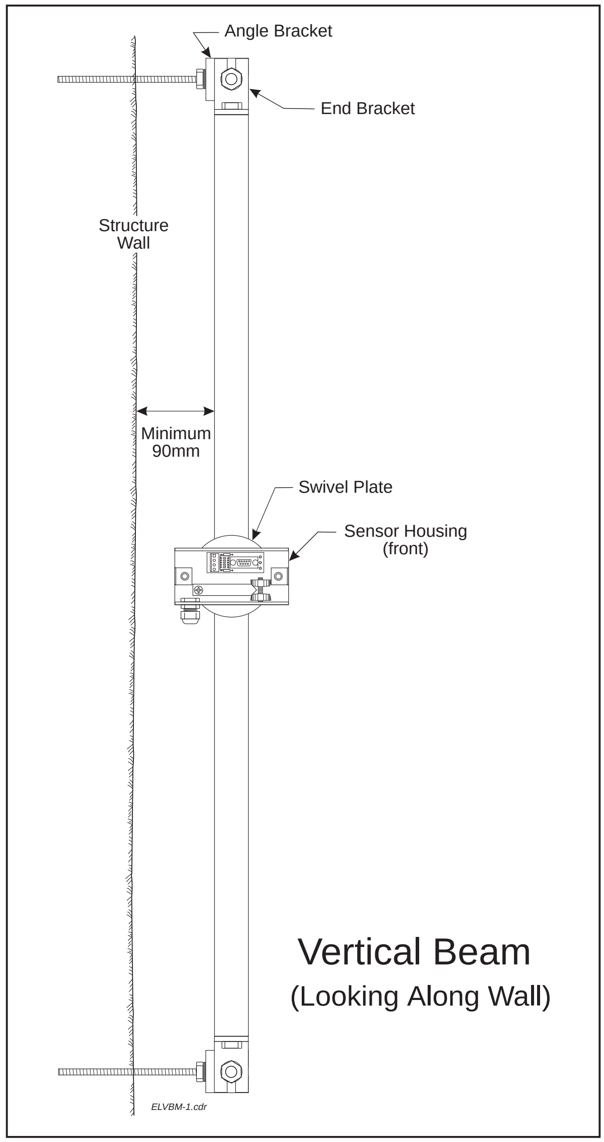
Horizontal Beam Sensors

1. Mount beam sensor inside sensor compartment.
2. Drill anchor holes. Fill the hole with grout, then insert anchor stud. Allow grout to harden.
3. Install signal cable and conduit.
4. Bolt angle-brackets onto stud as shown in drawing.
5. Bolt end-brackets of beam to angle brackets. Check that end brackets are loose enough to allow adjustment.
6. Zero the sensor using EL-35 readout, then tighten thumb wheels.

Vertical Beam Sensors

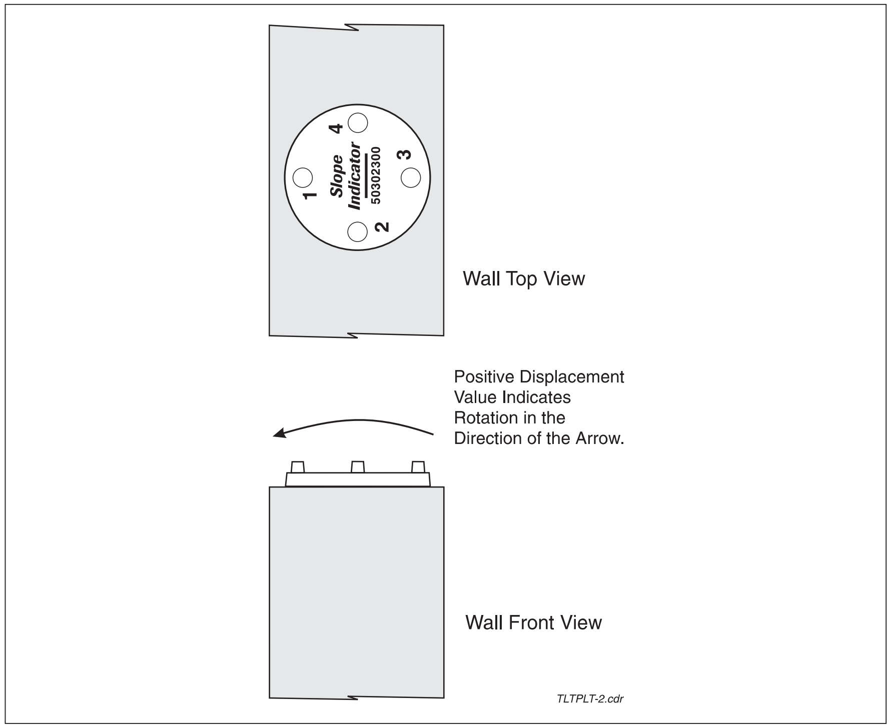
1. Slip mounting bracket and housing onto beam. See illustrations for proper orientation of housing.
2. Drill anchor holes. Fill the hole with grout, then insert anchor stud. Allow grout to harden.
3. Install signal cable and conduit.
4. Bolt angle-brackets onto stud as shown in drawing.
5. Bolt end-brackets of beam to angle brackets. Check that end brackets are loose enough to allow adjustment.
6. Zero the sensor using EL-35 readout, then tighten thumb wheels.



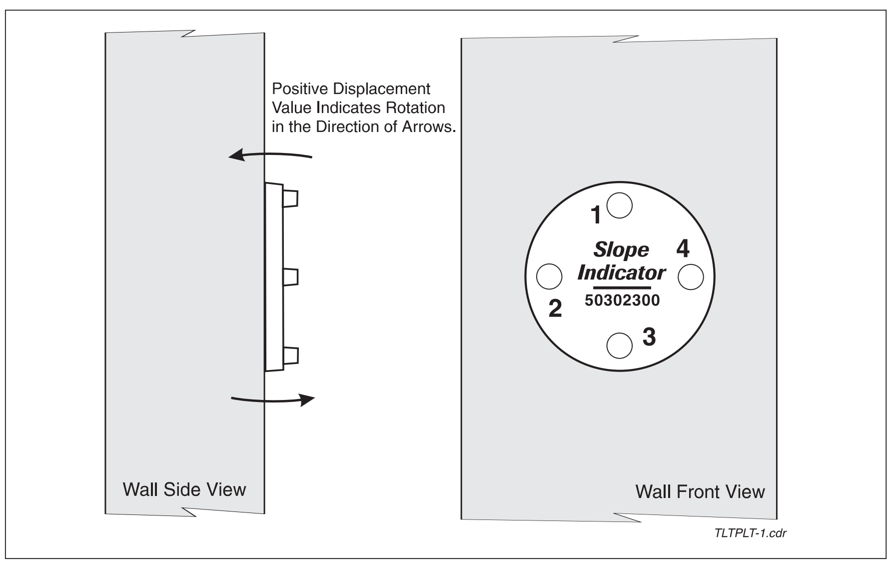


Tilt Plates

Ceramic tilt plates are bonded to the structure; bronze tilt plates can be bonded or screwed. Follow the manufacturer's instructions for grout or epoxy. Level the tilt plate with a spirit level or a tiltmeter sensor.



Place a horizontally mounted tilt plate so that pegs are square with the wall. Pegs 1 and 3 should be parallel to the expected direction of rotation.



Place a vertically mounted tilt plate so that pegs 1 and 3 are as nearly vertical as possible.

6

Borehole Extensometers

Notes

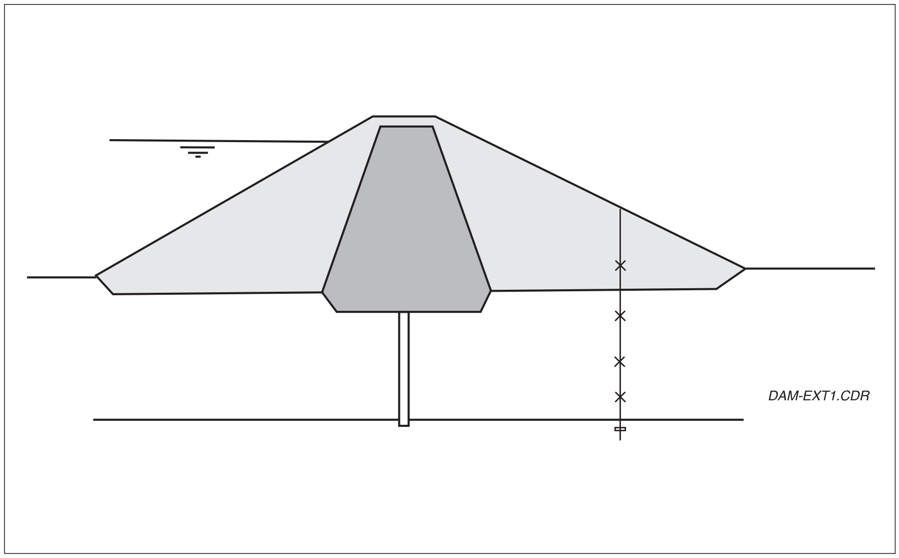
Borehole Extensometers

Borehole extensometers are used to monitor settlement, heave, convergence, and lateral deformation in soil and rock.

Typical applications include:

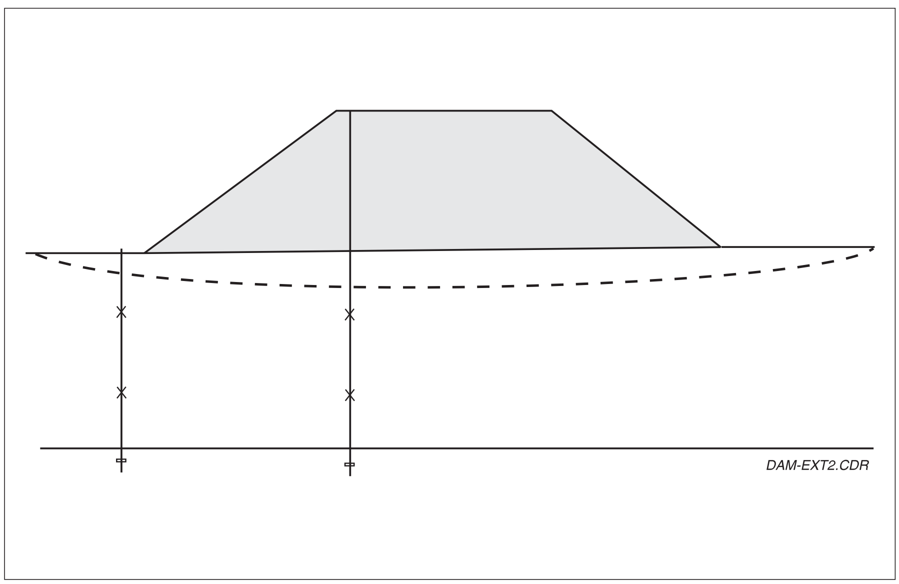
- Monitoring settlement or heave in excavations, foundations, and embankments.
- Monitoring settlement or heave above tunnels and other underground openings.
- Monitoring convergence in tunnel walls.
- Monitoring lateral displacement in slopes.

Earthfill Dams



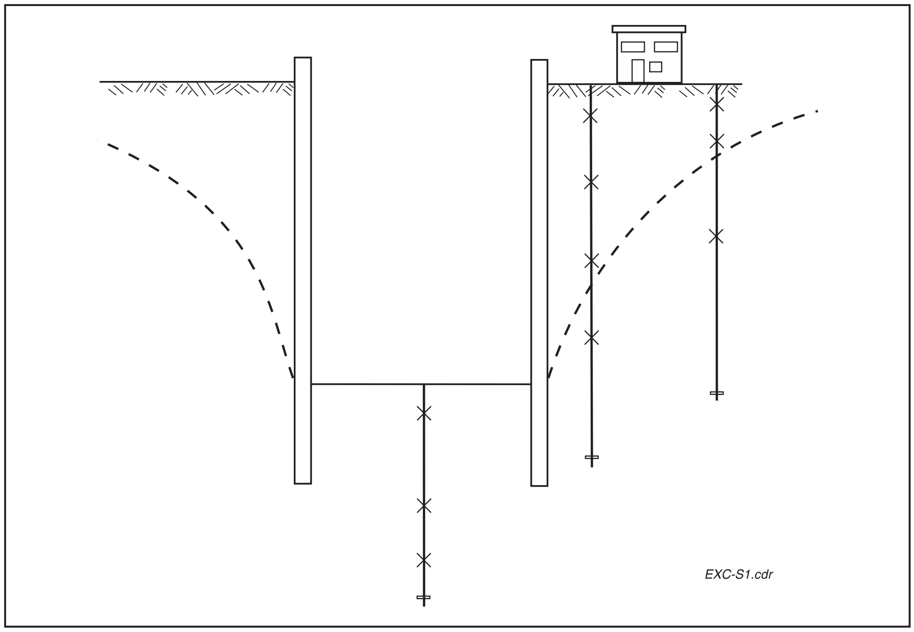
- ❑ Monitor vertical settlements in toe of dam (Magnetic extensometer).

Embankments



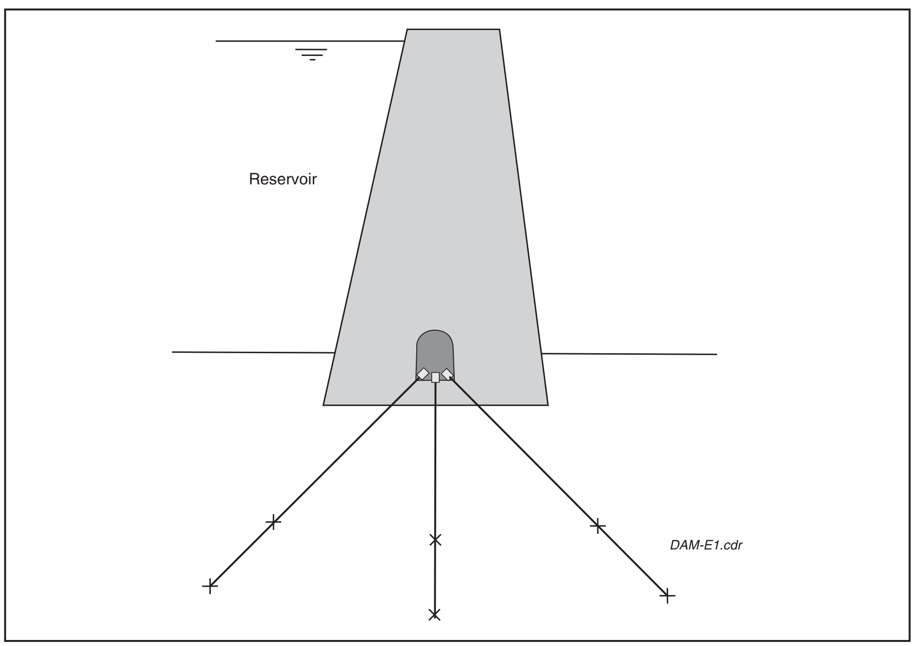
- ❑ Monitor settlement to determine when construction can continue (Magnetic extensometer used inside inclinometer casing).

Dewatered Excavation



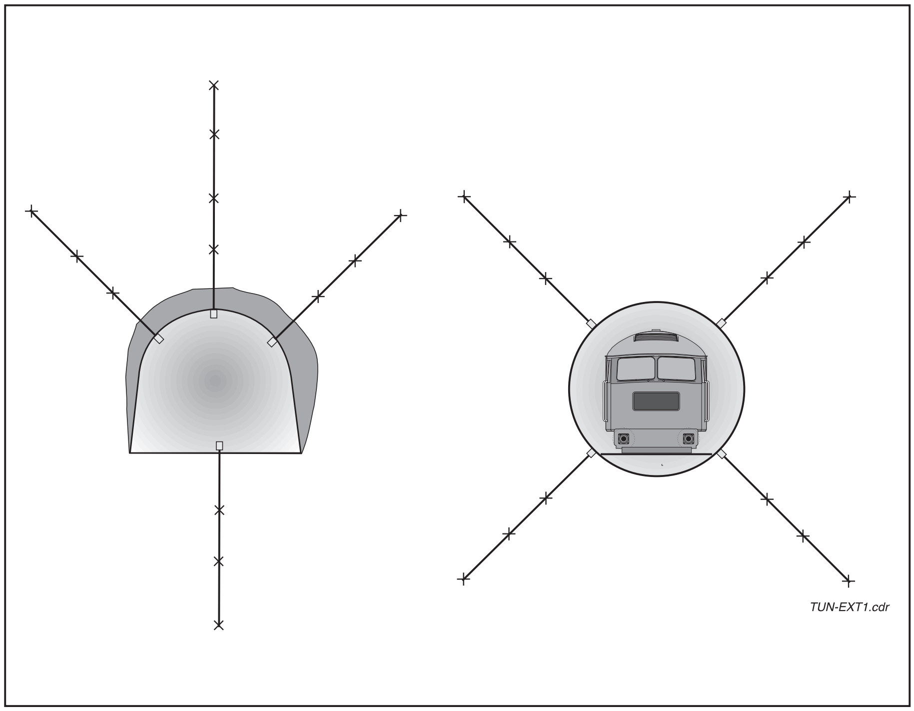
- Monitor settlement due to consolidation of dewatered soil. Remedial action can be taken if settlement threatens structures. (Magnetic extensometer)

Dam Foundations



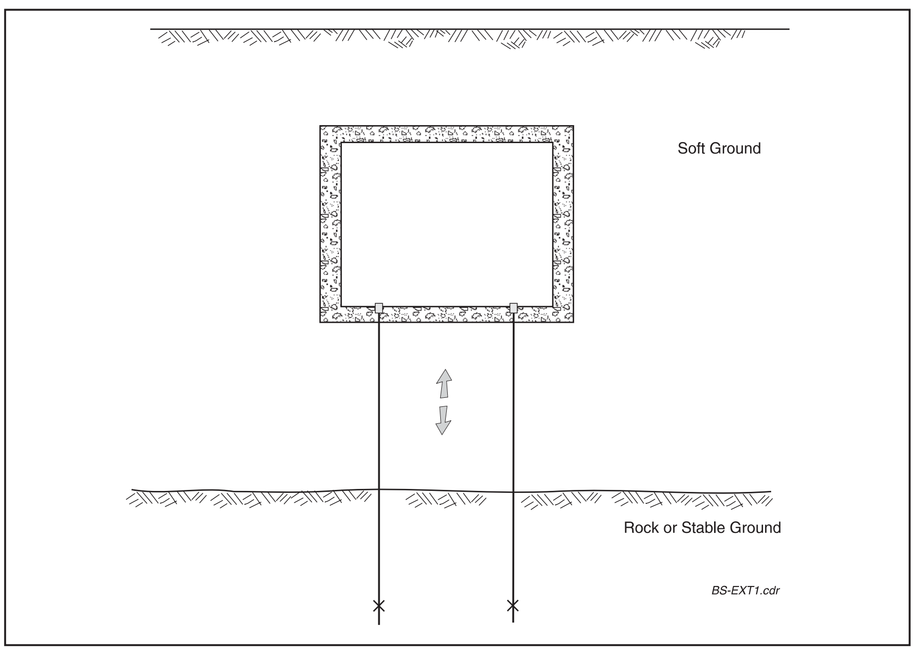
- Monitor stability of dam. Monitor rotation when full and empty. (Rod extensometer)

Tunnels



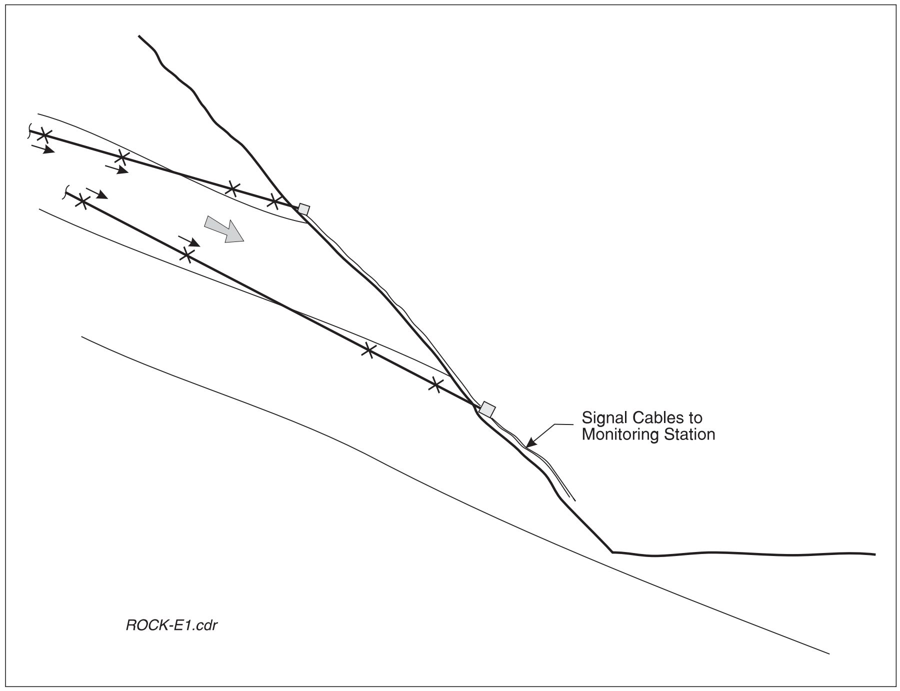
- Monitor stability and convergence. (Rod extensometer)

Underground structures



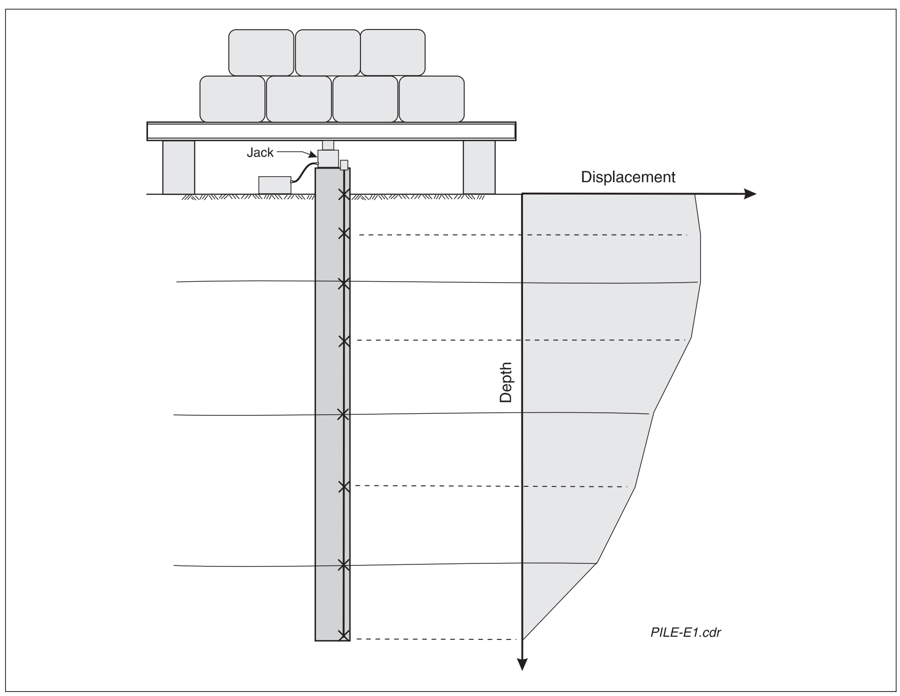
- Monitor stability, settlement, and heave.
- Detect rotation.

