ACHASM 2017 SUMMIT

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EXCAVATION HEALTH AND SAFETY (H&S)

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Introduction

- Presentation is based upon a one-day fifteen-module excavation H&S seminar developed upon the request of the Umhlathuze Municipality, and piloted on 11 October 2007
- The seminar was repeated and also delivered to eThekwini Municipality's water division, and to a range of organisations in various cities
- Challenging ito condensing one day to 25 minutes
- A number of slides have been included for later reference

Trench cave in, Cincinnati (1)

(Barstow, 2004)

Trench cave in, Cincinnati (2)

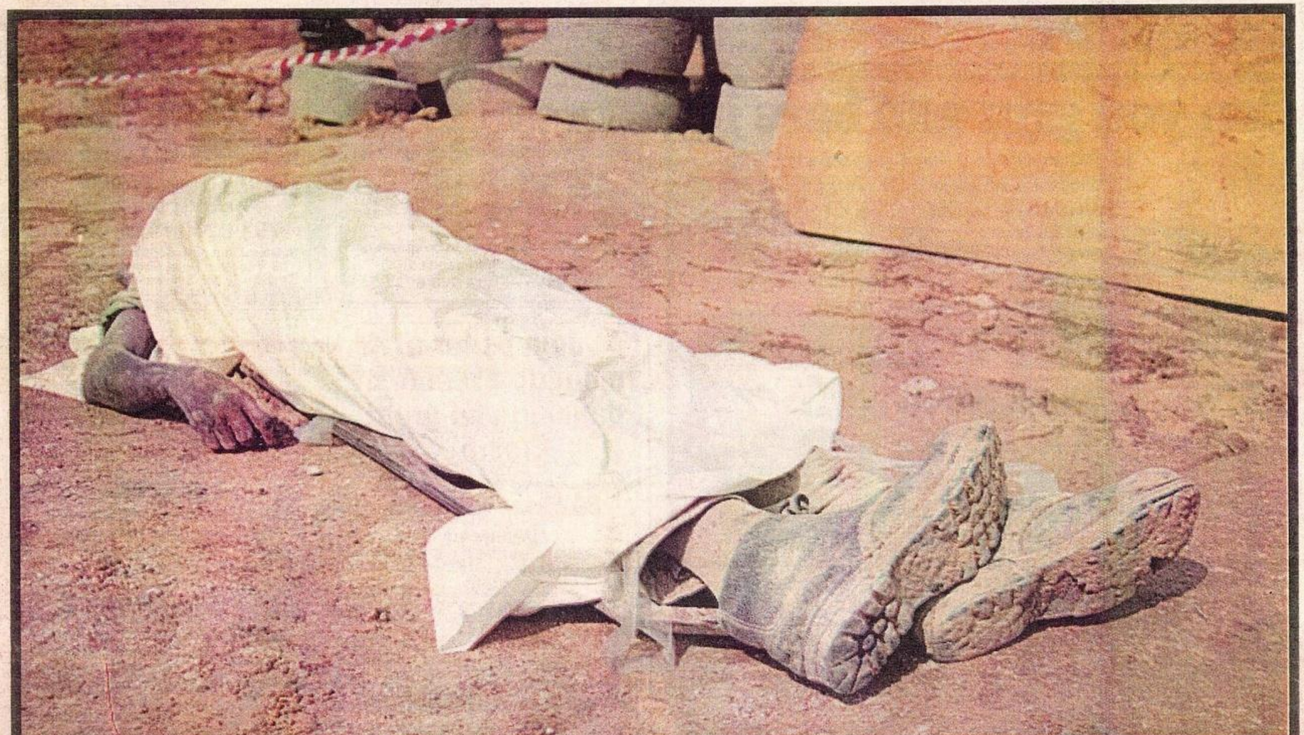
(Barstow, 2004)

Trench cave in, Cincinnati (3)

"As the autopsy confirmed, death did not come right away for Patrick M. Walters. On June 14, 2002, while working on a sewer pipe in a trench 10 feet deep, he was buried alive under a rush of collapsing muck and mud. A husky plumber's apprentice, barely 22 years old, Mr. Walters clawed for the surface. Sludge filled his throat. Thousands of pounds of dirt pressed on his chest, squeezing and squeezing until he could not draw another breath." (Barstow, 2004)

Wall (earth) collapse, Randburg (February, 1999)

Wall of death



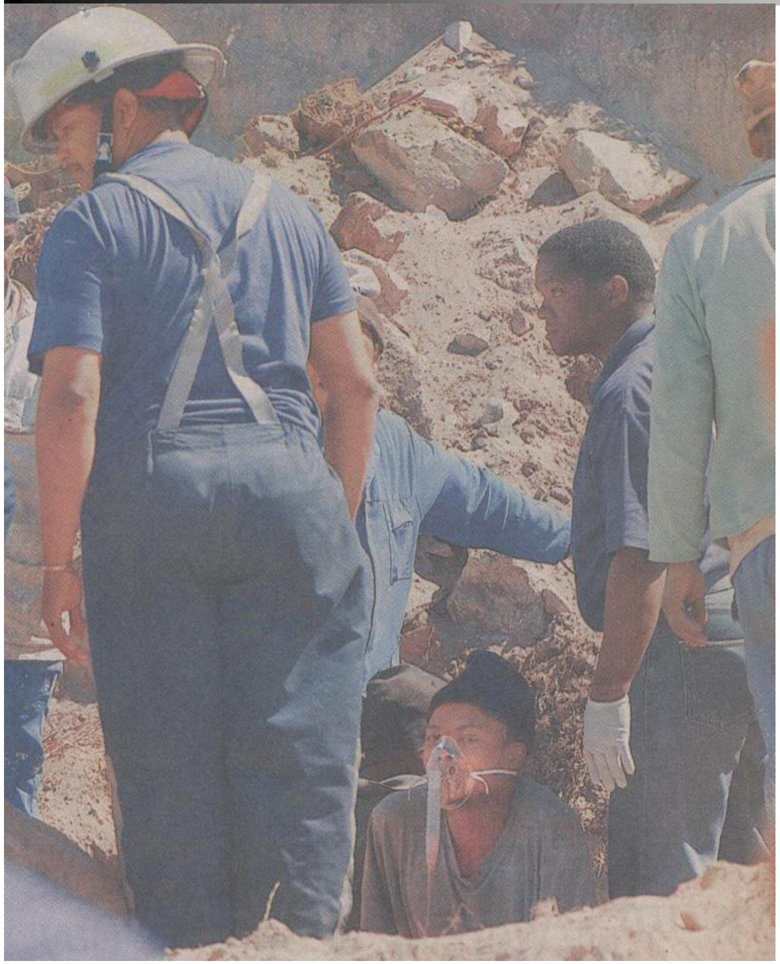
Tragic recovery...The body of the first construction worker removed from a mountain of soil that buried him while working with a jackhammer last week. Chris Fey