Rock Slide



- ❑ Monitor magnitude and rate of movement. (Rod extensometer)

Pile Load Tests



- ❑ Monitor compression of pile. (Rod extensometer)
- ❑ A deeper installation can monitor soil beneath pile. (Rod extensometer)

Probe Extensometers

Probe extensometers are used mostly in soils and can generally accommodate large settlements. Readings are obtained by drawing a probe through an access pipe. Resolution is typically limited to one millimeter.

- Magnetic Extensometers
- Sondex
- USBR Settlement Probe & Telescoping Casing

Rod Extensometers

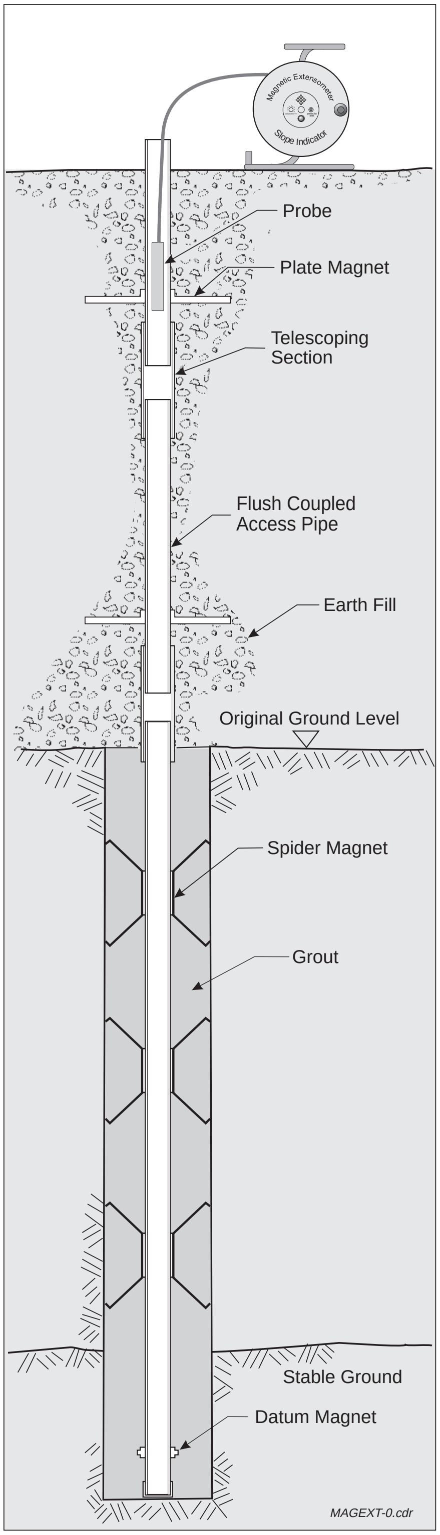
The Borros point extensometer can be driven into soft soils. Resolution is determined by the quality of the survey equipment.

Tensioned-rod and untensioned-rod extensometers are used in soil and rock. They have a smaller range, typically 100 to 150 millimeters, and can provide micro-millimeter resolution.

- Borros Point
- Tensioned-Rod Extensometers
- Untensioned-Rod Extensometers

Magnetic Extensometer

For Vertical Settlement Profiles



Data from the magnetic extensometer can reveal the depths at which settlement has occurred as well as the total amount of settlement.

The magnetic extensometer consists of a probe, a steel survey tape, a tape reel with built-in light and buzzer, and a number of magnets positioned along the length of an access pipe. The magnets are coupled to the surrounding soil and move up or down as heave or settlement occurs.

Readings are obtained by lowering the probe to the bottom of the access pipe and drawing it up to find the depth of each magnet. When the probe enters a magnetic field, a reed switch closes, activating the light and buzzer. Two buzzes are emitted, the first in the general vicinity of the magnet, and the second at the exact location of the magnet. The operator then refers to graduations on the survey tape and notes the depth of the magnet.

When the pipe is anchored in stable ground, the depth of each magnet is referenced to a “datum” magnet that is fixed to the bottom of the access pipe. Settlement and heave are determined by comparing the current depth of each magnet to its initial depth.

If the bottom of the access pipe is not in stable ground, the depths of the magnets must be referenced to the top of the pipe, which is optically surveyed before readings are taken.

Advantages

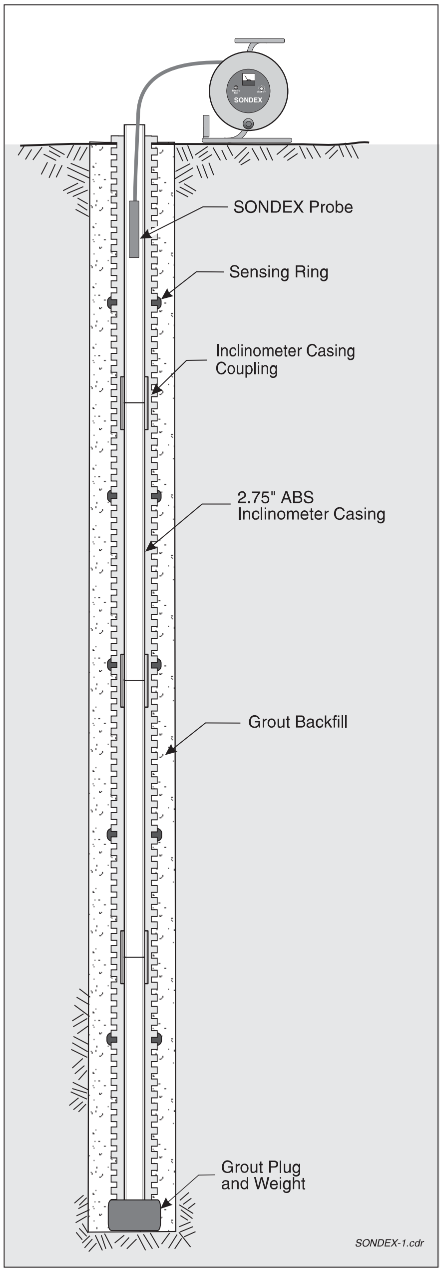
- Provides multiple measurements, indicating not only the total settlement, but also the “incremental” settlement at the depth of each magnet.
- Optical survey not required if bottom is fixed in stable ground.
- Inexpensive.
- Easy to read.
- Can be combined with inclinometer in certain soils.

Limitations

- Interferes with site operations. Not easily automated.

Sondex

For Vertical Settlement Profiles



Data from the Sondex system can reveal the depths at which settlement has occurred as well as the total amount of settlement.

The Sondex system consists of a probe attached to a cable or steel tape, a cable reel with a built-in voltmeter, and a number of stainless steel sensing rings positioned along the length of an access pipe. In soft ground, rings are fixed to a corrugated plastic pipe and the access pipe is installed inside the corrugated pipe for support. The corrugated pipe slips along the access pipe and allows the rings to move with the surrounding ground. In harder ground, sensing rings can be attached directly to telescoping plastic pipe.

The operator draws the probe through the pipe. The meter on the readout unit peaks and a buzzer sounds when the probe's internal coil is aligned with a sensing ring. The operator refers to cable markings or the steel tape and records the depth of each ring. Later, data from the current set of measurements is compared to the initial set of measurements to determine changes.

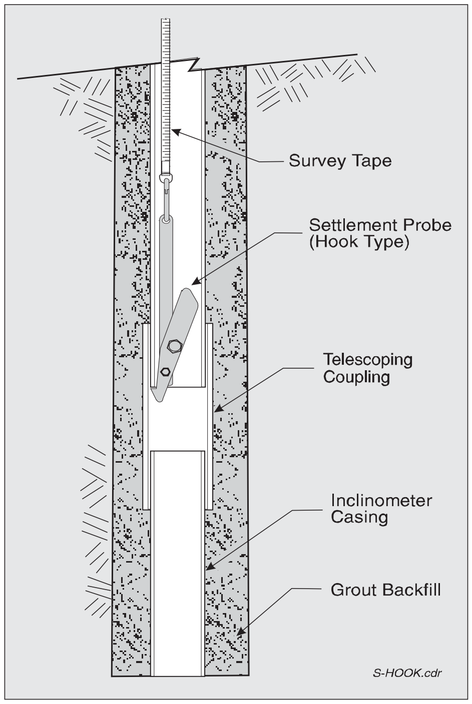
Advantages

- Provides multiple measurements, indicating not only the total settlement, but also the "incremental" settlement at the depth of each magnet.
- Optical survey not required if bottom is fixed in stable ground.
- Can be combined with inclinometer in certain soils.

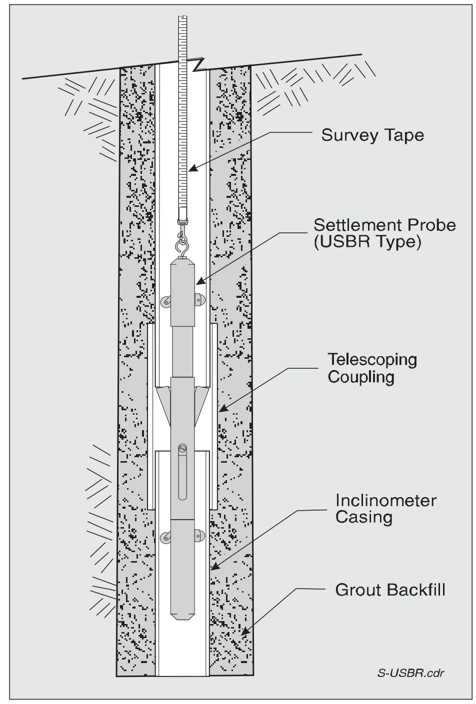
Limitations

- Interferes with site operations and cannot be automated.
- Readings are affected by operator's technique.
- Installation can be difficult.

Settlement Probe For Vertical Settlement Profiles



Hook type probe



USBR type probe

Data from the Settlement Probe can reveal the depths at which settlement has occurred as well as the total amount of settlement.

Settlement probes are used with telescoping inclinometer casing. The probe is attached to a steel measuring tape and lowered through the casing. As it passes a coupling, an arm on the probe “catches” on the edge of the casing section.

The operator notes the reading on the steel tape, disengages the arm, and continues lowering the probe. When the probe reaches bottom, a mechanical action locks the arm in the closed position so it can be withdrawn.

If bottom of casing is stable, readings are referenced to the bottom. Otherwise readings are referenced to top of casing which must be surveyed. Settlement is found by comparing current readings with initial readings.

Advantages

- Hook type probe is inexpensive.
- Obtains settlement profile, not just single point.

Limitations

- Requires telescoping inclinometer casing.
- Interferes with site operations and cannot be automated.
- USBR type probe is expensive.
- Clumsy to read.

Borros Point

For Single-Point Settlement Measurement

A borros point consists of a three-pronged anchor, a 1/4" inner pipe, and a one-inch outer pipe, both steel. The inner pipe is attached to the anchor and is free to move inside the one-inch pipe.

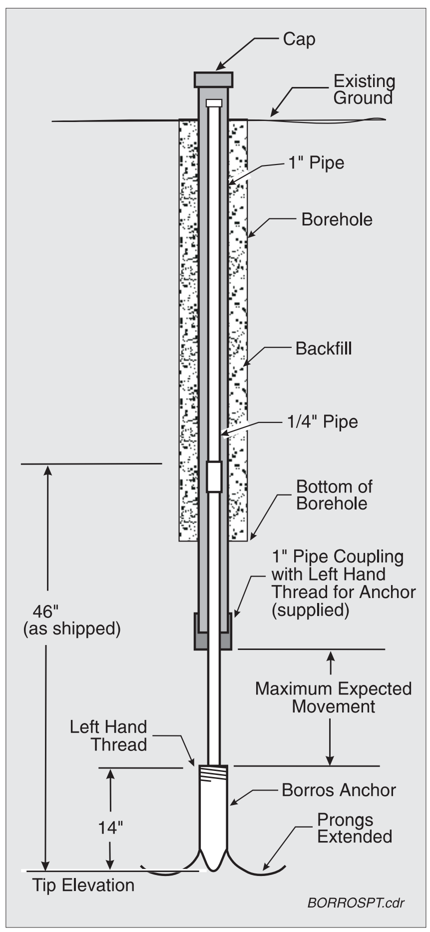
A precision leveling survey is used to determine the elevation of the top of the inner pipe. Changes in its elevation indicate an equivalent amount of settlement or heave in the ground around the anchor.

Advantages

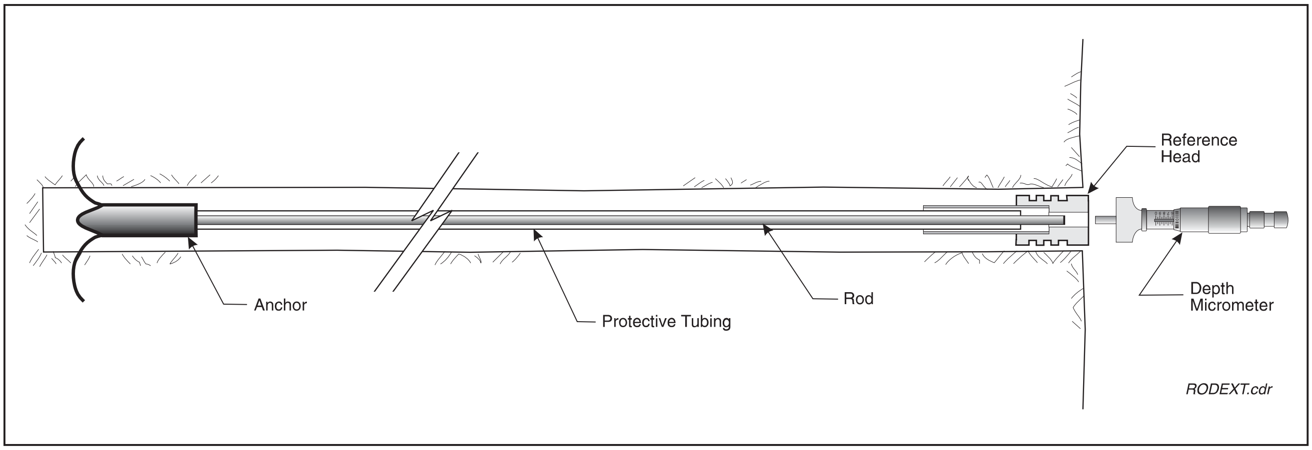
- Simple and inexpensive to install.
- Simple, reliable mechanism.

Limitations

- Used in soft materials only.
- Interferes with site operations and cannot be automated.
- Requires optical survey.



Tensioned & Untensioned Rod Extensometers



Rod extensometers are used to monitor small displacements of soil or rock along the axis of a borehole.

A **Single-Point Rod Extensometer** consists of an anchor, a rod, and a reference head. The anchor, with rod attached, is installed down hole. The reference head is installed at the borehole collar. The rod spans the distance from the anchor to the reference head. A change in this distance indicates that ground movement has occurred. Measurements are obtained at the reference head with a depth micrometer or an electronic sensor and are used to compute the magnitude, rate, and acceleration of displacement. When the reference head or the
anchor can be located with respect to a fixed reference datum, absolute displacements can be determined.

A **Multi-Point Rod Extensometer** consists of up to six anchors and rods and one reference head. Anchors are set near different stratigraphic boundaries. Measurements are obtained at the reference head with a depth micrometer or an electronic sensor. Multi-point extensometer data can reveal the *relative movement between anchors* and the *distribution of displacement* in addition to the magnitude, rate, and acceleration of displacement.

Tensioned-Rod Extensometers

Tensioned-rod extensometers are typically used in deep boreholes. In such installations, friction between the rod and its protective sleeves becomes a significant factor that can hide real movement. A mechanism in the reference head keeps the rod under tension, reducing the effect of friction.

Advantages

- Works in any orientation, from vertical to horizontal.
- Works well in both extension and compression.

Limitations

- Higher cost.
- More difficult to install.
- Lateral deformation can affect reading.

Untensioned-Rod Extensometers

There is no tensioning mechanism in the reference head.

Advantages

- Lower cost.
- Easier to install.

Limitations

- Useful length of rods is limited to 30 meters (fiberglass) or 50 meters (steel), except when rods are suspended from anchor (in up-holes at angle greater than 45⊃).
- Lateral deformation can affect reading.

Rod Material

Tensioned-Rods: Fiberglass or aluminum rods offer similar performance and ease of installation. Fiberglass is not subject to corrosion.

Untensioned-Rods: Stainless steel or fiberglass rods are available. Stainless steel rods are shipped in ten-foot lengths and are threaded together during installation. Steel rods may offer better performance under compression, but can be difficult to install in confined areas, such as small diameter tunnels. Fiberglass rods are shipped in continuous lengths and require little clearance for installation.

Anchors

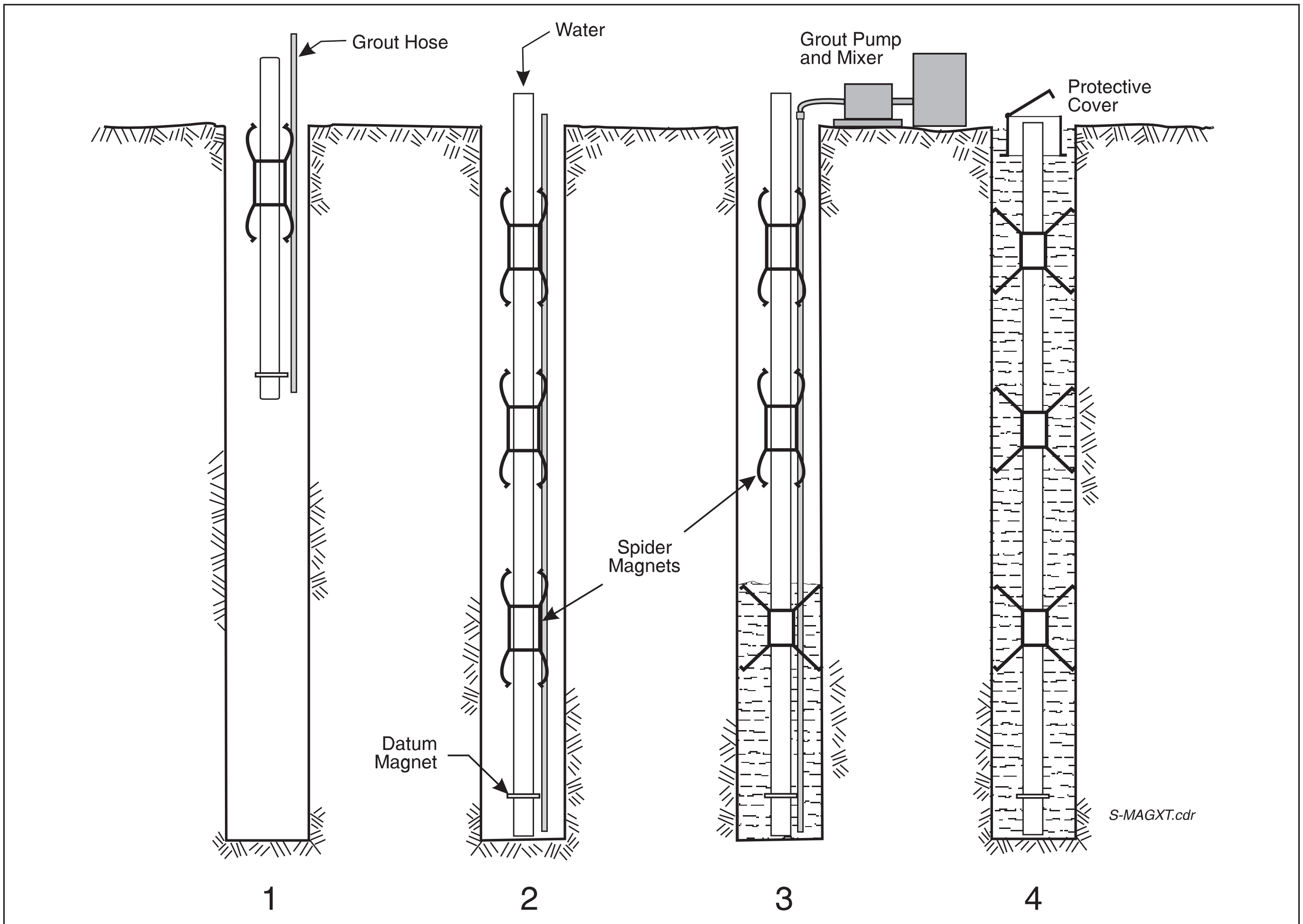
Groutable Anchors: Easy to install, prevents migration of water through borehole, suitable for long term monitoring. Requires grouting equipment. Strength of grout must be similar to surrounding ground. If grout is too stiff, anchor system may fail at grout/ground interface. Also, grout should allow anchor to move with surrounding ground. Sometimes styrofoam spacers are placed up and down-hole of anchor to ensure free movement. Cannot be used if ground has too many fissures or openings.

Hydraulic Anchors: *Bladder type* is useful for a wide range of rock type and can also be used in concrete. When the bladder, a coiled copper flat jack, is activated, it uncoils to press against borehole wall. The *prong type* is useful in soils. When activated, prongs extended outward into the ground. The single-acting anchor has three prongs; the double-acting anchor has six prongs and is better suited to deep holes or critical applications. Both bladder and prong type anchors can be grouted to block flow of water through borehole.

Hydraulic anchors are more expensive than groutable anchors. There is no waiting time as for groutable anchors, so the extensometer can be completed as soon as the anchor is activated. Hydraulic anchors may be preferred in up-holes or when grouting is not feasible, such as in highly fractured rock.

Mechanical Anchors: Used with short rods in good rock. Expansion shells are activated mechanically by turning anchor bolt. Rods, but not shells, can be retrieved for reuse. The mechanical anchor system is not compatible with grouting, since rods are not encased in protective sleeves.

Magnetic Extensometers



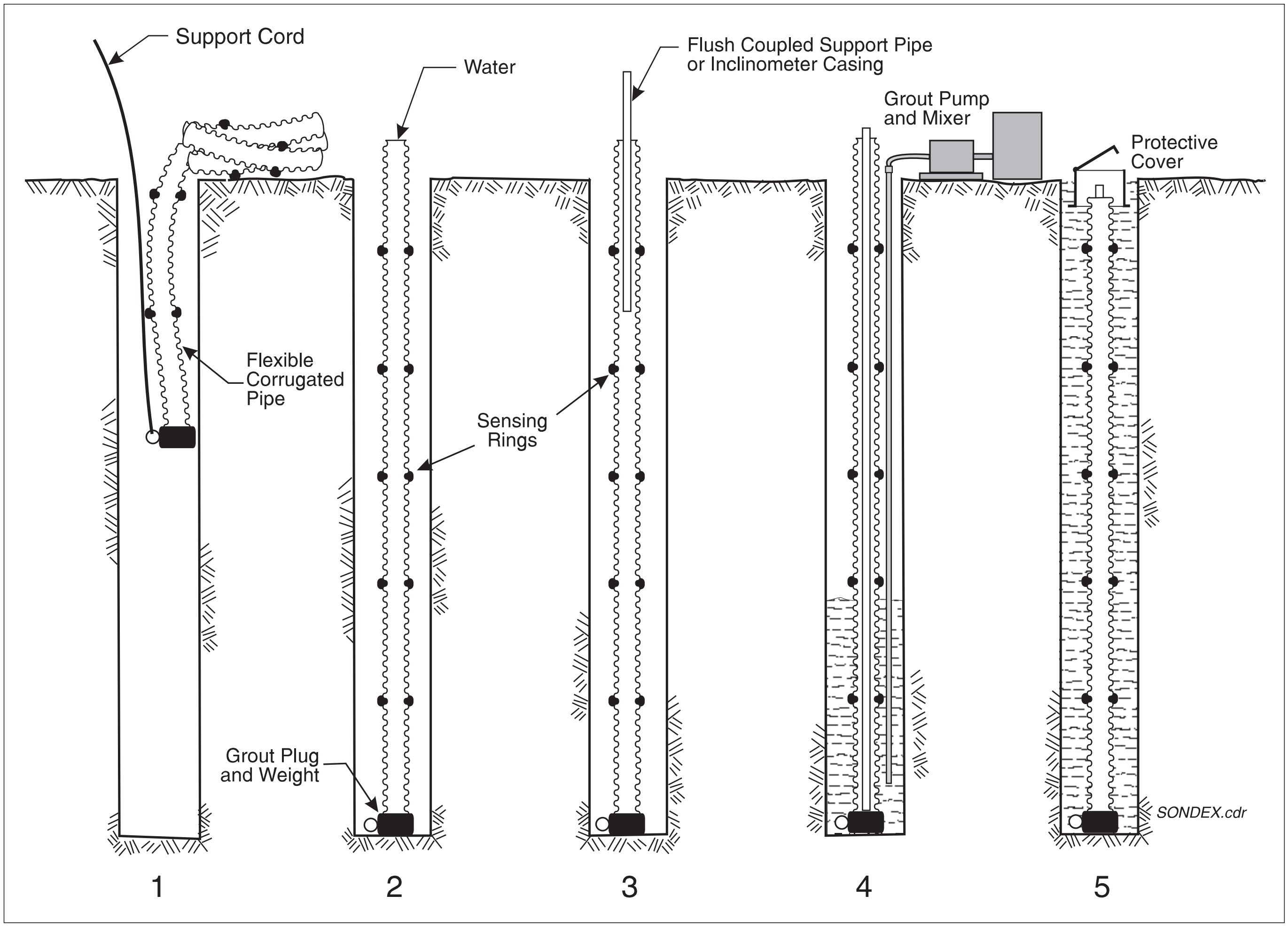
1 Flush debris from borehole. Fix datum magnet to bottom section of access pipe. Number other sections of pipe for installation. Fix spider magnets to each section. Label release cords, coil, and tape to pipe.

2 Attach grout hose to bottom section of pipe. Lower pipe into borehole. Add next section of pipe. Seal pipe joint. Carefully remove safety ties from magnet legs, then push pipe into borehole. Arrange release cord so legs are not released accidentally. Add additional sections of pipe as required. Check magnet depths.

3 Begin grouting. Release magnet legs as level of grout rises. If drill casing used, pull casing before releasing legs. Continue until all spider magnets are released and borehole is filled with grout.

4 Terminate as specified. Obtain good initial readings, then hand over to client.

Sondex



1. Attach rings to correct locations on corrugated pipe. Cast grout plug and weight into end of corrugated pipe. Attach eye bolt to serve as pulley for support-cord. Flush debris from borehole. Holding support cord, lower plugged end of corrugated pipe to bottom of borehole. It may be necessary to fill pipe with water.

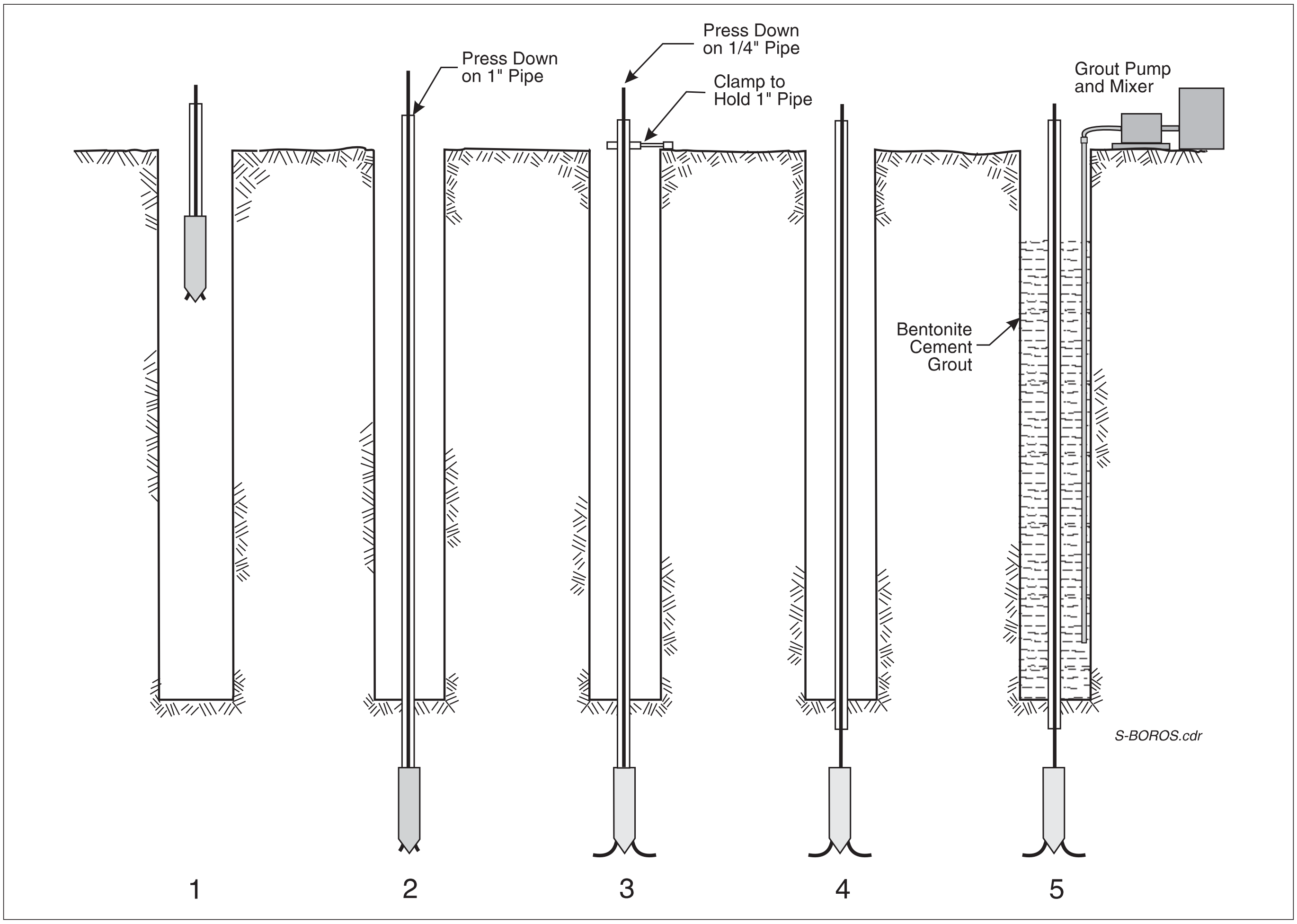
2. Secure top of corrugated pipe and fill with water. Retrieve support cord.

3. Assemble and insert access pipe or inclinometer casing inside corrugated pipe. Do not allow debris to enter between access pipe and corrugated pipe.

4. Check that corrugated pipe is secured at top of borehole. Backfill borehole. Do not allow grout to enter corrugated pipe.

5. Terminate installation as specified. Obtain datum readings, then hand over to client.

Heave-Settlement Points



1 Drill borehole to a depth slightly shallower than intended depth of anchor. Flush debris from borehole. Thread inner pipe to anchor. Grease threads of outer pipe. Then slip outer pipe over inner pipe and thread onto anchor. Bottom of pipe has left-hand thread. Do not over-tighten outer pipe since it must be detached from anchor later.

2 Lower anchor and pipe into borehole, adding additional sections of pipe of both sizes as necessary. When anchor reaches bottom of borehole, push or drive outer pipe until anchor is at specified depth.

3 Clamp outer pipe at top of borehole to hold anchor in place. Then use drill rig to push inner pipe down about 180 mm. This extends anchor prongs. Prevent rocks and other debris from entering space between inner and outer pipe.

4 Detach outer pipe from anchor with about 15 clockwise turns. Pull pipe upwards, away from anchor, until distance between bottom of pipe and anchor is slightly greater than maximum expected settlement or heave.

5 Backfill as specified. Do not allow rocks or other debris to enter between inner and outer pipe. Terminate pipes as specified. If installed in fill, top of inner pipe should be optically surveyed before and after adding pipe sections. If installed in excavation, top of inner pipe should be optically surveyed before and after removing pipe sections.

Rod Extensometers

Installation procedures tend to be application specific. Here are some general concerns.

Boreholes

Most rod extensometers are designed for installation in a 75 to 83 mm (3.0 to 3.25 in) diameter drill hole. Some reference heads require enlarged borehole collars.

Boreholes should be free-draining, if possible. Holes must be clean and free of debris before installation. Use either a diamond drill or a percussive drill.

Boreholes should be parallel with the direction of expected movement, since the extensometer measures only axial movements. In a tunnel, for example, the extensometer is typically perpendicular to the tunnel wall. In a fault zone, the extensometer is placed to measure separation. In a shear zone, the extensometer is placed at a narrow angle to measure displacement.

Spacing of anchors is determined mainly by geological factors and the size and geometry of the mass being instrumented. Diamond drill cores, if available, may reveal planes of weakness along which failure may occur. The anchor spacing should be adjusted to accommodate such planes.

It is useful to have one of the anchors positioned in stable ground so that the movements of the other anchors can be measured relative to this stationary anchor. In a tunnel, for example, the deepest anchor should be at least three tunnel diameters away from the surface of the tunnel opening.

Twisting of Rods

Do not twist rods during installation. It may help to color code rods and put corresponding colored marks around the borehole collar.

Grouting

The specified grout is usually a neat cement mix with a water/cement ratio of not more than 1:1. A fluidifier may be used to facilitate pumping through the small-diameter grout tube.

Other additives are not usually required. Grout pressure must be controlled to avoid collapse of the sleeves protecting extensometer rods.

When grouting through long lengths of polyethylene tubing, wet down the walls of the tube by pumping a small quantity of water ahead of the grout. This will help minimize friction.

Grouting Down-Holes

A single grout tube is usually adequate for vertical and inclined down-holes. Tape the end of the tube to the protective sleeve a few feet from the bottom anchor, so that the tube is drawn into the borehole as the extensometer is installed. Sometimes a second, shorter grout tube is taped to a protective sleeve about half-way down the length of the extensometer. This tube can be used if difficulties arise with the longer tube. When grouting begins, pull the tube free from the protective pipe. Draw it upwards as the level of grout rises in the borehole.

Grouting Up-Holes

1. Tape a tube to the protective sleeve so that it projects beyond the deepest anchor. This will act as a vent tube. Tape a second tube so that it reaches the deepest anchor. Tape a third tube to the protective sleeve so that it ends 2 to 3 m up from the borehole collar.

2. Insert the extensometer and tubes into the borehole. Seal borehole collar with rags soaked in quick-set cement, and pump grout into borehole through the shorter grout tube to form a plug.
Allow time for the grout to set.

3. Pump grout into the borehole using the longer grout tube. Grouting is complete when grout exits the vent tube. Fold tubes and tie off with wire.

Other Considerations

The most common problems with extensometers are mechanical damage to the instrument head, dial indicator, signal cable, or signal connectors, and moisture or dirt in the signal cable connectors or dial indicator. In wet installations subjected to freezing temperatures, ice accumulations in or near the instrument head may interfere with instrument operation. To protect the reference head, install a cover or recess the head at installation.

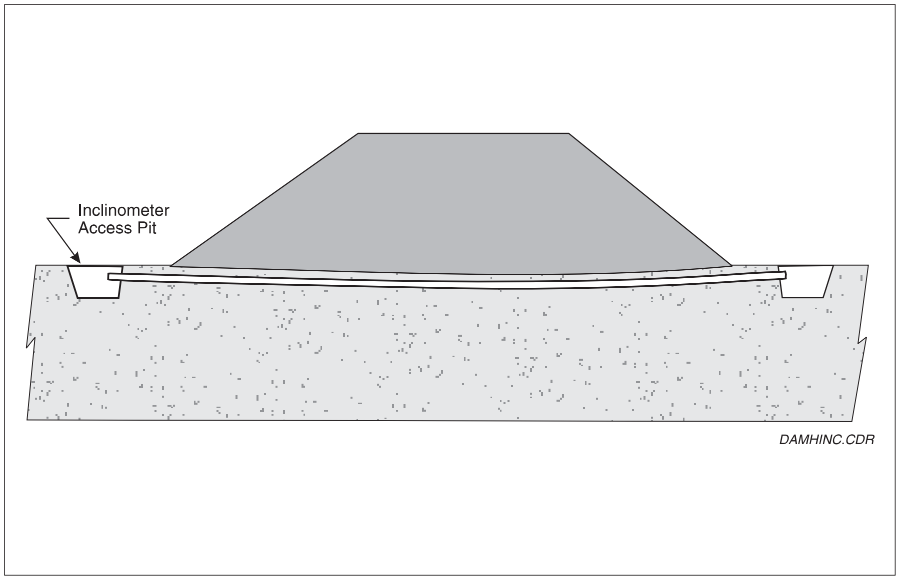
7

Horizontal Inclinometers

Notes

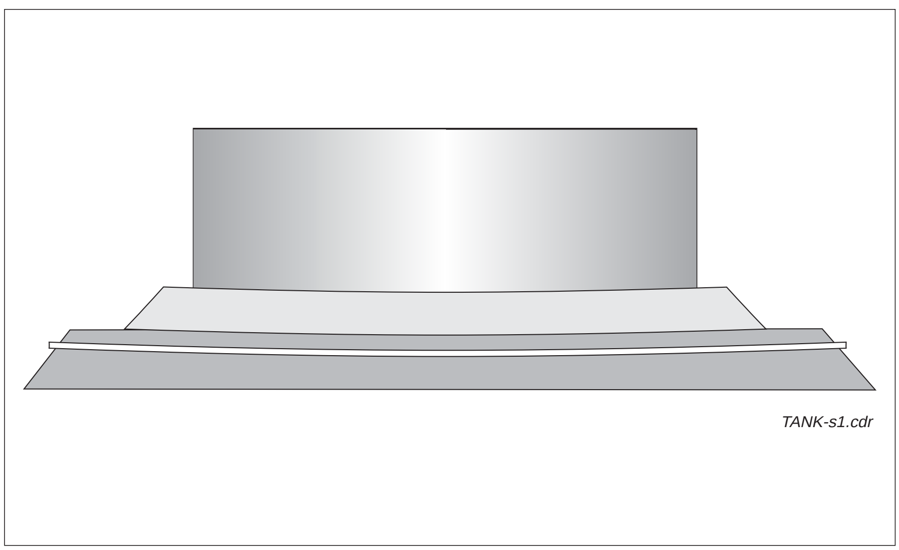
Horizontal inclinometers provide settlement profiles of embankments, foundations and other structures.

Embankment



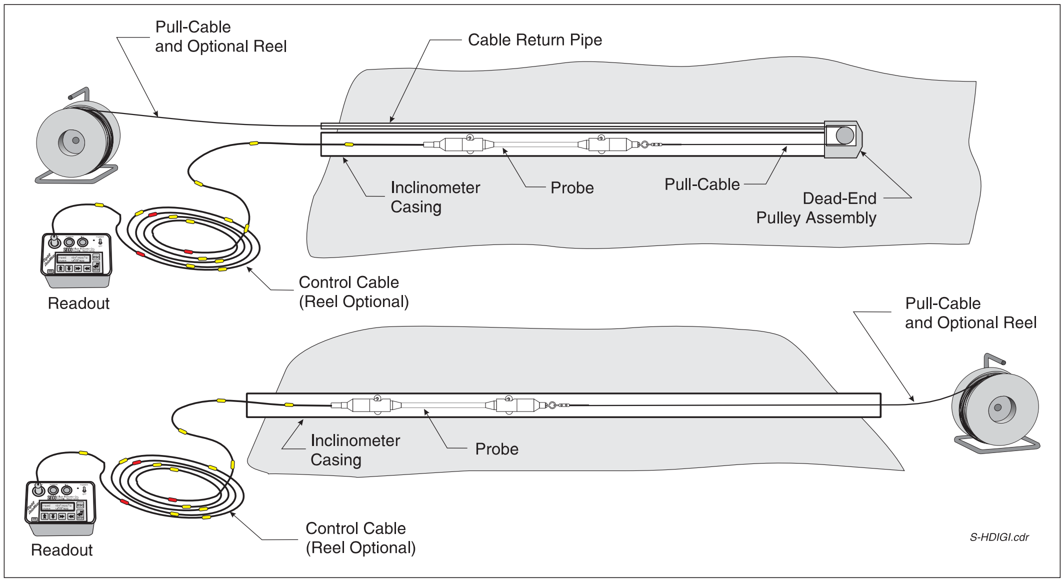
- Horizontal inclinometers provide a settlement profile of the embankment.

Storage Tank



- Settlement can over-stress the base of the storage tank, causing leaks or rupture. A horizontal inclinometer can provide a settlement profile of the foundation, an indirect indication of how much the base of the tank has deflected.
- Settlement is controlled by stage-filling the tank and monitoring foundation profile.

Horizontal Inclinometer



Slope Indicator's horizontal inclinometer system consists of inclinometer casing, a horizontal inclinometer probe, control cable, a stainless steel pull-cable, and a readout device. The casing is buried in a trench or attached to a structure. When the casing is accessible only at one end, a dead-end pulley and return pipe is installed for the pull-cable.

The inclinometer probe, control cable, and readout unit are used to survey the casing. The first survey establishes the initial profile of the casing. Subsequent surveys reveal changes in the profile if ground movement occurs.

During the survey, the probe is drawn through the casing and halted at one-meter intervals for inclination (tilt) measurements. Displacement, the distance the casing has been moved by settlement, is calculated as $L(\text{sine } \theta_1 - \text{sine } \theta_0)$, where L is the gauge length of the sensor, θ_1 is the current tilt and θ_0 is the initial tilt. Data processing is similar to that of vertical inclinometers.

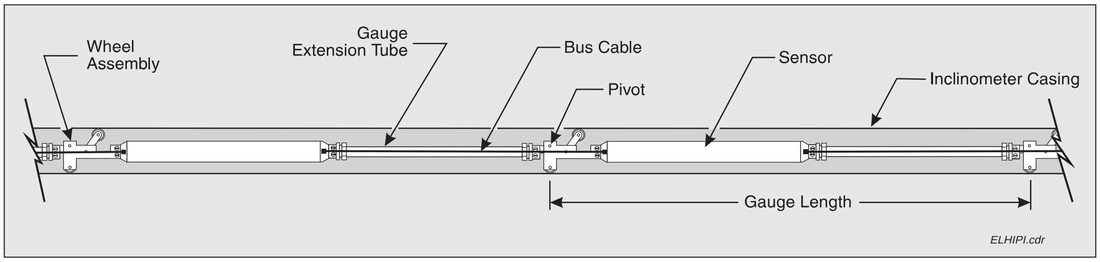
Advantages

- Provides continuous settlement profile.
- Does not interfere with site operations.

Limitations

- Expensive.
- Slow, labor-intensive readings.
- Practical limit of 150 to 200 meter casing.
- Optical survey required for absolute measurements.

EL In-Place Inclinometer



The in-place inclinometer system consists of a string of inclinometer sensors permanently deployed in inclinometer casing. The electrolytic sensors are similar to those used in EL beam sensors. No on-site operator is required, since the sensors are not moved. The system is ideal for data logging and real-time, remote monitoring for critical applications such as construction control.

The string of inclinometer sensors is positioned inside the casing to span the zone where movement is anticipated. The casing deforms with the adjacent ground or structure, causing a change in the tilt of the sensors inside.

In most applications, in-place inclinometer sensors are connected to a data acquisition system that continuously monitors movements and can trigger an alarm when it detects a change or rate of change that exceeds a preset value.

Advantages

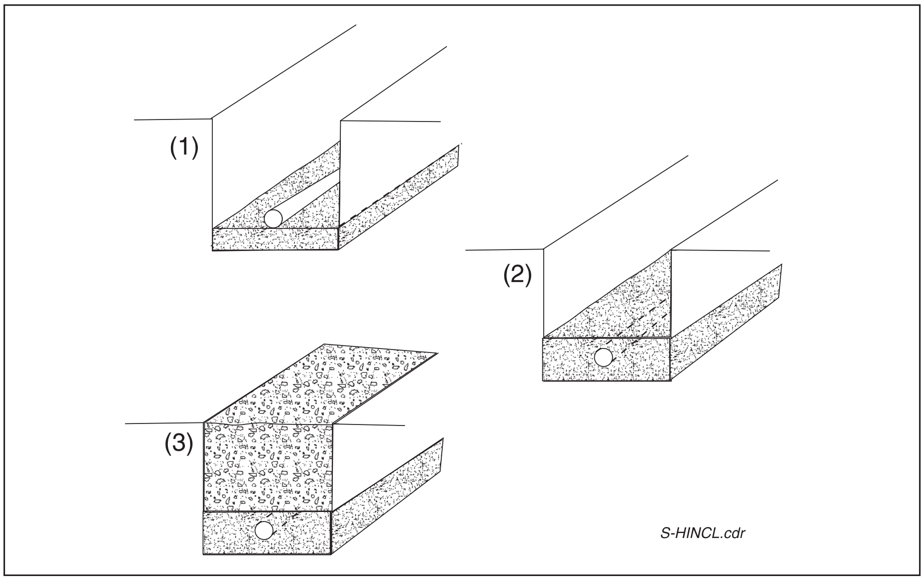
- High resolution.
- Easy to automate.
- Easy to install.