(Frey, 1999)

Wall (earth) collapse, Port Elizabeth (September, 2005)(1)

(Coetzee, 2005)

Wall (earth) collapse, Port Elizabeth (September, 2005)(2)



(Coetzee, 2005)

Trench collapse, Klein Brak River (March, 2005)

(Myer, 2005)

Gas explosion

Aftermath of a gas explosion following damage to an underground gas service pipe (HSE, 2000)

Construction Regulations: Clients

Clients required to, among other (Republic of South Africa, 2014):

- 5 (1) (a) Prepare a baseline risk assessment (BRA)
- 5 (1) (b) Prepare an H&S specification based on the BRA
- 5 (1) (c) Provide the designer with the H&S specification
- 5 (1) (d) Ensure that the designer takes the H&S specification into account during design
- 5 (1) (e) Ensure that the designer carries out the duties in Regulation 6 'Duties of designers'
- 5 (1) (f) Include the H&S specification (revised after the designers' reports?) in the tender documents
- 5 (1) (g) Ensure that potential PCs have made provision for the cost of H&S in their tenders
- 5 (1) (h) Ensure that the PC to be appointed has the necessary competencies and resources

Construction Regulations: Designers (1)

Relative to Structures 6 (1) designers of a structure must:

- (a) ensure that the H&S standards incorporated into the regulations are complied with in the design
- (b) take the H&S specification into consideration
- (c) include in a report to the client before tender stage:
  - all relevant H&S information about the design that may affect the pricing of the work
  - the geotechnical-science aspects
  - the loading that the structure is designed to withstand
- (d) inform the client of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is changed – may require 'design and construction' method statements

Construction Regulations: Designers (2)

(e) modify the design or make use of substitute materials where the design necessitates the use of dangerous procedures or materials hazardous to H&S

- (f) consider hazards relating to subsequent maintenance of the structure and make provision in the design for that work to be performed to minimize the risk
- (g) when mandated by the client conduct inspections to ensure conformance of construction to design. If not mandated then the client's agent is responsible
- (h) when mandated by the client stop construction work not in accordance with the design's H&S aspects. If not mandated then the client's agent is responsible
- (i) when mandated by the client, during his / her final inspection of the structure include the H&S aspects of the

Construction Regulations: Excavations (1)

- Ensure excavation work is supervised by a competent person who has been appointed in writing
- Evaluate, as far as is reasonably practicable, the stability of the ground before commencing excavation work
- Contractors performing excavation work:
  - Take suitable and sufficient steps to prevent, as far as is reasonably practicable, any person from being buried or trapped
  - Not require or permit any person to work in an excavation which has not been adequately shored or braced – provided that shoring or bracing may not be necessary where:
    - Sides have been sloped to at least the maximum angle of repose, or
    - Such an excavation is in stable material. Provided that:
      - The competent person has given permission in writing, and

Construction Regulations: Excavations (2)

  - Where any uncertainty pertaining to the stability of the soil still exists, the decision from a professional engineer or a professional technologist competent in excavations shall be decisive and such a decision shall be noted in writing and signed by both the competent person contemplated in and the professional engineer or technologist
- Ensure that the shoring or bracing is designed and constructed in such a manner rendering it strong enough to support the sides of the excavation
- Ensure that no load, material, plant or equipment is placed or moved near the edge of any excavation where it is likely to cause its collapse, unless the excavation is shored or braced
- Ensure that where the stability of an adjoining building, structure or road is likely to be affected steps are taken to ensure the stability of such building, structure or road and the safety of persons