Limitations

- Expensive.

Installation

Horizontal Inclinometers



1. Excavate trench with small gradient (0.5%) for drainage. Bottom of trench should be flat. Place and compact 100 mm layer of sand in trench. Lay assembled casing in trench. Orient casing so one set of grooves is vertical.

2. Cover casing with 100 mm of sand. Compact evenly.

3. Backfill remainder of trench with select fill. Compact evenly. Obtain datum readings, then hand over to client.

EL Horizontal In-Place Inclinometers

Inclinometer casing is installed in a horizontal borehole, buried in a trench, or attached to a structure.

1. Install casing as above.

2. Position the string of EL sensors inside the casing. Sensors are connected by a signal cable.

3. Connect readout and obtain a datum reading.

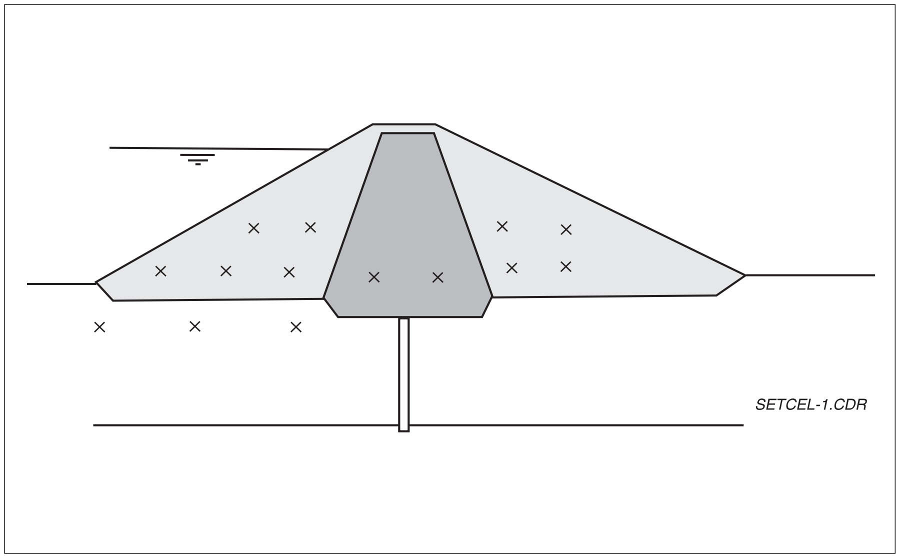
8

Settlement Cells

Notes

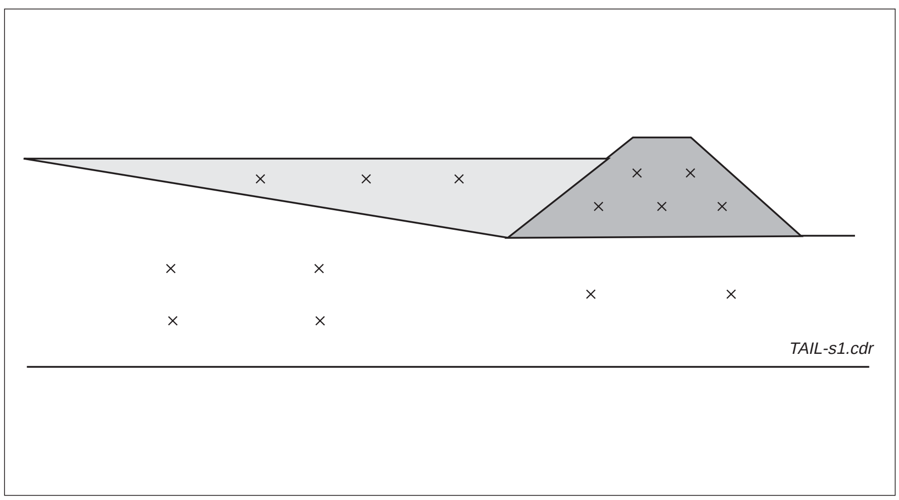
Pneumatic settlement cells provide a single-point measurement of settlement. They can be read from a central location and are particularly useful where access is difficult.

Earthfill Dams



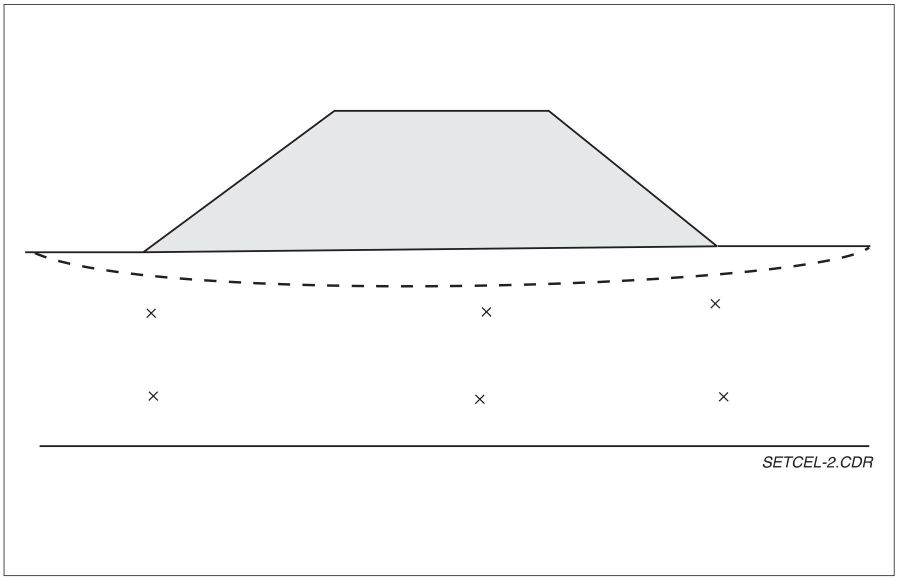
- ❑ Monitor consolidation in the foundation during construction.
- ❑ Monitor long-term settlement in the foundation and fill.

Tailings Dam



- ❑ Monitor consolidation in the foundation during construction.
- ❑ Monitor long-term settlement in the foundation and fill.

Embankments



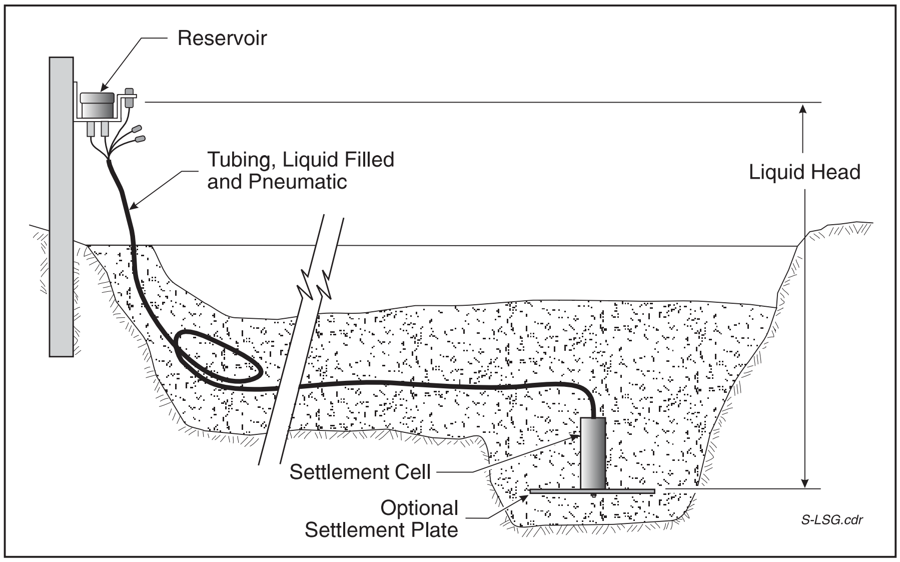
- ❑ Monitor consolidation and long term settlement in the foundation.

Settlement Cell

Slope Indicator's settlement cells have three main components: a pressure transducer, a liquid-filled tube, and a reservoir. Settlement cells are available in pneumatic and VS versions.

The pressure transducer, with liquid-filled tube attached, is embedded in fill. The other end of the tube is terminated at the reservoir. The reservoir should be located at a higher elevation on stable ground. The tube acts as a column of liquid, and the transducer at the bottom of the tube measures the pressure created by the height of the column.

The transducer settles with the surrounding soil, effectively increasing the height of the column of liquid and the pressure on the transducer. Settlement is calculated by finding the change in pressure and converting it to feet or meters of liquid head.



Advantages

- Readout station is remote from work area and does not interfere with construction activity.

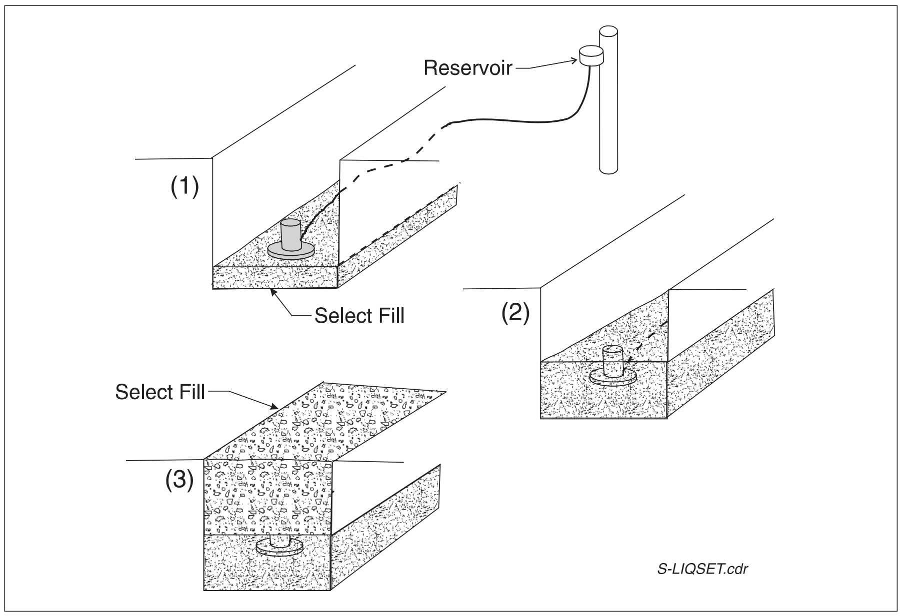
Limitations

- Pneumatic type: Slow readout with long lengths of tubing (30 minutes for 500 m of tubing). Difficult to automate.
- Fluid must be added to reservoir regularly.
- Trenching required to route liquid-filled tubes to readout station.
- Affected by temperature changes since density of the liquid increases in colder temperatures. Cannot be allowed to freeze (but US type uses 50/50 water - ethylene glycol mix).
- Precision leveling survey required if reservoir is not located on stable ground.
- Optional back-pressure unit may be required for best results.

Installation

General Concerns

- Specifications sometimes require that tubing be snaked in trenches to accommodate settlement. There is some question whether this practice is necessary, however. This view holds that normal forces acting on snaked tubing prevent it from slipping and therefore snaking does nothing to accommodate settlement.
- Use only deaired liquid in tubing. Keep the reservoir full to the base of the overflow tube to keep air out of the system.
- The reservoir should be on stable ground. If it is not, it will need to be surveyed before every reading is taken.
- Minimize unburied tubing to keep temperature constant.



1 Excavate trench from intended location of transducer to reading station (on stable ground). Place 100 mm layer of fine sand on bottom of trench. Place pneumatic settlement cell in vertical orientation.

2 Backfill with wet sand. Connect settlement cell to reservoir and test.

3 Cover tubing with 100 mm layer of fine sand. Fill remainder of trench with selected fill. Obtain datum readings, then hand over to client.

9

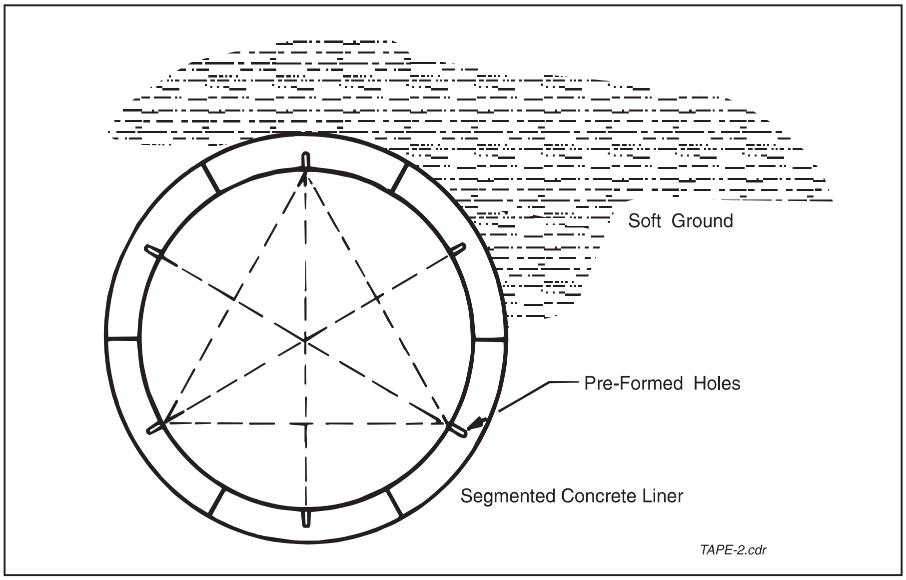
Surface Extensometers

Notes

Surface Extensometers

The **Tape Extensometer** is used to determine changes in the distance between reference points anchored in walls or structures of an excavation. Typical applications include:

- Monitoring convergence of tunnel walls.
- Monitoring deformations in underground openings.
- Monitoring displacement of retaining structures, deep excavations, bridge supports, and other concrete or steel structures.



The **3-Dimensional Crackmeter** measures displacement in 3 axes of surface cracks and expansion joints.

Instruments

Tape Extensometers

The Tape Extensometer consists of stainless steel reference points, a steel tape, and a portable measuring instrument. The reference points are permanently installed at measurement stations along the tunnel or structure.

To obtain a reading, the operator hooks the steel tape to the far reference point and walks to the near reference point, allowing the tape to unreel until the instrument body can be hooked to the near reference point. The operator then tensions the tape and notes the distance between the two reference points. This procedure is repeated for the remaining points at the measurement station.

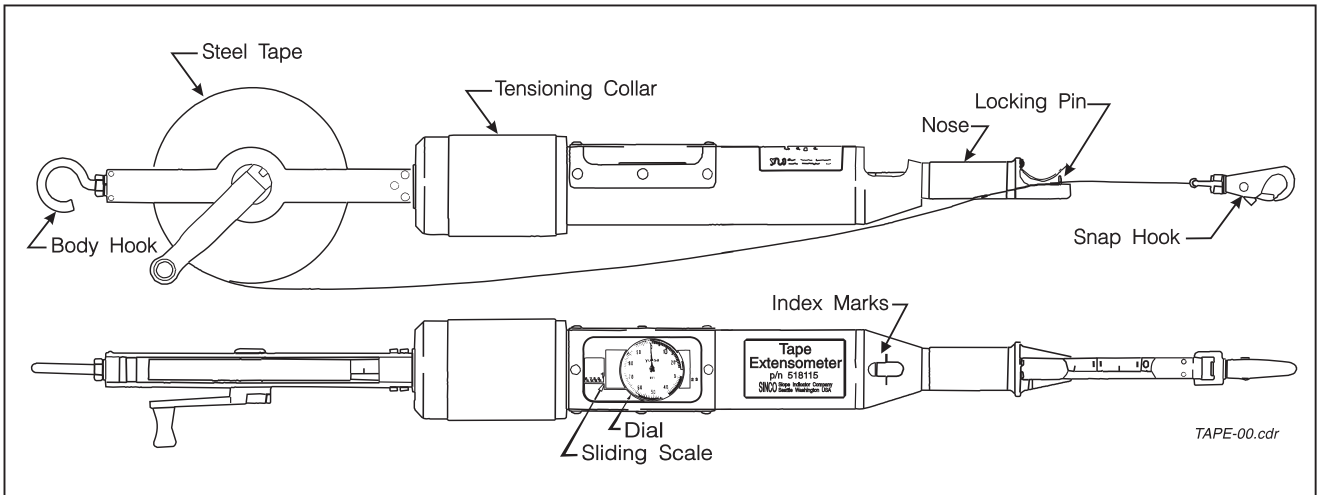
By comparing current readings to initial readings, the operator can calculate the change in distance between the two reference points and use the resulting data to plot the magnitude, direction, and rate of movement.

Advantages

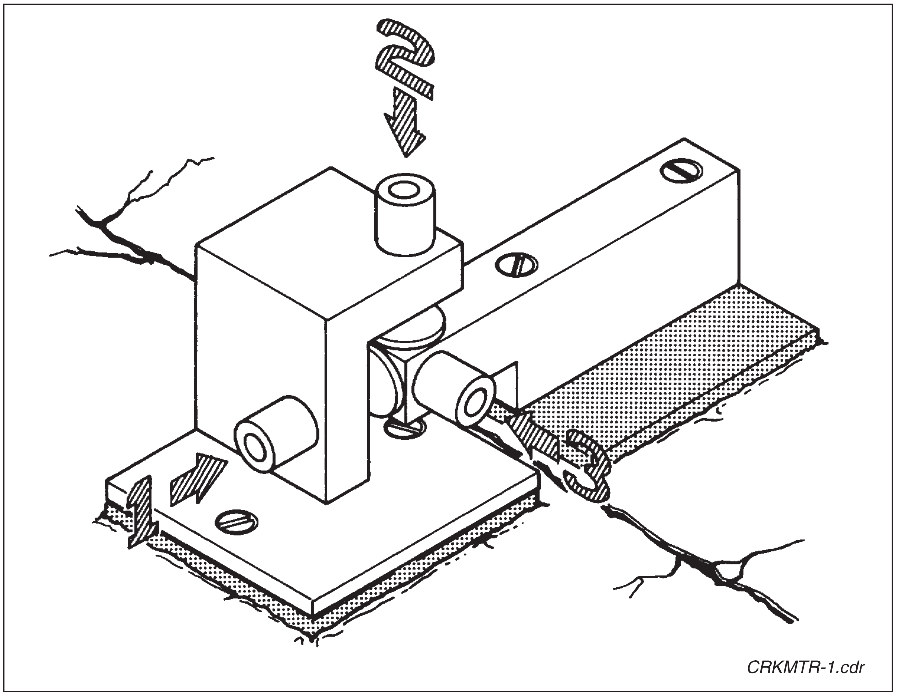
- Compact and lightweight.
- Rugged.
- Easy to use and maintain.

Limitations

- Intended for relative measurements. Should not be used as a substitute for a surveyor's chain.



3-Dimensional Crackmeter



The Crackmeter consists of two half-gauge fixtures, one mounted on each side of the crack. A portable dial indicator is inserted into one of the three stainless steel sleeves of the gauge fixture until it shoulders, and its tip is in contact with the opposite stainless steel gauge surface. The dial indicator shows the relative distance between the two gauge fixtures. A change in this distance indicates movement in the joint. The other two gauge axes are read in the same manner.

Advantages

- Monitors 3 axes.
- High precision micrometer reading.
- Reusable.

Limitations

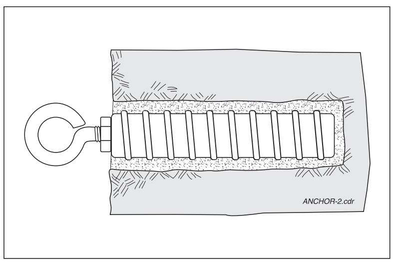
- More expensive than simpler crackmeters.
- Difficult to automate.

Tape Extensometer

Reference points consist of eyebolts that are secured directly to a structure or threaded into a groutable or expansion anchor. They should be positioned to reveal the magnitude and direction of movements. Initial alignment is not critical, because the hook and eyebolt system can accommodate almost any tape angle. It is important to protect the eyebolts once they are installed, since any change in their position or condition will affect the repeatability of measurements.

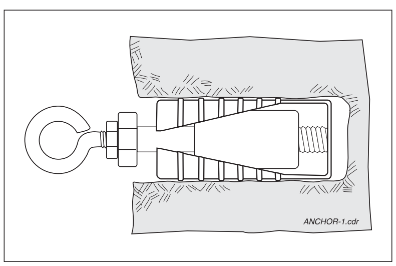
Groutable Rebar Anchors

1 Drill hole for anchor. Grout anchor in hole using non-shrinking grout. Allow time for grout to set.



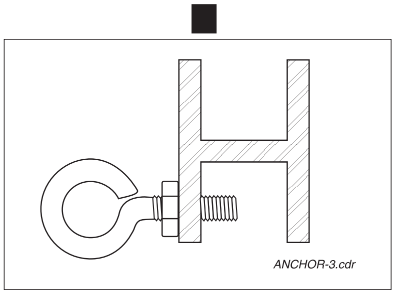
2 Thread a spare eyebolt into the anchor and pull-test to 130 newtons (30 lbf). If there is no measurable movement, remove the spare eyebolt.

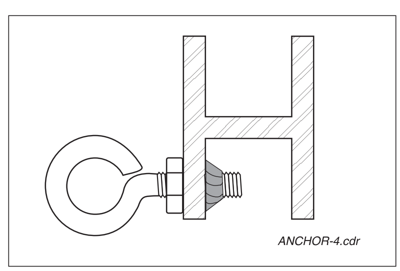
3 Thread a lock nut onto the eyebolt, and then thread the eyebolt into the anchor. Tighten the lock nut.



Expansion Anchors

1 Drill hole for anchor. Adjust anchor to fit hole, then insert until setting bolt is slightly below rock face. Tighten anchor to refusal point.



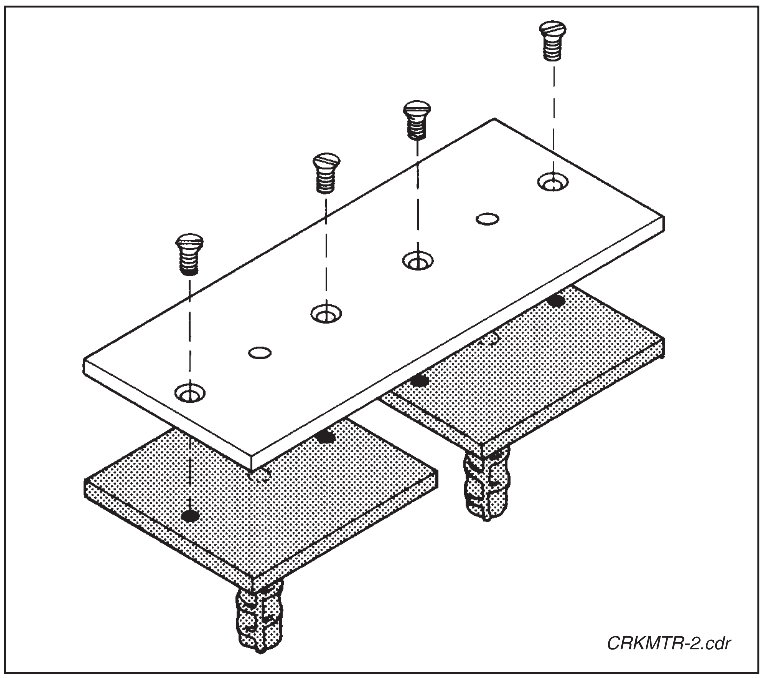


Thread a spare eyebolt into the anchor and pull-test to 130 newtons (30 lbf). If there is no measurable movement, remove the spare eyebolt.

3. Thread a lock nut onto the eyebolt, and then thread the eyebolt into the anchor. Tighten the lock nut.

Securing Eyebolts Directly

1. Drill and tap a hole for the eyebolt.
2. Thread a lock nut onto the eyebolt, and then thread the eyebolt into the hole. Tighten the lock nut.
3. Weld back of bolt for extra security.



Template and anchor plate assembly

3-Dimensional Crackmeter

1. Use the template to mark position for two anchor holes.
2. Drill and grout anchor holes.
3. Temporarily attach anchor plates to template to maintain anchor plate alignment. Press anchor plate rods into anchor holes. Allow grout to set.
4. Remove the template and attach the crackmeter. Crackmeter may later be removed and reinstalled on different anchor plates.

Notes

10

Strain Gauges

Notes

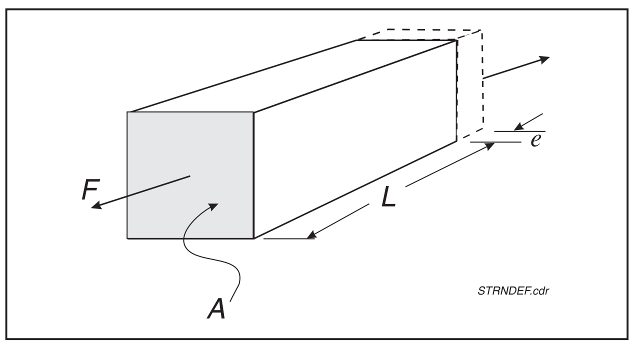
Stress & Strain Basics

Stress Stress is force divided by area. It is generally expressed in units such as N/mm^2 or psi. In symbolic form, stress σ equals force *F* divided by area *A:*

$$\sigma = \frac{F}{A}$$

The strength of a material is usually presented in terms of stress: *Ultimate stress* is determined by applying increasing loads to a sample of the material until it fails. *Yield point* is a stress level at which considerable extension or contraction of the member occurs with little or no increase in tensile or compressive stress.

The designer determines a "working stress" for the structural member by dividing the yield stress (or alternatively, the ultimate stress) by a factor of safety. Strain gauges help the engineer verify that working stress is not exceeded.



Strain Strain occurs simultaneously with stress. When a structural member is loaded, it undergoes dimensional changes. The member lengthens with tensile stress and shortens with compressive stress.

Strain is the change in the member's length divided by its original length. In symbolic form, strain ε equals change in length *e* divided by original length *L:*

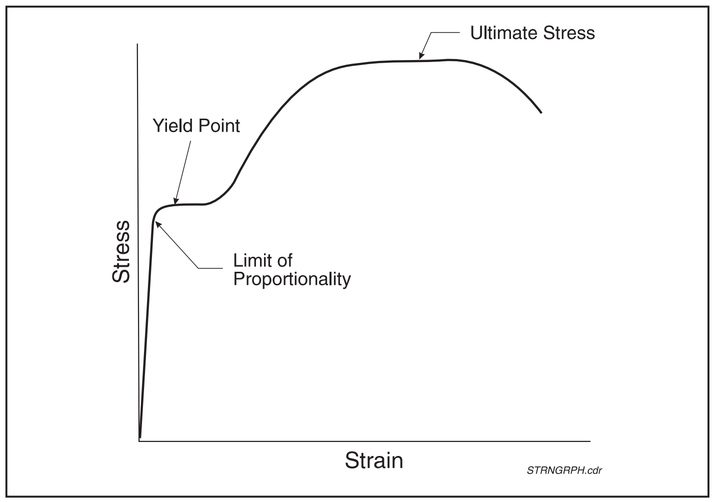
$$\varepsilon = \frac{e}{L}$$

Note that a strain gauge is calibrated to report a strain value based on the original length of the gauge.

Hooke's Law

Hooke's law describes the relation between stress and strain in an elastic body. An elastic body is one which reverts to its original size and shape when a deforming force is removed. The law states that so long as the member remains perfectly elastic, the strain produced is proportional to the stress applied.

Hooke's law holds for a certain range of stresses. Within this range, a graph of stress and strain will be a straight line. The top end of the range is the limit of proportionality. The yield point marks the limit of elasticity. The graph below is based on mild steel, but is exaggerated for purposes of explanation.



Young's Modulus

Young's modulus of elasticity appears in strength tables along with ultimate stress and yield point. Young's modulus is the ratio of stress to strain within limits of proportionality. It is a constant for each material, does not vary with the cross-sectional area of the material, and for ferrous metals, is generally the same for tensile or compressive stresses. The symbol used for Young's modulus is the letter "E."

$$E = \frac{stress}{strain} \qquad \text{or} \qquad E = \frac{F\,L}{A\,e}$$

Calculating Stress & Load

Stress σ is equal to the product of Young's modulus E and strain ε.

$$\sigma = E \times \varepsilon$$

Load F is equal to the product of Young's modulus E, strain ε, and the cross sectional area A of the member.

$$F = E \times \varepsilon \times A$$

Strain Gauge Applications

Steel

Weldable strain gauges measure strain in steel. Typical applications include:

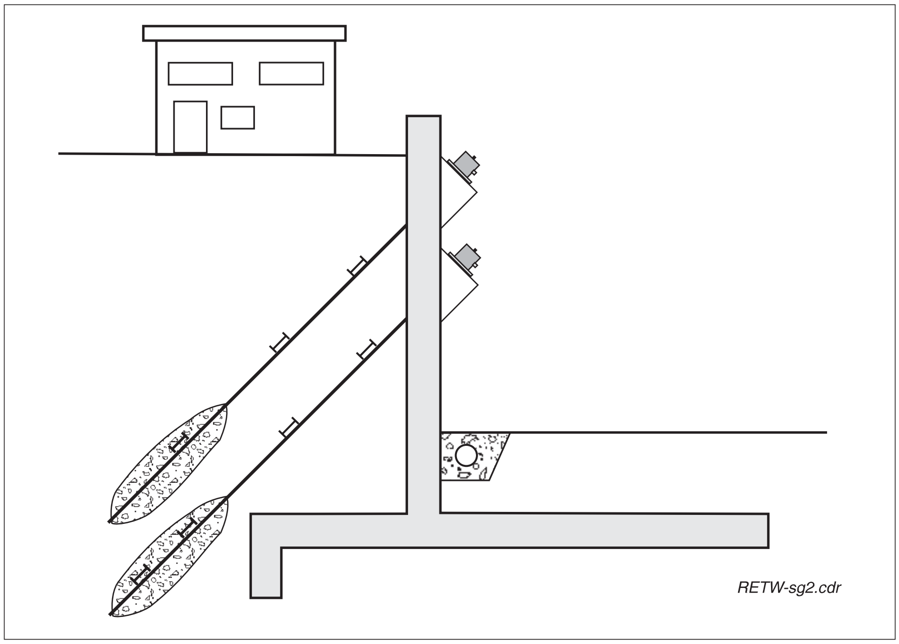
- Monitoring stresses in structural members of buildings, bridges, tunnel linings and supports during and after construction.
- Monitoring the performance of in wall anchors and other post-tensioned support systems.
- Monitoring loads in strutting systems for deep excavations.
- Measuring strain in tunnel linings and supports.
- Monitoring areas of concentrated stress in pipelines.
- Monitoring distribution of load in pile tests.

Concrete

Embedment strain gauges and concrete surface strain gauges measure strain in concrete. Typical applications include:

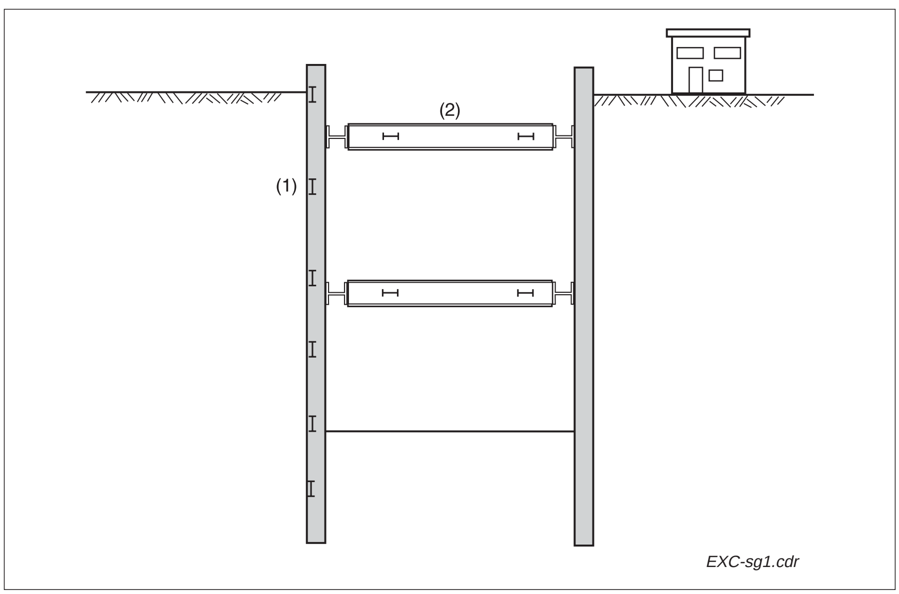
- Measuring strains in reinforced concrete and mass concrete.
- Measuring curing strains.
- Monitoring for changes in load.
- Measuring strain in tunnel linings and supports.

Tie-Back Anchors



- ❑ Monitor load in tie-back bar to check for loss of tension.
- ❑ With strand type anchors, use clamp-on strain gauges instead of weldable gauges.

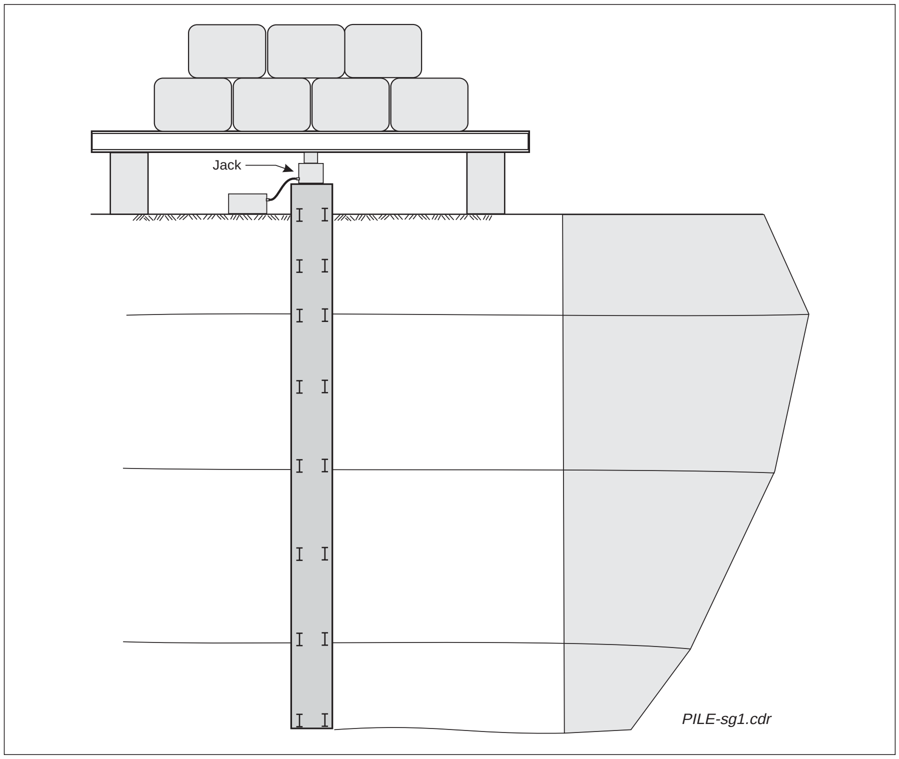
Diaphragm Wall or Sheet-Pile Wall



1 Monitor bending in sheet-pile wall.

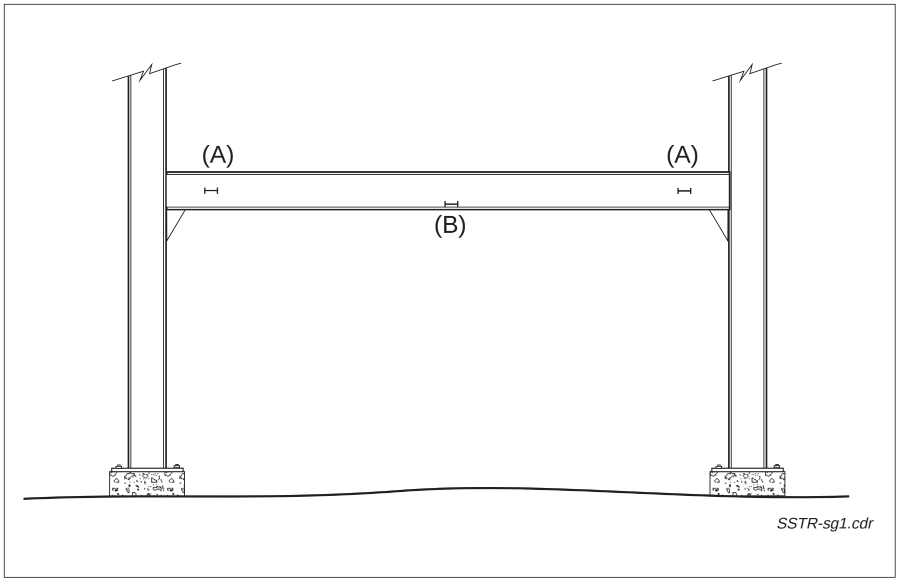
2 Calculate load on struts.

Pile Load-Test



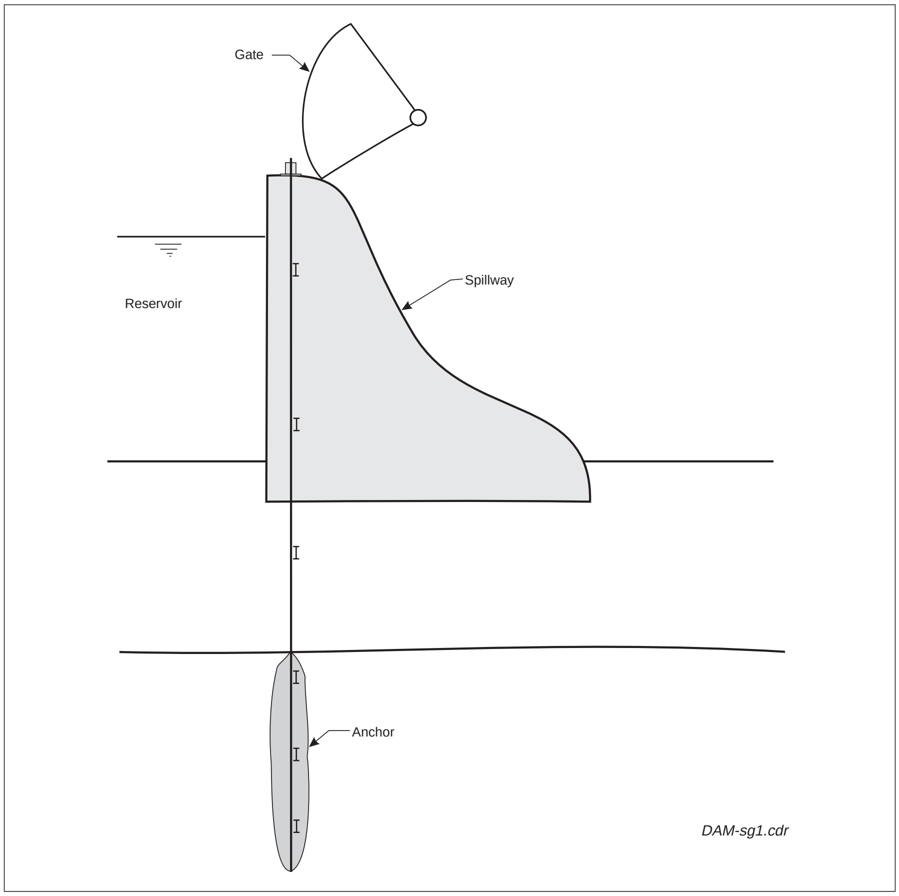
- Determine distribution of load in pile.
- Evaluate design of pile.
- Evaluate quality of materials and construction of cast-in-place pile.

Truss System



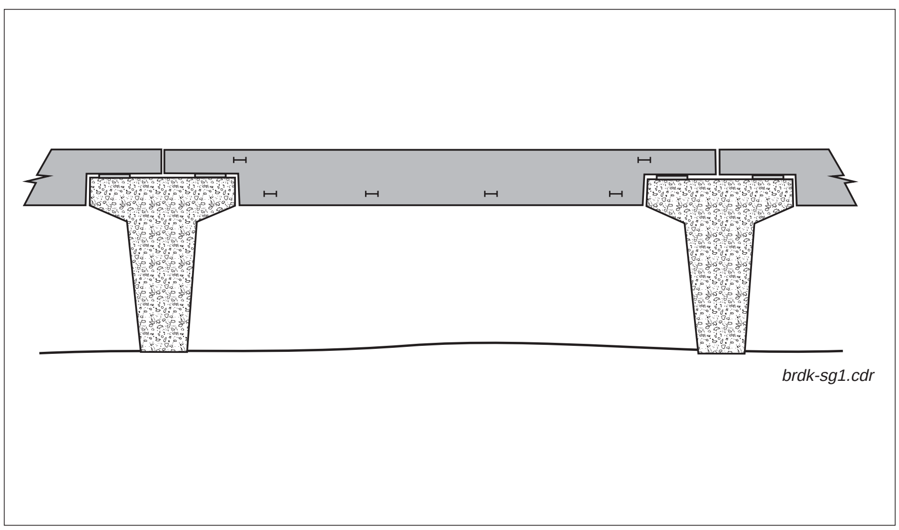
- Calculate loads on struts (A).
- Determine approximate bending stress in beam (B).

Retrofit Ground Anchor



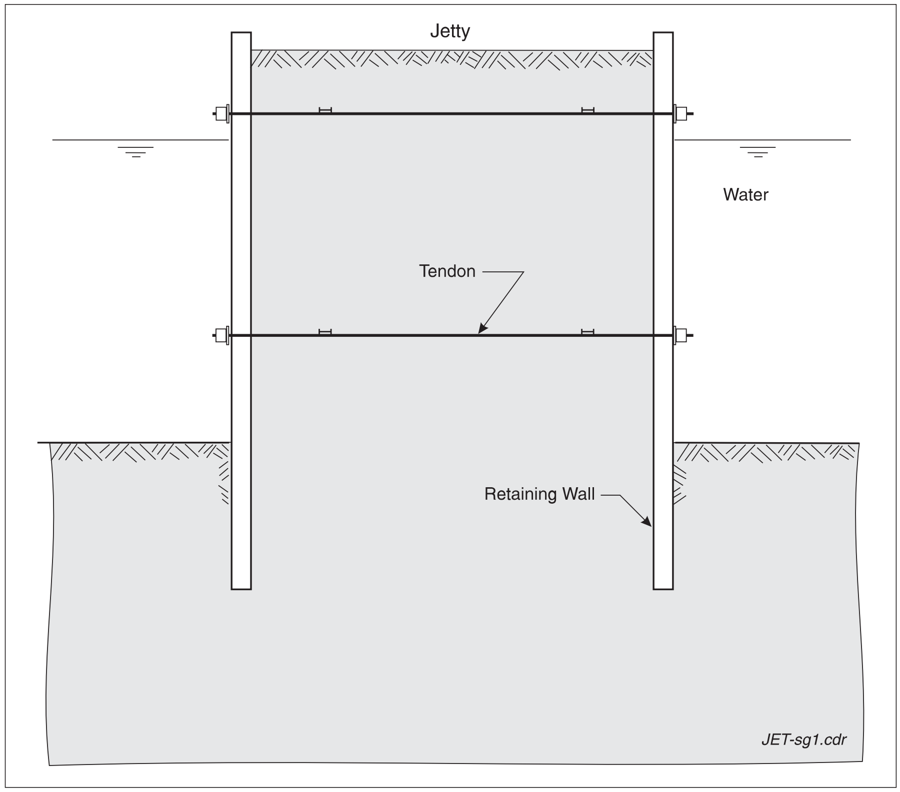
- Monitor distribution of load in restraining anchor. (Clamp-on type strain gauges)
- Verify that bond between grout and soil is holding.

Concrete Bridge Deck



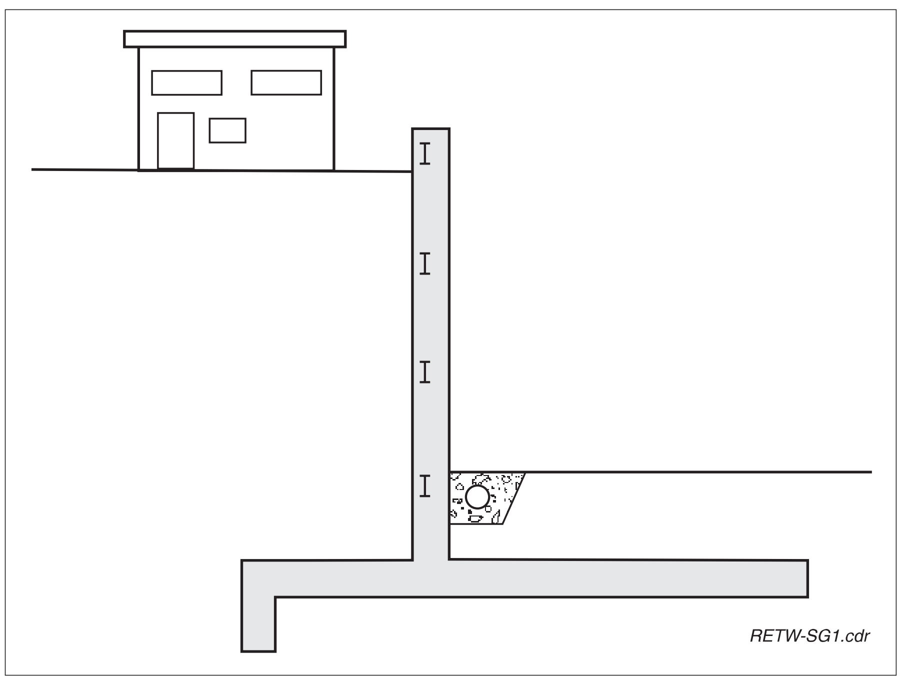
- Monitor compressive loads due to post-tensioning.
- Monitor load over time.
- Monitor in-service bending.