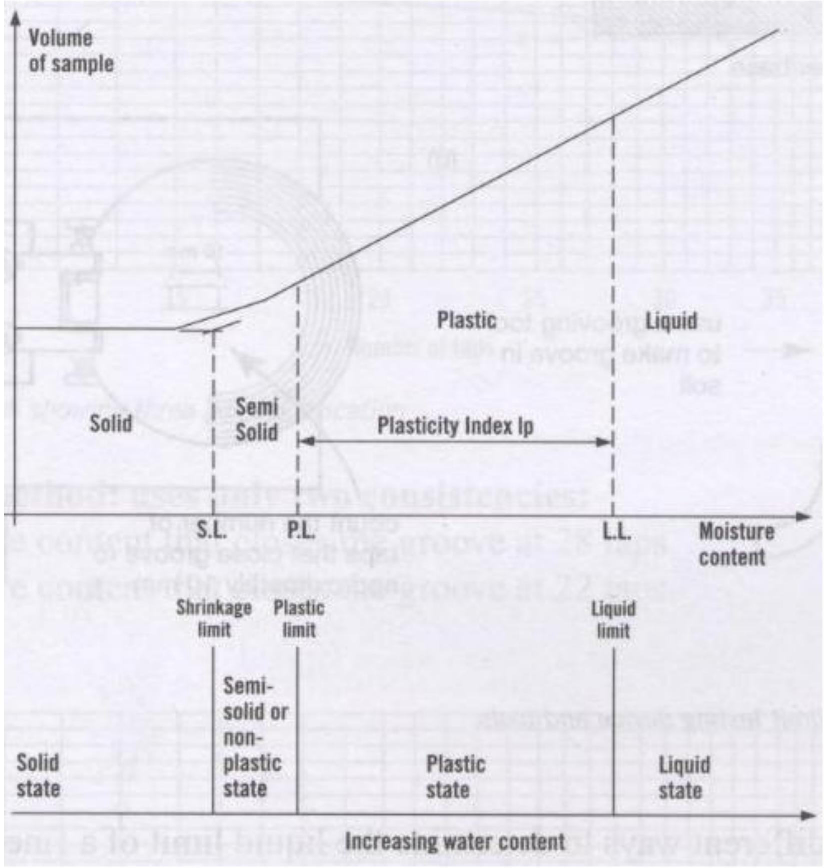
Construction Regulations: Excavations (3)

- Provide convenient and safe means of access not further than 6m from the point where any worker within the excavation is working
- Ascertain as far as is reasonably practicable the location and nature of electricity, water, gas or other similar services which may be affected by the excavations, and take the necessary steps to render the circumstances safe
- Inspect every excavation, including all bracing and shoring:
  - Daily, prior to each shift
  - After every blasting operation
  - After an unexpected fall of ground
  - After substantial damage to supports
  - After rain (competent person) in order to pronounce the safety of the excavation, to ensure the safety of persons, and record the results in a register available to an inspector, client, client's agent, contractor or employee upon request

Soil strength

- Properties of a soil depend on the grain size, mineralogy and water content, which are interrelated
- Water changes the properties of soil
- Differing soils behave differently

Soil consistency (1)



Consistency limits of soil (van Amsterdam, 2000)

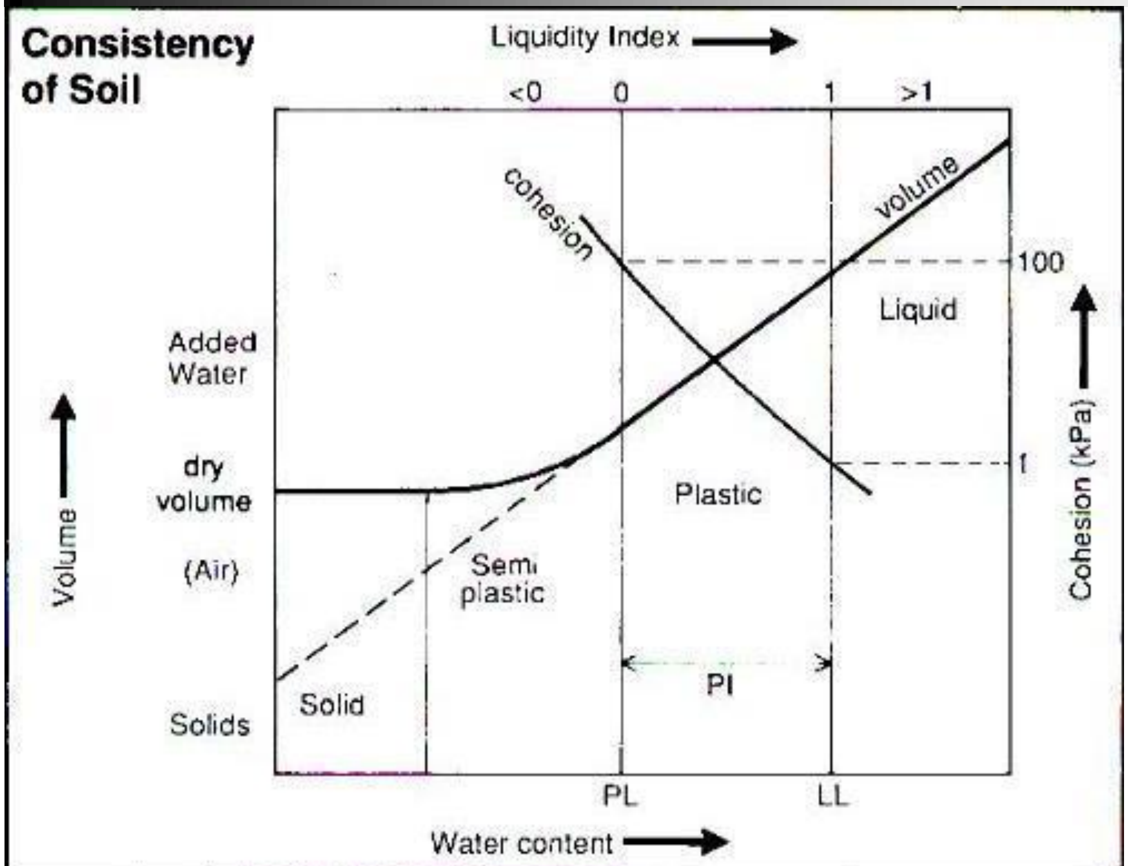
Soil consistency (2)

- That property of a soil that displays resistance to flow
- Reflects the cohesive abilities of a soil
- Affected by the moisture content in the soil
- By changing the water content a soil can move from a solid to a liquid phase
- Varying water content results in a soil being either solid, plastic, or liquid
- Water content (w) = Weight of water as percentage of dry weight
- Plastic limit (PL) = minimum moisture content where a soil can be rolled into a cylinder 3mm in diameter

Soil consistency (3)

- Liquid limit (LL) = minimum moisture content at which soil flows under its own weight
- Plasticity index (PI):
  - = LL – PL (change in water content required to increase the strength a 100 X)
  - High PL soils are less stable, with large swelling potential
- Liquidity index (LI):
  - = (w - PL) / PI
  - Measure of soil consistency and strength at a given water content

Soil consistency (4)



Consistency of soil (Waltham, 2002)

Soil classification (1)

- Cohesive, fissured, and granular (Oregon OSHA, 2006)
- Cohesive:
  - Clay, or soil with a high clay content
  - Has cohesive strength
  - Does not crumble
  - Can be excavated with vertical side slopes
  - Plastic when moist
  - Hard to break up when dry
  - Exhibits significant cohesion when submerged
- Fissured:
  - A soil material that has a tendency to break along definite planes of fracture with little resistance, or a material that exhibits open cracks, such as tension cracks, in an exposed surface

Soil classification (2)

- Granular:
  - Gravel, sand, or silt (coarse grained soil) with little or no clay content
  - No cohesive strength
  - Cannot be molded when moist
  - Crumbles easily when dry
  - Some moist granular soils exhibit apparent cohesion

Soil classification (3)

- Types A, B, and C (Oregon OSHA, 2006)
- Type A:
  - Cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (tsf) or greater
  - Clay, silty clay, sandy clay, clay loam, and in some cases, silty clay loam and sandy clay loam
  - Cemented soils such as hardpan are also considered Type A
  - No soil can be Type A if fissured, subjected to significant vibration, or has been previously disturbed
- Type B:
  - Cohesive soils with an unconfined compressive strength greater than 0.5 tsf but less than 1.5 tsf
  - Granular cohesion less soils including angular gravel, silt, silt loam, sandy loam, and in some cases, silty clay loam, and sandy clay loam
  - Type B also includes previously disturbed soils except those which would otherwise be classed as Type C

Soil classification (4)

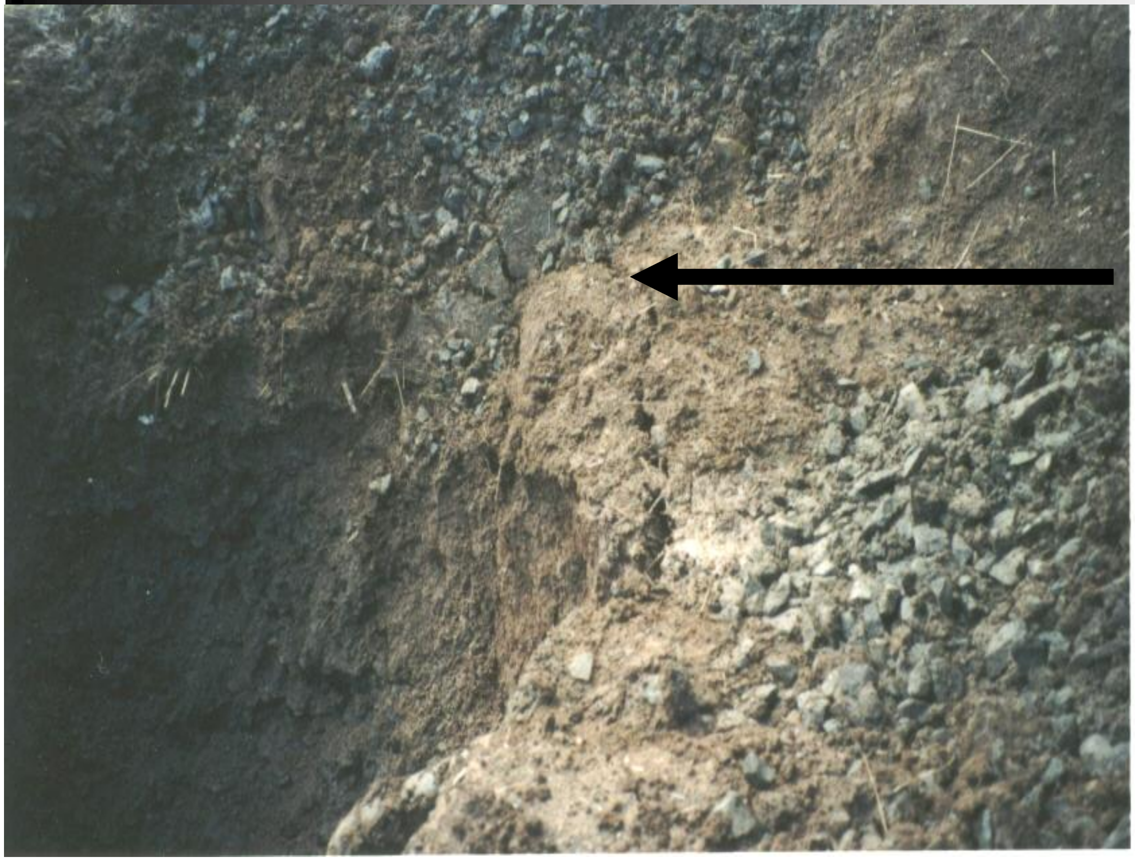
- **Type C:**
  - **Cohesive soils with an unconfined compressive strength of 0.5 tsf or less**
  - **Gravel, sand, and loamy sand**
  - **Also included may be submerged soil or soil from which water is freely seeping, and submerged rock that is not stable**

Soil classification (5)