Sheet-Pile Jetty



- Monitor loads in tendon.

Retaining Wall



- Calculate distribution of load.
- Check for bending (but not magnitude of bending).

Weldable Strain Gauges

Weldable strain gauges are installed on steel structural members. Slope Indicator manufactures a spot-weldable strain gauge and an arc-weldable strain gauge.

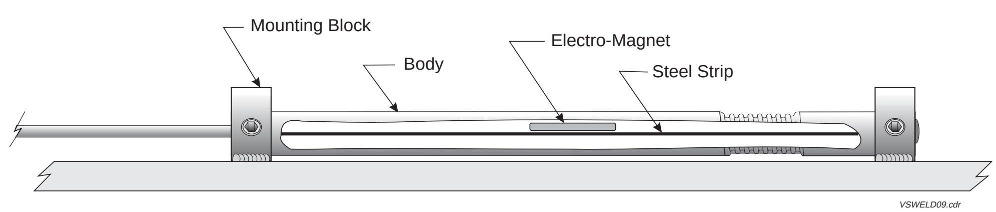
Operating Principle

The arc-weldable strain gauge consists of steel strip and an electro-magnetic coil sealed inside a steel tube body. The strip is held in tension between the two ends of the body. The body is fixed to a structural member by weldable mounting blocks.

Strain in the structural member is transferred through the mounting blocks and the body to the steel strip inside. An increase in tensile strain increases tension in the strip, and a decrease in tensile strain decreases tension in the strip.

The coil is used to “pluck” the strip, causing it to vibrate at a frequency relative to its tension. The vibration of the strip within the magnetic field of the coil induces a frequency signal which is transmitted to the readout device.

The readout device processes the frequency signal using calibration factors that relate frequency to strain in the strip, and then displays a number representing microstrain. For additional information, please refer to “Data Reduction” later in this chapter.



Weldable Strain Gauges continued

Arc-Weldable Gauge

Advantages

- Arc-welder readily available.
- Can be tensioned in the field.
- Can be removed from mounting blocks and reused.
- Gauge cannot be damaged by welder.

Disadvantages

- More costly than spot-weldable gauge.
- Higher profile than spot-weldable gauge.

Spot-Weldable Gauge

The spot-weldable gauge operates as explained above, but consists of two components: (1) the strain gauge itself, which is welded to the surface, and (2) the electromagnetic coil, which is mounted on top of the strain gauge.

Advantages

- Quickly installed.
- More economical than resistance strain gauges.
- Durable.
- Patented, low-profile design reduces error caused by bending of the structural member.

Disadvantages

- Requires spot-welder.
- Pickup sensor must be protected during installation.
- Installed gauges can be over-stressed by careless handling of member.
- Gauge attrition likely if installed on driven piles.

Concrete Strain Gauges

Embedment Strain Gauge

Embedment strain gauges are embedded in concrete. The body of the VS embedment strain gauge is a steel tube with flanges at either end. Inside the body is a steel strip and a magnetic coil. The strip is held in tension between the flanges, and the coil magnetically "plucks" the steel strip, which then vibrates at its natural frequency.

Strain in the concrete is transferred through the flanges to the body and the steel strip, causing a change in the tension of the strip. When the strip is plucked and set into vibration in the proximity of the magnetic coil, it generates a frequency signal that is transmitted to the readout device. The readout device processes the signal and displays a reading.

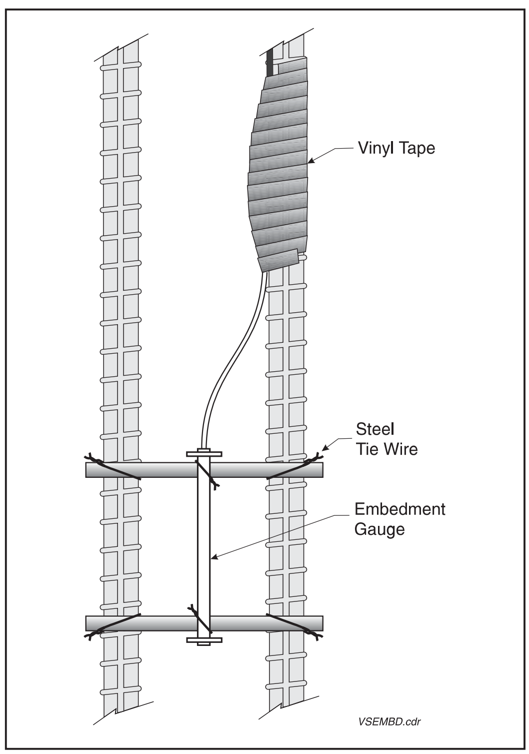
The relationship between strain in the concrete and the frequency signal returned to the readout device is established by a second order polynomial expression.

Advantages

- Special low-modulus gauge available for monitoring curing strains.

Limitations

- In concrete, strain is caused not only by stress and temperature change, but also by creep, shrinkage, swelling, and autogenous volume change. The strain gauge will measure all of these strains.



Concrete Strain Gauges continued

Concrete Surface Strain Gauge

The body of the strain gauge is a sealed steel tube with weldable groutable mounting-blocks at both ends. Inside the body is a magnetic coil and a steel strip or wire, which is held in tension between the ends of the body. When the steel strip is magnetically "plucked" by the coil, it vibrates at its natural frequency.

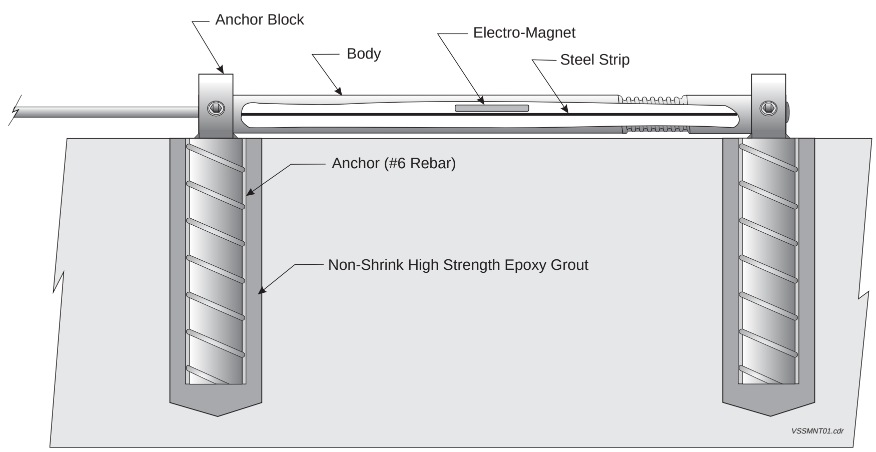
Strain in the concrete is transferred through the groutable mounting-blocks to the body and the steel strip, causing a change in the tension of the strip. When the strip is plucked and set into vibration in the proximity of the magnetic coil, a frequency signal is induced in the coil and transmitted to the readout device. The readout device processes the signal and displays a reading.

Advantages

- Can be fitted to existing structures.
- Can be tensioned in the field.
- Can be removed from mounting blocks and reused.

Limitations

- In concrete, strain is caused not only by stress and temperature change, but also by creep, shrinkage, swelling, and autogenous volume change. The strain gauge will measure all of these strains.



Data Reduction

Calculating $\Delta\mu\varepsilon$

The number displayed by the readout represents microstrain, but not necessarily the total strain in the structural member. There are two reasons for this. First, there is already strain in the strip because it has to be tensioned in order to operate. This strain is treated as an "offset" and is eliminated by the $\Delta\mu\varepsilon$ calculation. Second, there may be strain in the member before the strain gauge is installed.

If you need to obtain a reading for total strain, you must obtain a datum reading before the member is loaded. The datum is then subtracted from any subsequent strain reading to find the total strain in the member.

$$\Delta\mu\varepsilon = \mu\varepsilon_{current} - \mu\varepsilon_{datum}$$

If you wish to measure a change in strain due to a new load, take the datum reading before the new load is added. The datum reading will then include the strain due to the original load, and $\Delta\mu\varepsilon$ will represent the change in strain.

Positive or Negative $\Delta\mu\varepsilon$ *?*

Due to its design, the strain gauge reports larger numbers as the structural member lengthens and smaller numbers as the structural member shortens.

If the strain gauge is set to measure extension and tensile load increases, successive strain readings will be larger and the $\Delta\mu\varepsilon$ value will be positive.

If the strain gauge is set to measure compression and the compressive load increases, successive strain readings will be smaller and the $\Delta\mu\varepsilon$ value will be negative. If you wish to work with positive values for compressive strain, simply reverse the sign.

Correcting for Bending Strains

To correct strain readings for bending strains, you must have installed strain gauges on opposite sides of the neutral axis or at evenly spaced intervals on the circumference of a pipe. Calculate the corrected strain value as below:

$$\Delta\mu\varepsilon_{corrected} = \frac{\Delta\mu\varepsilon_{gauge_1} + \Delta\mu\varepsilon_{gauge_2} + \ldots + \Delta\mu\varepsilon_{gauge_n}}{n}$$

Correcting for Changes in Temperature

1. Obtain a datum reading for temperature, at the same time you obtain the initial strain reading.
2. Obtain the thermal coefficient of expansion of the structural member. Refer to the instruction manual to obtain the thermal coefficient of expansion for the strain gauge.

$$\Delta\mu\varepsilon_{corrected} = \Delta\mu\varepsilon - [\,(TC_{member} - TC_{gauge}) \times (T_{current} - T_{initial})\,]$$

Where:

$\Delta\mu\varepsilon$ = the change in strain from the datum value.

$\mathrm{TC}_{\mathrm{member}}$ = the thermal coefficient for the structural member.

$\mathrm{TC}_{\mathrm{gauge}}$ = the thermal coefficient for the strain gauge.

$\mathrm{T}_{\mathrm{current}}$ = the current temperature reading in ⊃C.

$\mathrm{T}_{\mathrm{initial}}$ = the datum reading for temperature in ⊃C.

General Concerns

Handling Strain gauges are sensitive instruments. Do not drop or bend.

Orientation Position the strain gauge so that its long axis is parallel with the axis of loading.

Bending The strain gauge should be installed along the neutral axis of the structural member when possible.

Irregularities Avoid installing strain gauges near irregularities in the member or at the ends of the member since readings from these locations may not adequately represent strain in other portions of the member.

Protect Signal Cable

- ❑ Store the cable in a place that is dry and safe from rodents and other possible sources of damage.
- ❑ Protect the cable from nicks and cuts. Do not pull on cable to free it from obstructions.
- ❑ Terminate the cable with a waterproof connector. If bare-wire termination is sufficient, protect the end of the cable from moisture.

Identify Cables

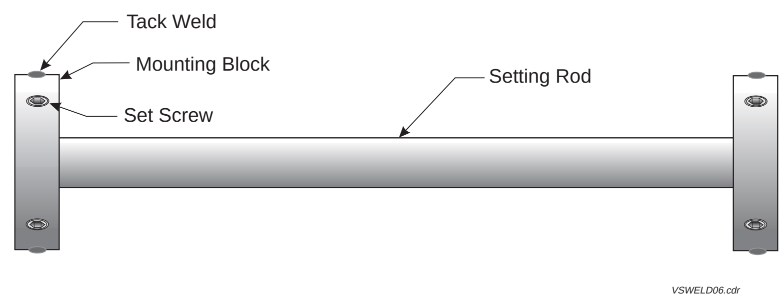
- ❑ Mark cables carefully for positive identification later. Attach identifying numbers with a durable, waterproof tape or use tape for color-coding. At a minimum, mark the end of the cable three times at one foot intervals, then mark the rest of the cable at 6 to 10 foot intervals or as specified. If the cable is cut or spliced, mark the end three times as above.
- ❑ If your identification scheme differs from the instrument identification used on engineering drawings, note the differences in site log books and on the relevant drawings. For example: “Strain Gauge 4-IA = Red and Brown.”
- ❑ Make a record of the location of each strain gauge and its associated cable.

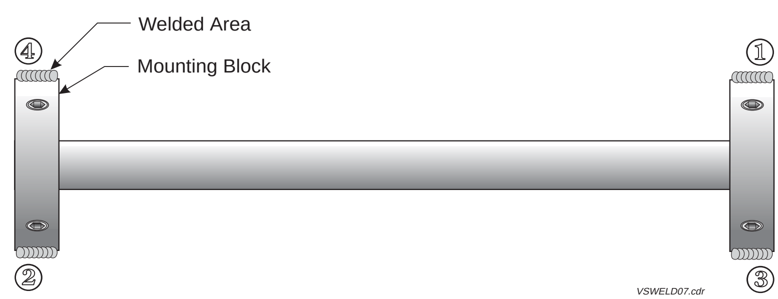
Installation of VS Arc-Weldable Strain Gauge

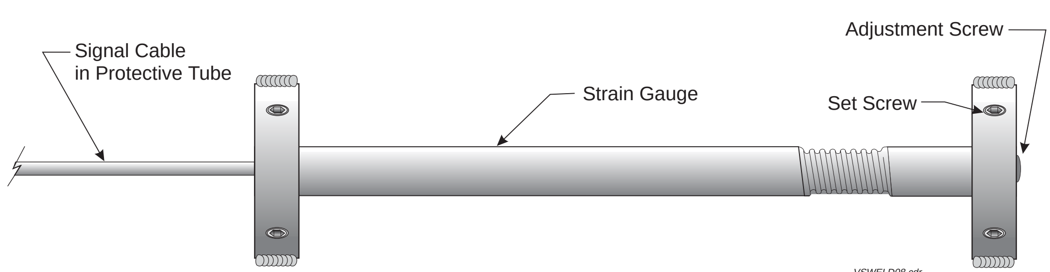
1. Prepare surface: Remove rust with sander. If necessary, create a flat surface with grinder. Check that surface is clean.
2. Secure mounting blocks to setting rod. Tack weld mounting blocks to surface. Then follow weld sequence 1-4 as shown in drawing. Allow welds to cool.
3. Remove setting rod and insert strain gauge in its place.
4. Connect sensor to indicator to obtain reading. Turn adjustment screw to set starting tension to frequency shown in table.

To accommodate:	Set to:
Maximum compressive strain	1410 Hz
Equal compressive/tensile strain	1100 Hz
Maximum tensile strain	750 Hz

5. Apply corrosion protection to strain gauge, mounting blocks, and welds.







Installation of VWP Spot-Weldable Strain Gauge

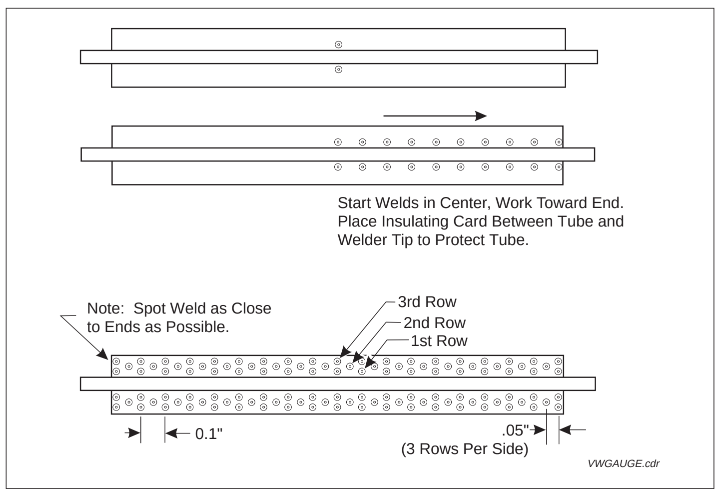
1 Prepare surface: Remove rust with sander. If necessary, create a flat surface with grinder. Check that surface is clean.

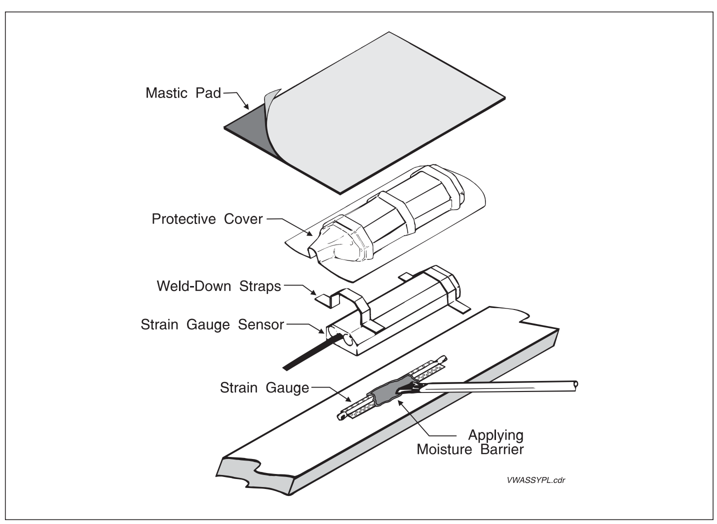
2 Weld gauge to surface, as shown in drawing. Hold insulating card between welding tip and tube to prevent welding damage.

3 Apply corrosion protection to gauge (3M Scotch Kote).

4 Mount strain gauge sensor on top of strain gauge. If the gauge is on rebar, use plastic tie-wraps to secure sensor. Then wrap mastic pad around sensor and gauge. Finally, wrap self-vulcanizing tape over the entire assembly.

If gauge is on beam, place tie-down straps over sensor and weld to beam. Do not allow contact between welder tip and sensor. Weld protective cover over installation. Fit mastic pad over protective cover and exit point of cable.





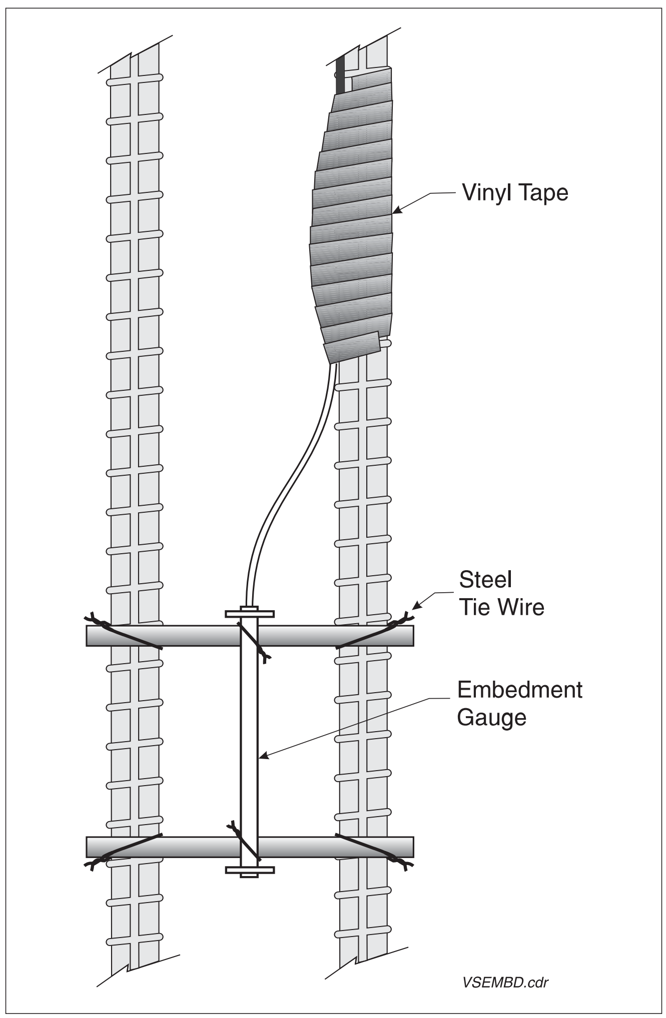
Installation of VS Embedment Strain Gauge

In reinforced or pre-stressed concrete applications, the embedment strain gauge is usually wired to the reinforcement cage. Specifications may require that the gauge be cast in a concrete briquette prior to installation.

In mass concrete applications, the gauge may be installed either before or immediately after placement of the concrete.

Gauges may be configured in a rosette either by direct placement in the soft concrete or by attachment to a rosette adaptor. The rosettes positions gauges so the stress field can be deduced from the principal strain directions.

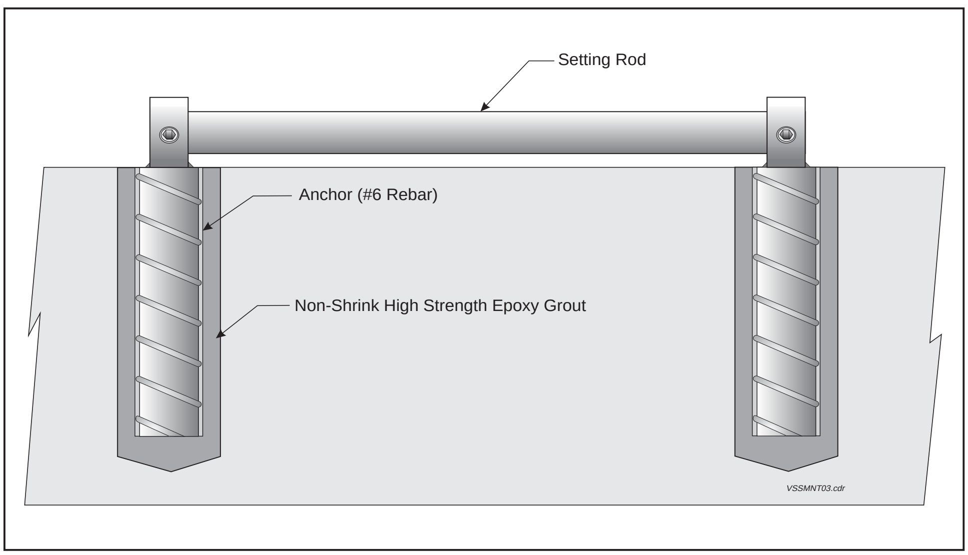
No-stress enclosures are sometimes specified so that aging effects of an un-stressed gauge can be monitored and compared with directly embedded gauges.



Installation of VS Concrete Surface Strain Gauge

1. Drill two holes into structure.
2. Secure groutable mounting blocks to setting rod.
3. Fill holes with non-shrink grout, then insert groutable mounting blocks.
4. When grout hardens, remove setting rod and insert strain gauge in its place.
5. Connect sensor to indicator to obtain reading. Turn adjustment screw to set starting tension to frequency shown in table.

To accommodate:	Set to:
Maximum compressive strain	1410 Hz
Equal compressive/tensile strain	1100 Hz
Maximum tensile strain	750 Hz



11

Load Cells

Notes

Applications

Load Cells

Load cells are used to proof-test and measure loads in tie-backs, rock bolts, ground anchors, and struts.

Proof-Testing Tie-Back Anchors

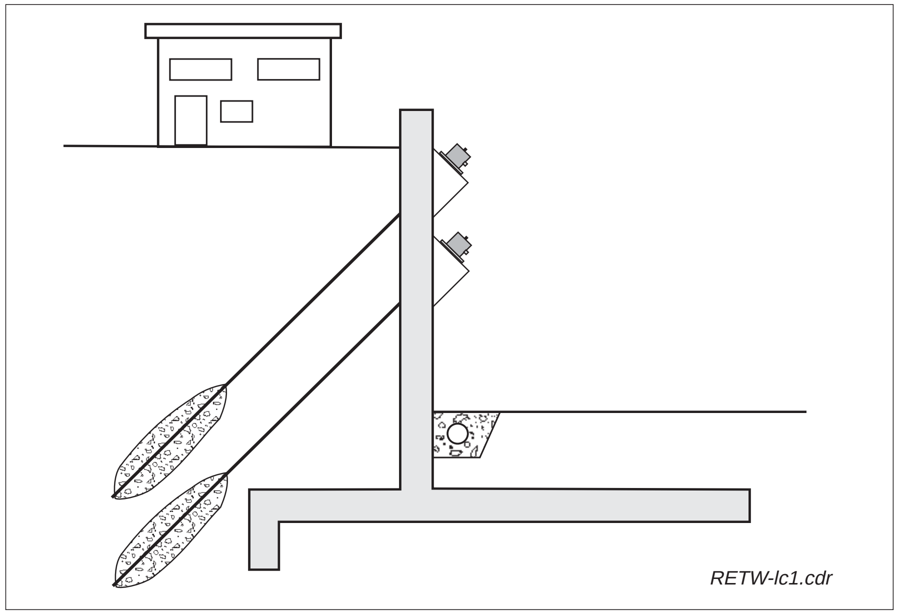
Proof-testing involves applying a load to a tie-back anchor with an in-line hydraulic jack. A load cell is placed between the retaining wall and the jack. The output of the load cell is recorded as the jack applies an increasing load. Load cell data is then correlated with strain measurements obtained with a long-stroke dial indicator.

ASTM standards suggest that a 10% pre-load be applied to the anchor before the test begins. Pre-loading activates shear resistance at the anchor, prevents sagging of the tie-back, seats the load cell on its platens, and eliminates low-load non-linearities in the output of the cell. All additional loads applied by the jack are then referenced to the 10% pre-load.

Monitoring Performance

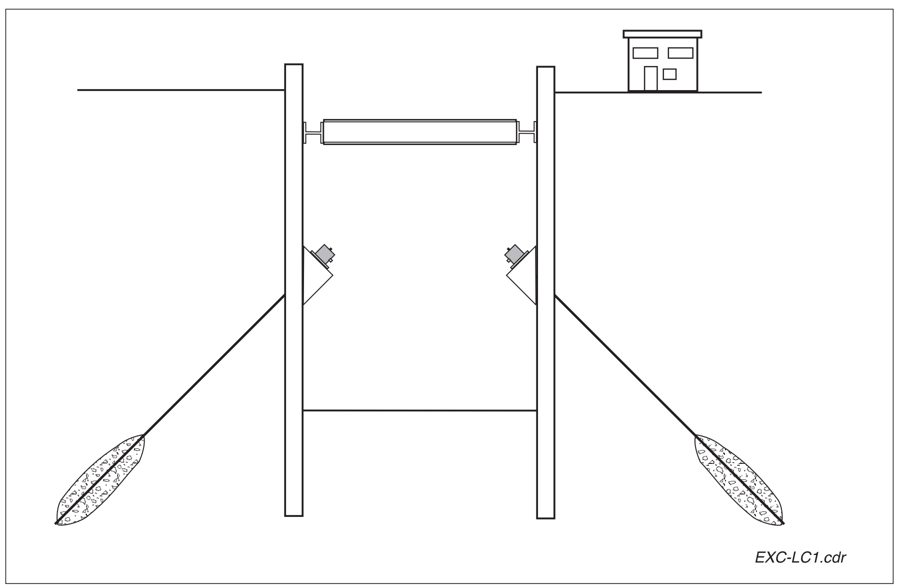
Load cells are installed with the tie-back and monitored as the tie-back is brought up to design load. The cell is monitored afterwards for changes in load on the anchor. A loss of load may indicate anchor failure or loss of material behind the wall. An increase in load may require remedial action to prevent failure of the wall. An increase in load may occur if adjacent anchors fail. It may also occur when material behind the retaining wall is loaded.

Retaining Wall



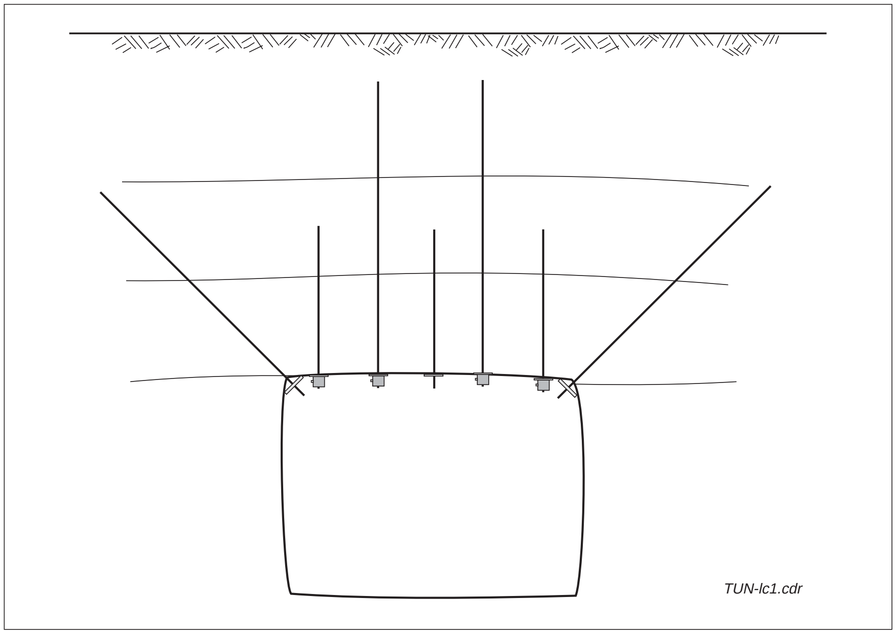
- Indicate the effectiveness of restraining systems and monitors changes in passive pressure behind the wall.
- Provide early warning of excessive load so that remedial action can be taken.

Diaphragm or Sheet Pile Wall



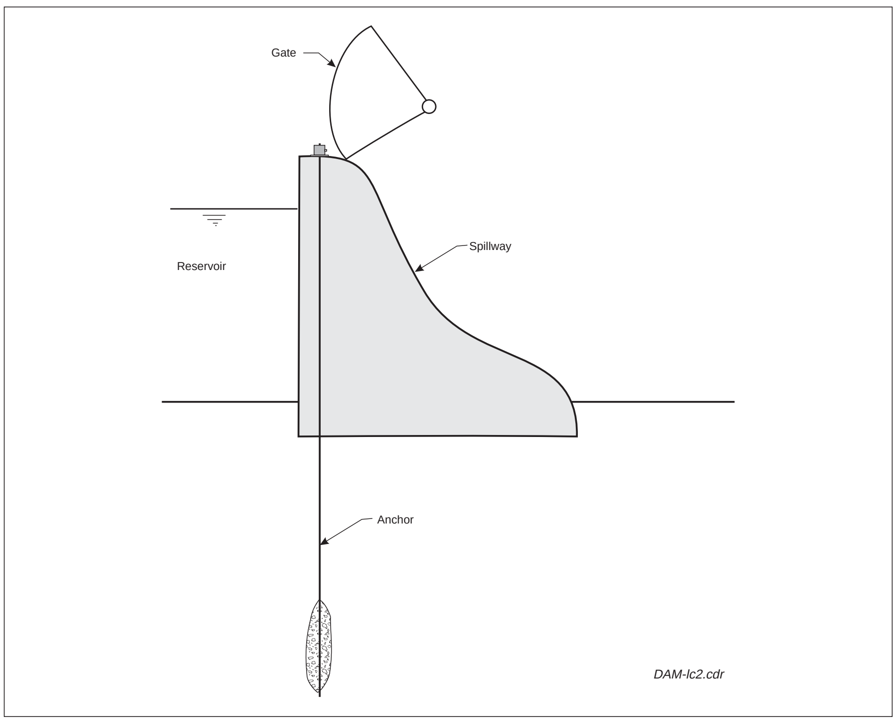
- Evaluate the efficiency of the tie-back anchor system and confirm stability of wall.
- Load cell may be placed inline with strut, but this changes the characteristics of the strut. Readings may not be representative of other struts.

Roof Support in Underground Openings



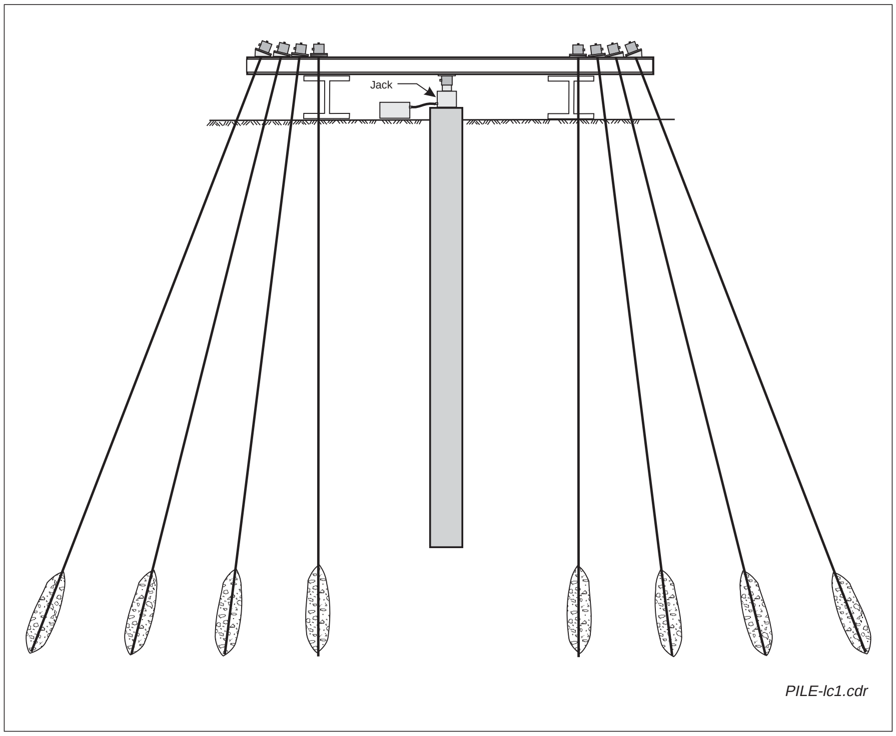
- Rock bolts are installed for roof control. Some bolts are fitted with load cells to monitor the effectiveness of the anchors.
- Load cells provide early warning of impending failure in time for remedial action to be taken.

Dam Remediation



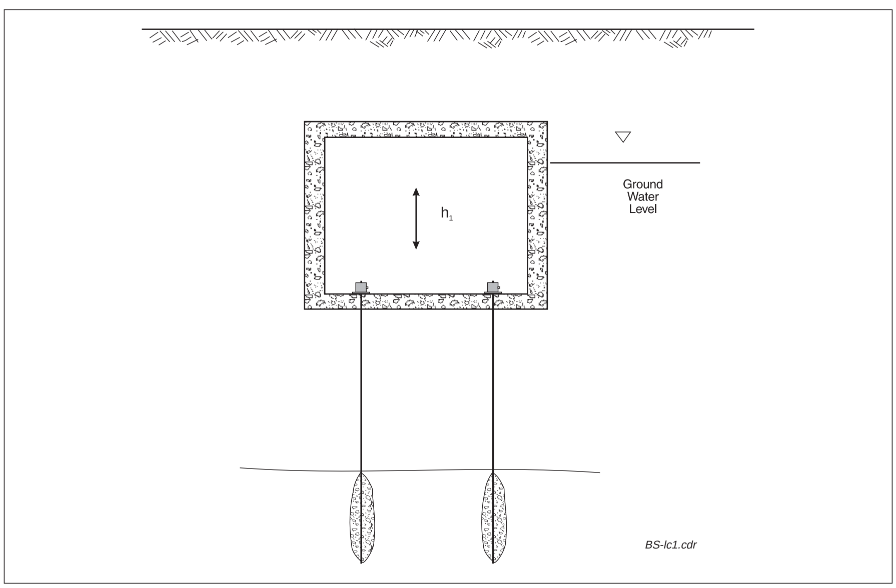
- Tie-back anchors installed on upstream section of concrete dam resist over-turning moments caused by very high flood conditions. Load on anchor is one measure of the stability of the dam and provides early warning of trouble.

Pile Testing



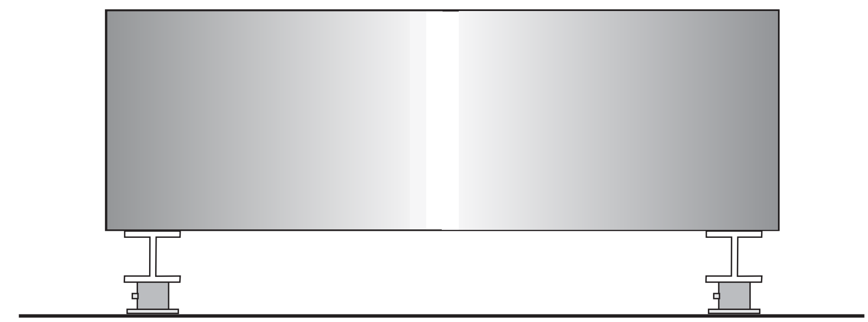
- Load cells monitor the loads applied to the pile and transferred to the strands.
- Non-symmetrical loading can cause premature failure of over-loaded strands, so all strands are monitored and corrective action taken if necessary.

Uplift Forces



- Load cells used to measure anchor loads due to uplift forces on underground structures that are partially or fully below the water table. Load will increase with buoyancy.
- Load cell data may be used to control de-watering operations.

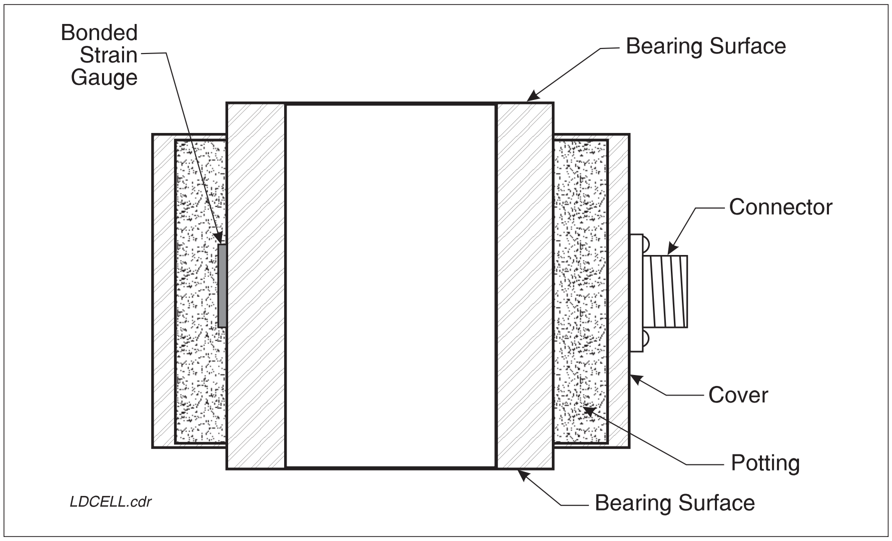
Weighing



- Load cells measure force on beams. Weight of contents of tank can be calculated by subtracting the empty weight of the tank from the current load reading.

Resistance Strain Gauge Load Cells

The core of Slope Indicator's strain-gauge load cell is a cylinder of



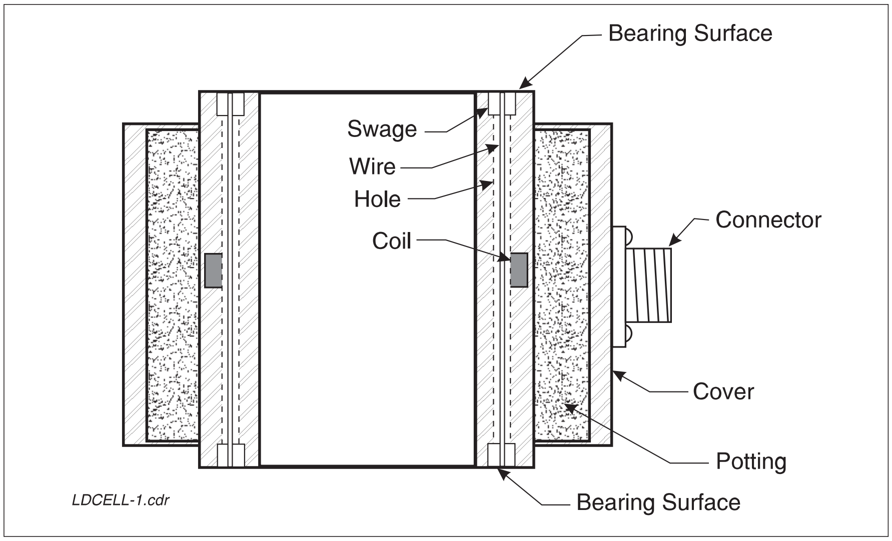
heat-treated steel with machined bearing surfaces top and bottom. Strain gauges are bonded to the outside surface of the cylinder at equally-spaced locations. The gauges are connected to form a Wheatstone bridge, which results in a single output for all four gauges. When the cylinder is loaded axially, the output of the gauges changes proportionally with the compression of the steel cylinder. The cylinder is placed inside an oversize protective case and the space between is filled with potting material.

Slope Indicator has considerable flexibility in the design of the cells regarding diameter and load range. We are limited only by the availability of high capacity testing machines. If there is a large quantity of cells involved, we will prepare a quote to meet the requirement.

Advantages

- Accurate.
- Stable.
- Temperature-compensated.
- Suitable for monitoring remotely or with data logger.

Vibrating-Wire Load Cells



Similar to the resistance strain gauge load cells, with vibrating wire strain gauges attached to the cylinder instead of resistance gauges. Normally three gauges are attached at equal intervals around the cylinder. Sometimes the gauges are fitted in machined slots in the wall to minimize size of the entire cell.

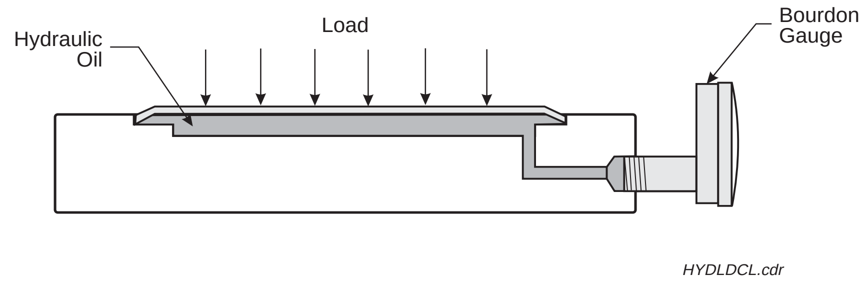
Advantages

- Uses same indicator as other vibrating wire instruments.

Limitations

- Each gauge must be read separately. Later readings must be averaged. Some readout units do this automatically.
- Gauges are temperature sensitive.

Hydraulic Load Cells



The hydraulic load cell consists of a hollow cylinder sealed by a welded plate. The volume enclosed is filled with hydraulic oil. The load is measured by a Bourdon pressure gauge, hydraulic transducer, or electrical transducer.

Hydraulic load cells are appropriate for monitoring loads on anchors. The pressure reading will show if the anchor is still loaded or has lost its load.

Hydraulic load cells can be used with vibrating wire or other pressure transducers for remote operation.

Advantages

- Low profile.
- Non-electrical - safe where electrical devices are forbidden.
- Robust.
- Economical.

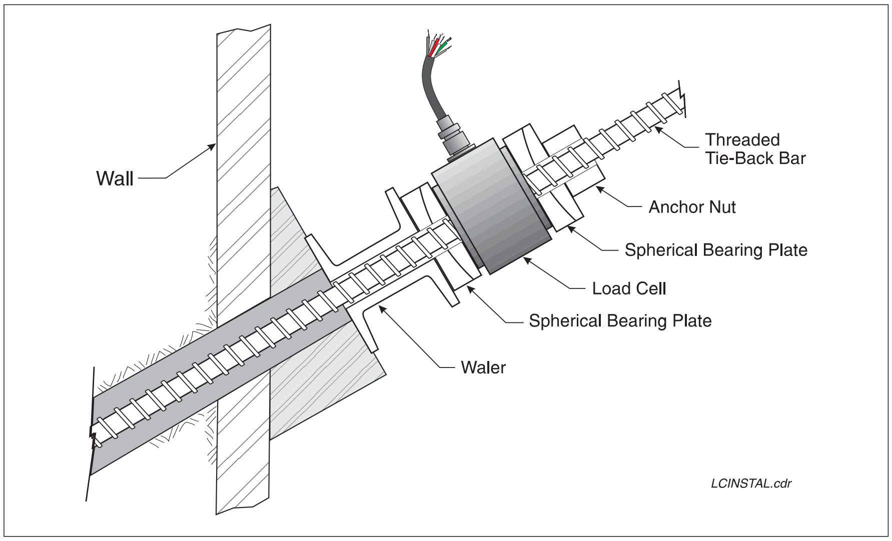
Disadvantages

- Less accurate than electrical load cells.
- Not temperature compensated.
- Not a rigid system.