Soil classification		Grain size (mm)	Typical values		
Type	Class		LL	PI	φ
Gravel	G	2-60			>32
Sand	S	0.06-2			>32
Silt	ML	0.002-0.006	30	5	32
Clayey silt	MH	0.002-0.06	70	30	25
Clay	CL	<0.002	35	20	28
Plastic clay	CH	<0.002	70	45	19
Organic	O	-			<10

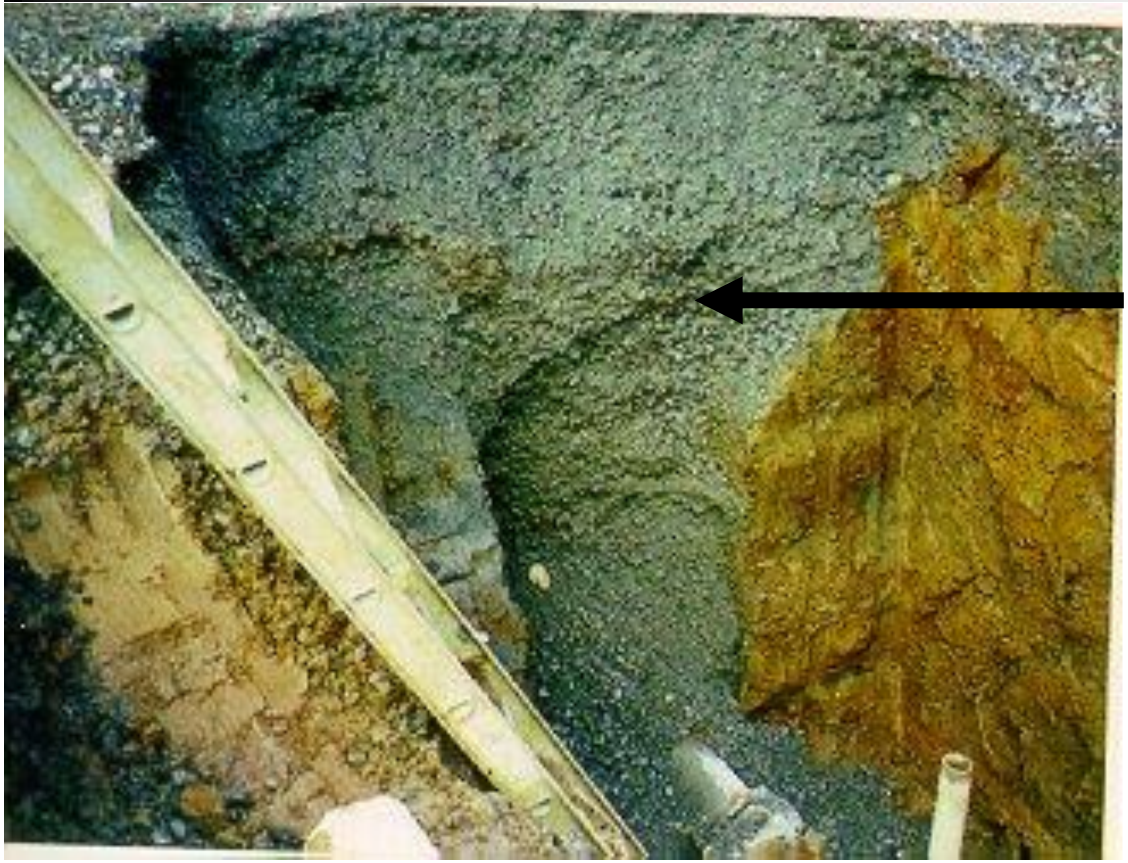
Soil classification (Waltham, 2002)

Soil classification (6)



Observe the side of the opened excavation and the surface area adjacent to the excavation. Crack-like openings such as tension cracks could indicate fissured material (Oregon OSHA, 2006)

Soil classification (7)



Observe the area adjacent to the excavation to identify previously disturbed soil i.e. evidence of existing utility, prior fill material (Oregon OSHA, 2006)