General Considerations

For highest accuracy and consistent readings, the load cells should be installed between platens that distribute the load evenly. These should be of heat-treated steel with ground parallel faces. For an expected load of up to 75 tons, the platens should be approximately 38 mm thick. For an expected load of 75-200 tons, the platens should be approximately 64 mm thick. For an expected load of 200-350 tons, the platens should be approximately 90 mm thick.

The spherical bearing plates should be between 25 and 50 mm thick depending on load rating.



Center the load cell on the tie-back so that loading is distributed equally.

Notes

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Total Pressure Cells

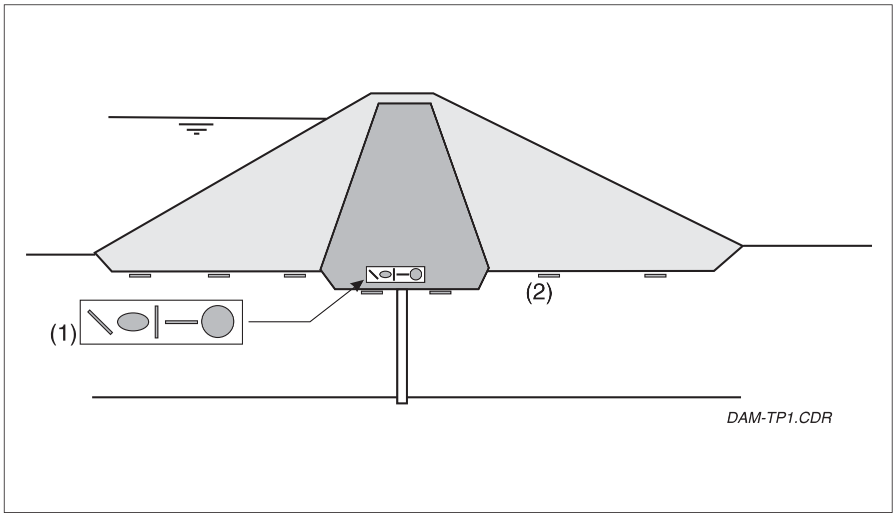
Notes

Total Pressure Cells

Total pressure cells measure the combined pressure of effective stress and pore-water pressure. In general, they are used to verify design assumptions and to warn of soil pressures in excess of those a structure is designed to withstand.

Total pressure cells are installed within fills to determine the distribution, magnitude and directions of total stresses. They can also be installed with one surface against a structure to measure total stresses acting on retaining walls, against piles, pipes, and slurry trench walls.

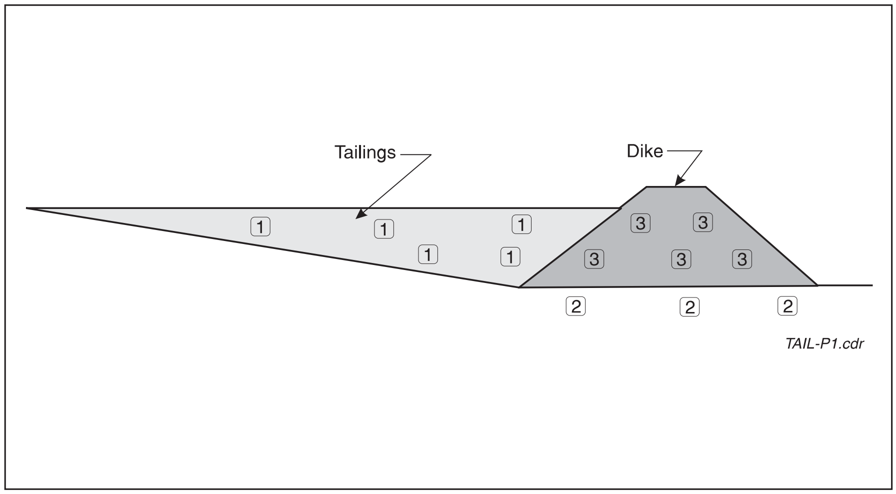
Embankment Dam



1 Total pressure cells used to confirm design assumptions.

2 An array of cells provides data to determine distribution, size, and direction of total stresses within the clay core.

Tailings Dam

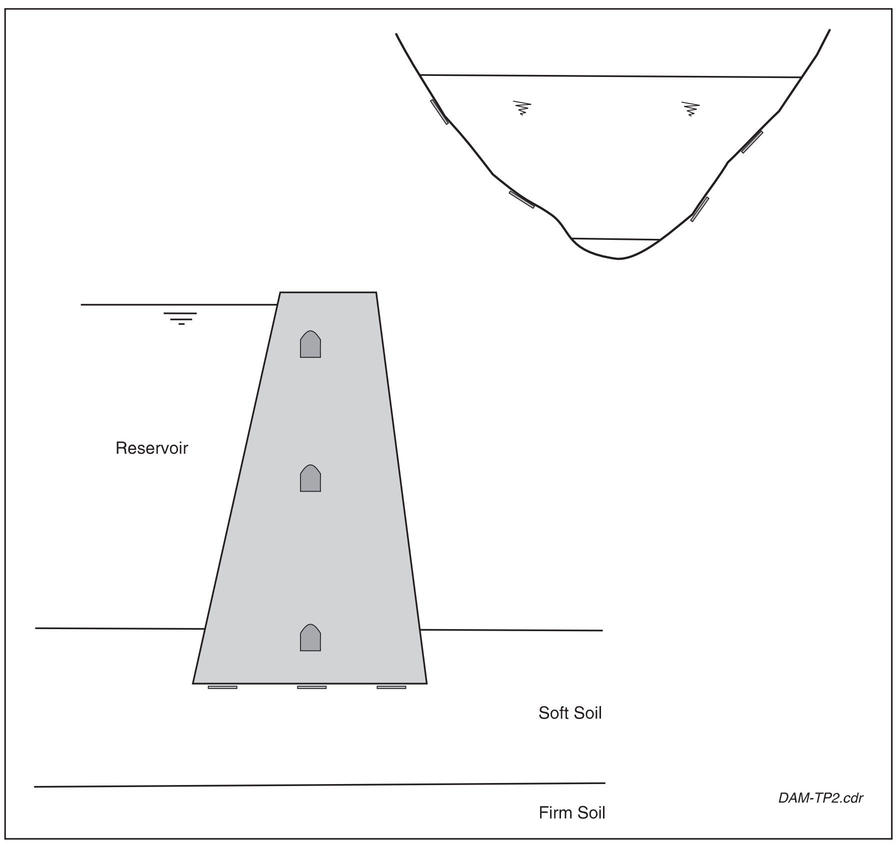


$\boxed{1}$ Confirm that tailings material is densifying at design rate. Could indicate need for increased drainage.

$\boxed{2}$ Estimate total overburden pressure acting on foundation.

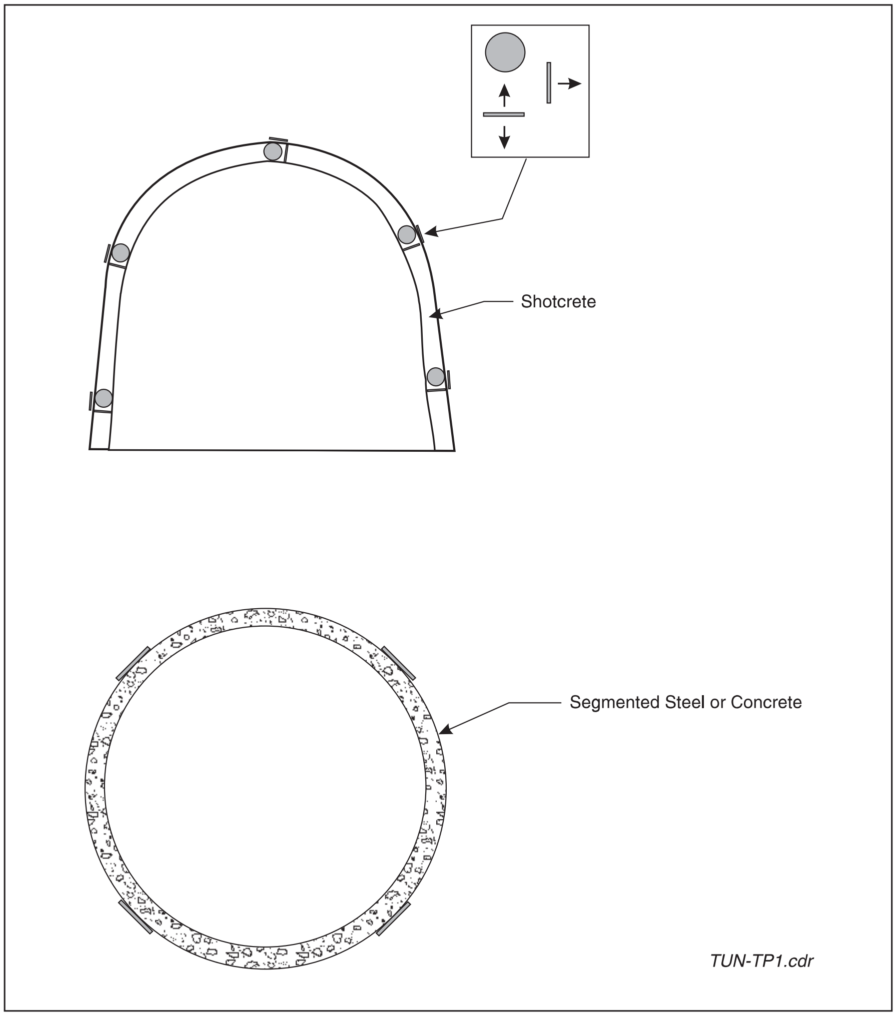
$\boxed{3}$ Determine total stresses in dike.

Concrete Dam



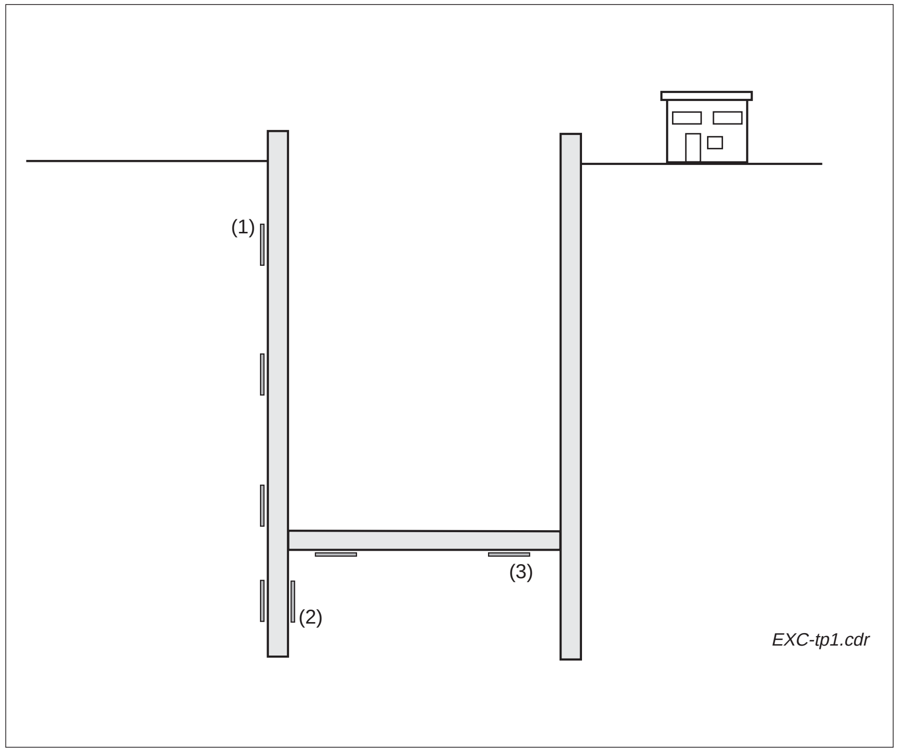
- Measure contact pressures in abutments and foundation (upper drawing).
- Confirm competence of material.
- Measure total stress acting on foundation.

Tunnels



- Measure stress field in shotcrete (upper drawing).
- Measure stresses acting on tunnel. Used in conjunction with a diameter measuring device such as a tape extensometer, total pressure cells provide data for deformation profile and validate design of liner.
- Use of strain gauges in liner may provide better data.

Diaphragm or Sheet-Pile Wall

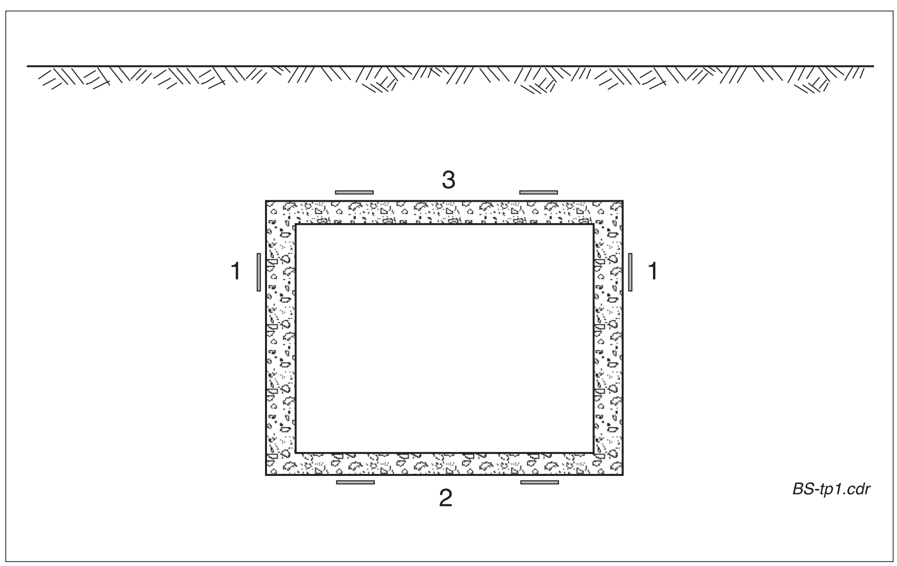


1 Confirm active pressures are within design limits.

2 Confirm passive pressures.

3 Measure uplift pressure on foundation.

Buried Structures

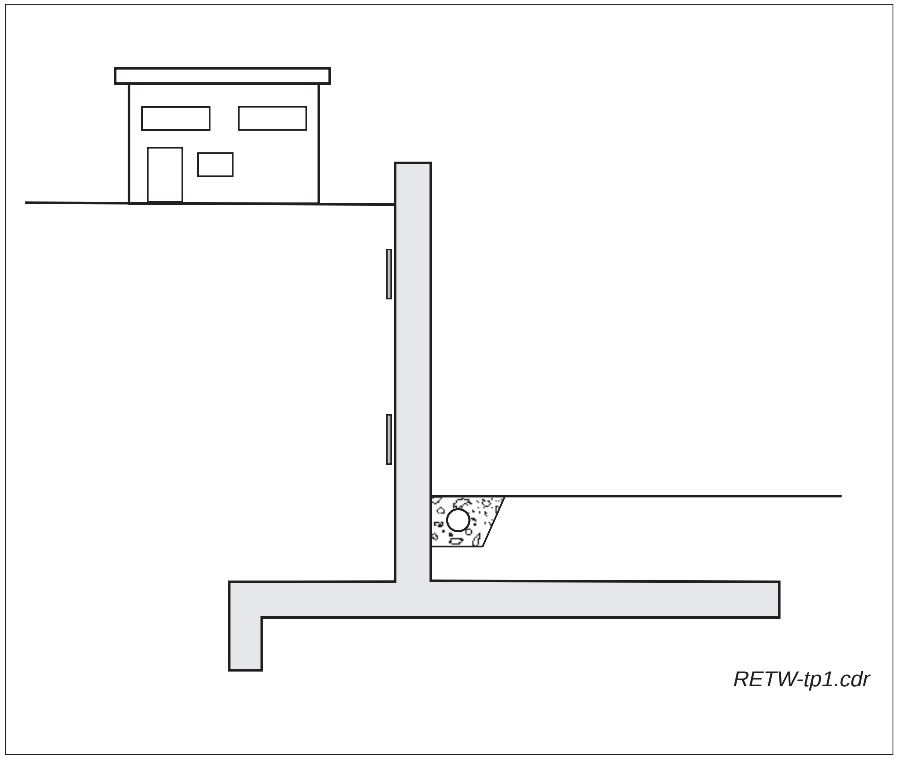


1 Provide estimate of total horizontal stress acting on structure.

2 Provide estimate of total uplift forces acting on structure.

3 Measure arching of topsoil over structure.

Retaining Wall



- Confirm design assumptions of active pressures.

Total Pressure Cell

The total pressure cell consists of two 9-inch diameter steel plates edge-welded together to form a sealed space. The space is filled with fluid, a de-aired glycol-water mixture. A high pressure tube connects the cell to a pneumatic or vibrating wire pressure transducer.

One plate, thinner than the other, acts as the sensitive or active face of the total pressure cell and is placed in direct contact with the soil. The other plate may be in contact with soil (when installed in fill) or fixed to a recess in a retaining wall. Loads applied to the active face are transmitted to the fluid inside the cell and measured with the transducer.

The inclusion of the cell in the soil mass alters the stress fields around the cell. This effect is minimized when the cell's thickness to diameter ration is less than 1:10. The total pressure cell manufactured by Slope Indicator has a ratio of 1:20.

Jack-Out Total Pressure Cell

The *jack-out* total pressure cell is specially designed for installation in cast-in-place structures, such as diaphragm walls. Its name is derived from the use of a hydraulic jack that is activated to keep the cell in contact with the soil during concreting.

Installation

Total Pressure Cell

Installation in Fill

The total pressure cell can be installed directly into the fill if the soil used is of uniform grain size. The material must be hand compacted to the same density as the surrounding fill (not always easy to do).

Where fill includes rocks, the cell is buried in fine dampened sand. There should be a 100 mm layer of sand at the bottom of the trench and an additional 200-300 mm layer of sand over the cell before fill placement begins. Where fill is clay, sand is not used.

Specifications sometimes require that tubing and cable be snaked in trenches to accommodate settlement. There is some question whether this practice is necessary, however. This view holds that normal forces acting on snaked tubing or cable prevent it from slipping and therefore snaking does nothing to accommodate settlement.

Cells are usually place in groups of four. One cell is vertical, one horizontal, and two are at 45⊃.

Installation in Retaining Wall

Formwork is designed with recesses or “pockets” to accommodate the thickness of the total pressure cell. The base of the cell is fixed to the recess with epoxy, so the active face of the cell is in the same plane as the wall. Cells have also been mounted directly to the face of the wall with acceptable results.

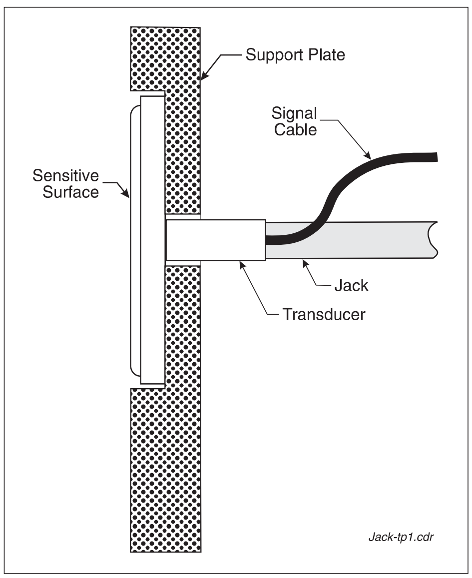
Make sure that uniform material contacts active face of the gauge. The fill may have to be graded and locally placed by hand to a similar density and moisture content as the surrounding soil.

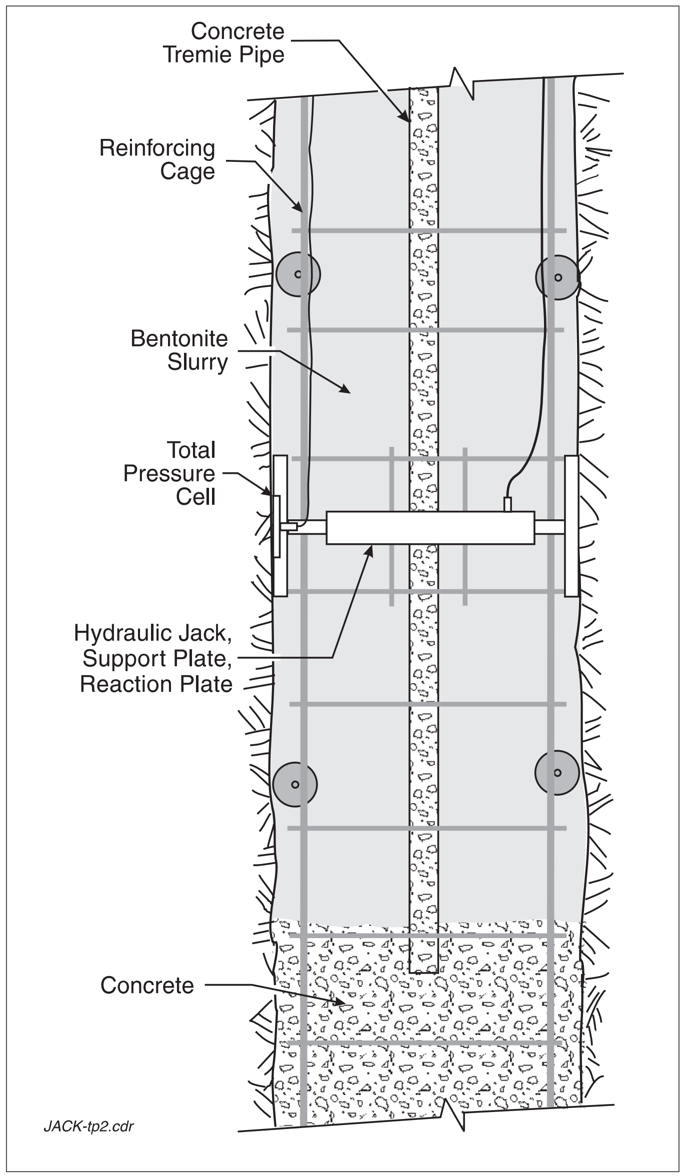
Jack-Out Total Pressure Cell

The jack-out cell, together with a rigid steel support plate, a reaction plate of similar dimensions, and a double-acting hydraulic jack, is installed in the reinforcing cage. Additional jack-out cells are installed as specified.

Signal cable and hydraulic hose are secured, and the cage is lowered into the slurry trench. When the cage is in position, the jack is activated and locked, holding the cell in contact with the soil. To prevent distortion of the cell, the jack acts on the support plate, rather than directly on the cell. An equal force is applied to the reaction plate.

The trench is then concreted. In the illustration at right, the jack has been activated, forcing the cell into contact with the soil. Concrete is being placed through a tremie pipe. Concrete cannot enter between the soil and the sensitive face of the cell.





Notes