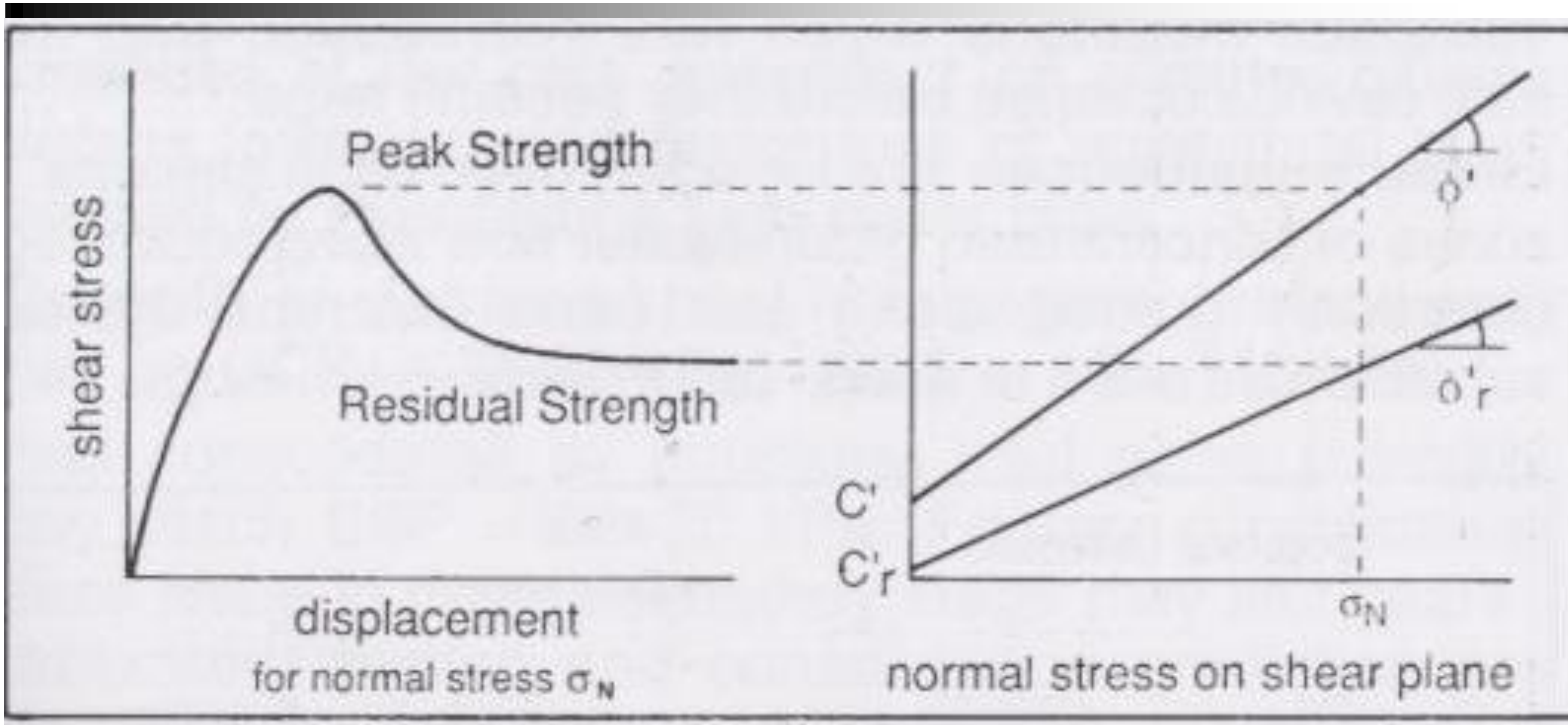
Strength decline in clays (1)

- Drainage progress of a loaded clay is critical as any increase of pore water pressure may lead to failure – significant in new excavations and embankments
- Peak strength declines to residual strength due to restructuring, notably alignment of mineral plates, during dislocation along a plane
- Change is due to almost total loss of cohesion and also reduction in friction angle – significant in all clays, notably those with higher PI
- Brittleness = % decline from peak strength
- Sensitive clays lose great proportion of their strength on restructuring of entire mass – have high LI and small grain size. Therefore cannot drain rapidly and load is taken by pwp

Strength decline in clays (2)

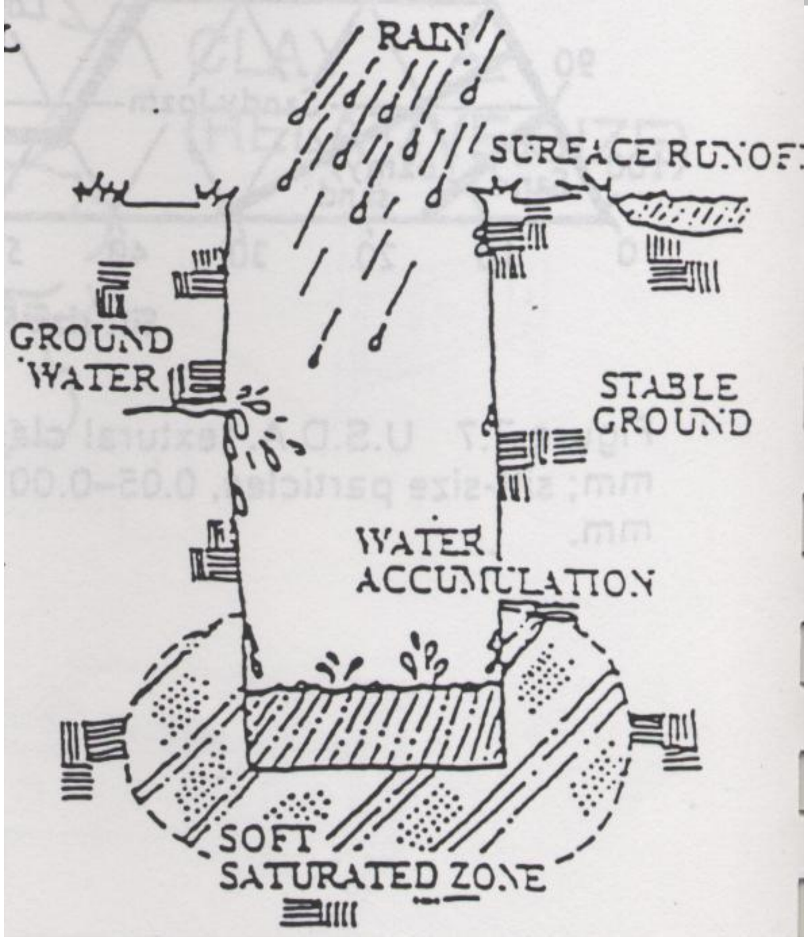
- Sensitive clays lose great proportion of their strength on restructuring of entire mass:
  - Have high LI and small grain size
  - Therefore cannot drain rapidly and load is taken by pwp
  - Shear strength approaches zero
  - Sensitivity = ratio of undisturbed: disturbed strengths and relates to undrained brittleness

Strength decline in clays (3)



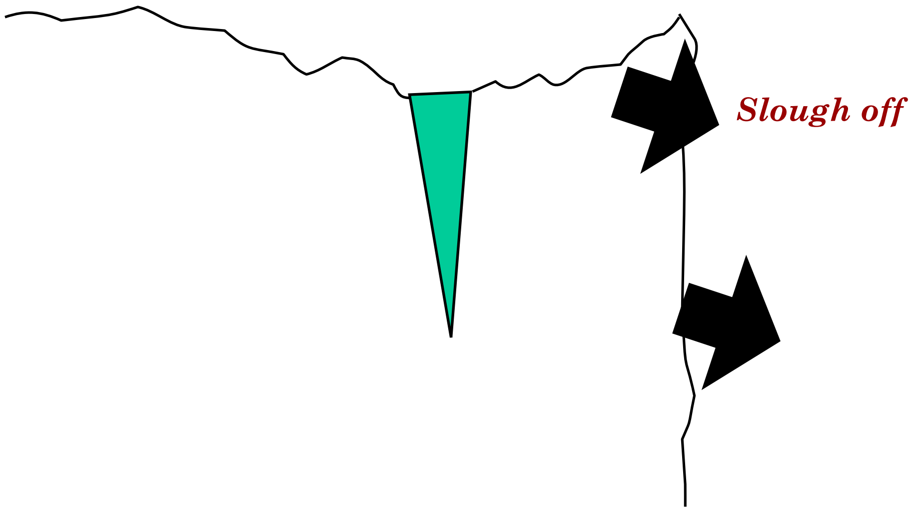
Strength decline of clays (Waltham, 2002)

Effects of water (1)



Effects of water (Lew and Thompson, 1997)

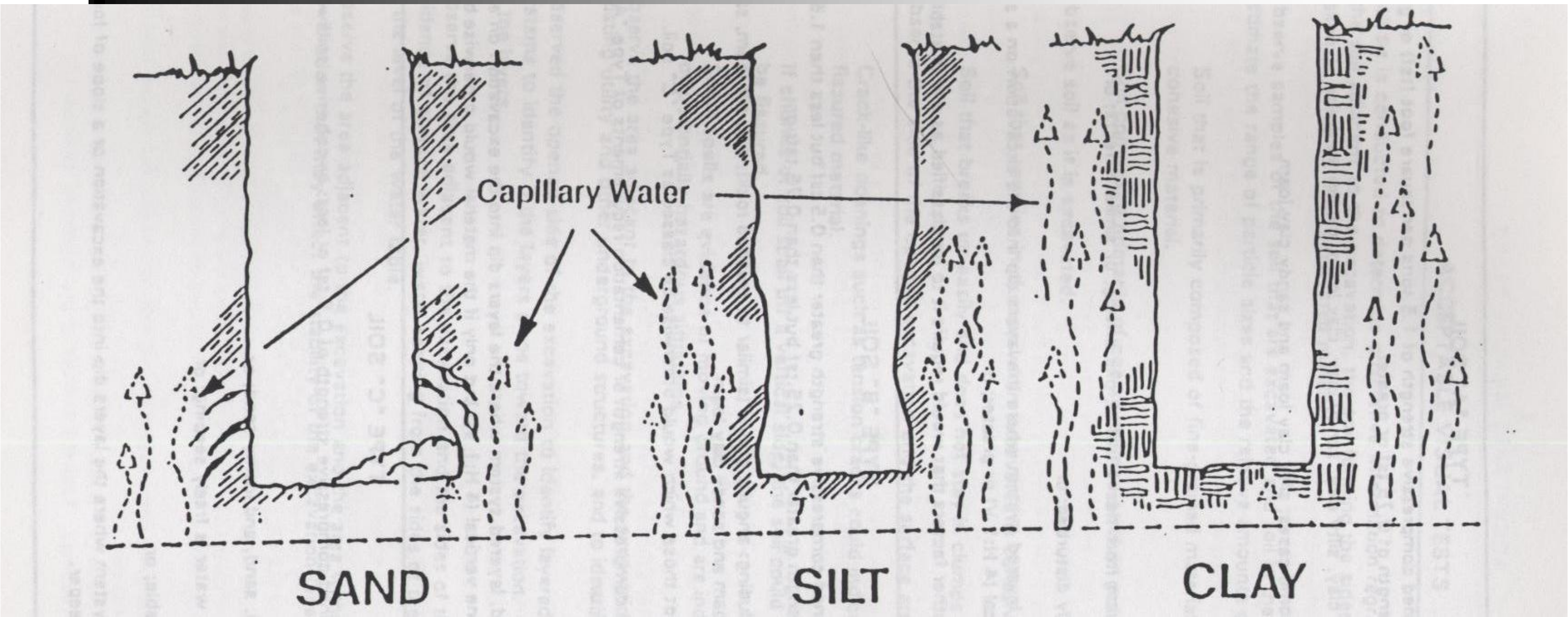
Effects of water (2)



Effects of water (Oregon OSHA, 2006)

Water (i.e. rain) can also fill tension and surface cracks at the edge of the trench causing a hydrostatic effect Within this 'tube' leading to wedge failure

Effects of water (3)



Upward movement by capillarity (Lew and Thompson, 1997)

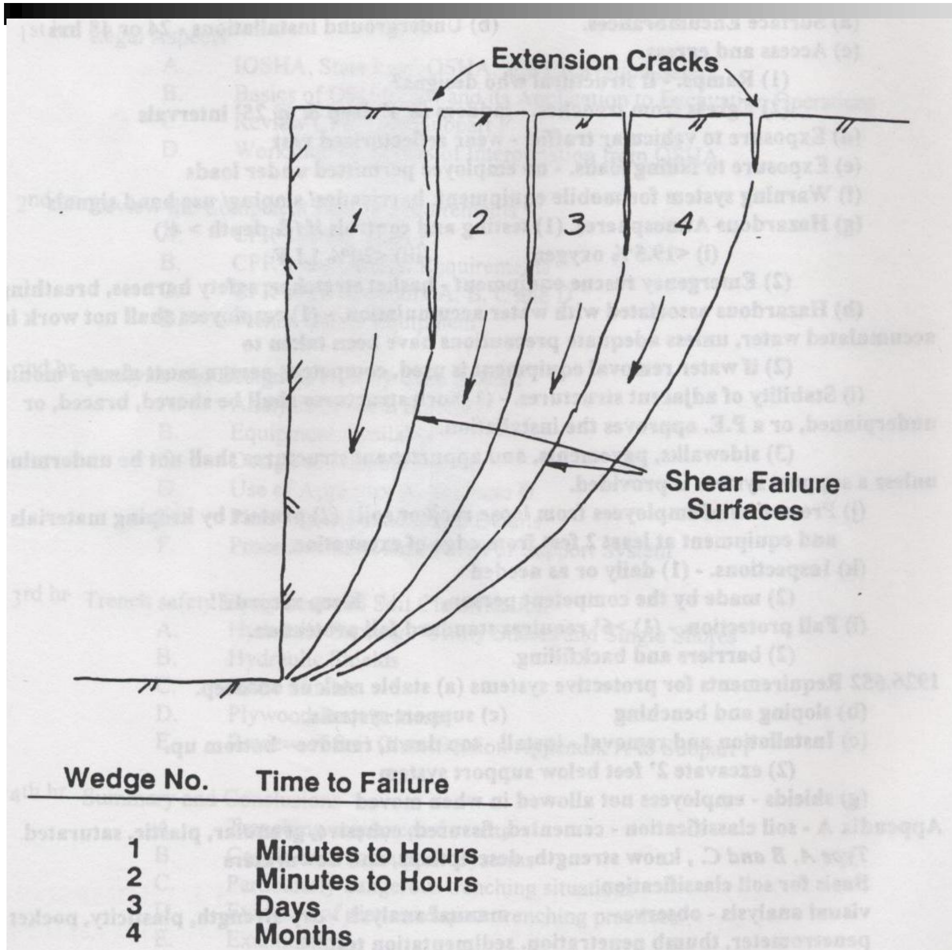
Trench collapse - before

Trench collapse, Umhlathuze Municipality, 2007 (Umhlathuze Municipality Excavation H&S Seminar Delegate, 2007)

Trench collapse - after

Trench collapse, Umhlathuze Municipality, 2007 (Umhlathuze Municipality Excavation H&S Seminar Delegate, 2007)

Mechanics of failures (1)



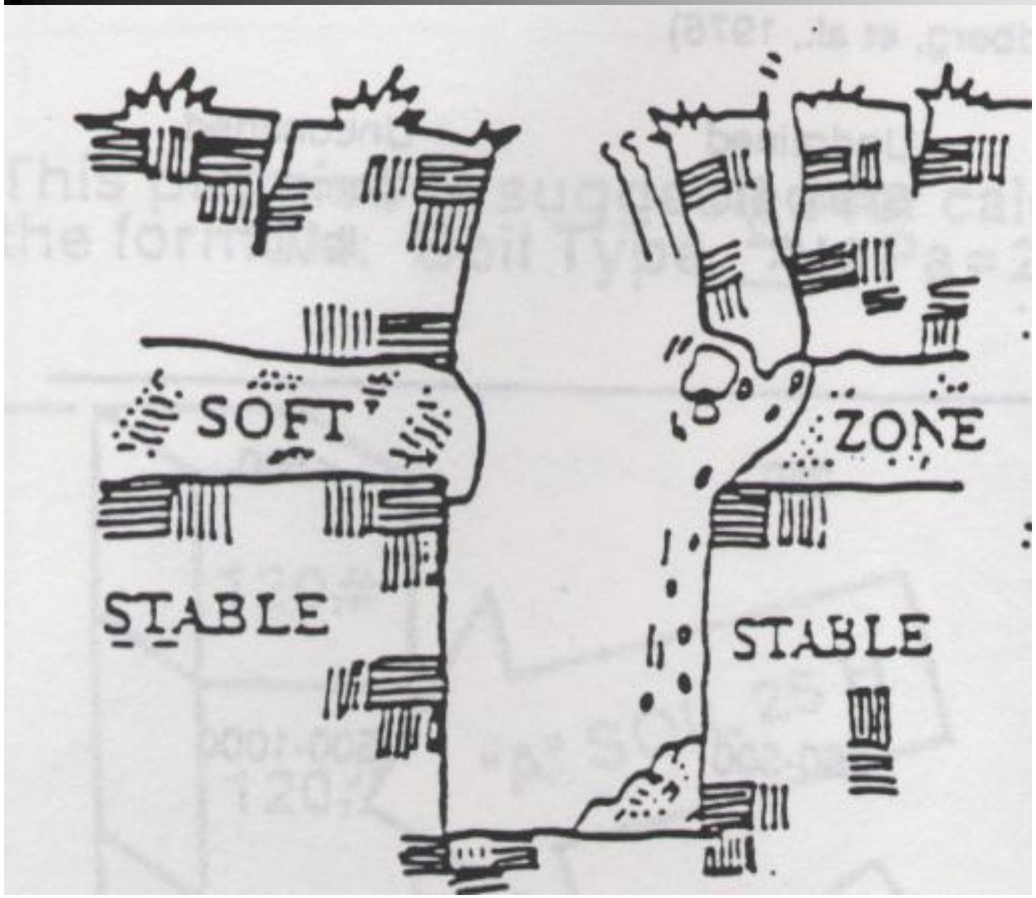
Sequence of failures of an unsupported trench wall (Lew and Thompson, 1997)

Mechanics of failures (2)

Trench stand-up time depends on (Lew and Thompson, 1997):

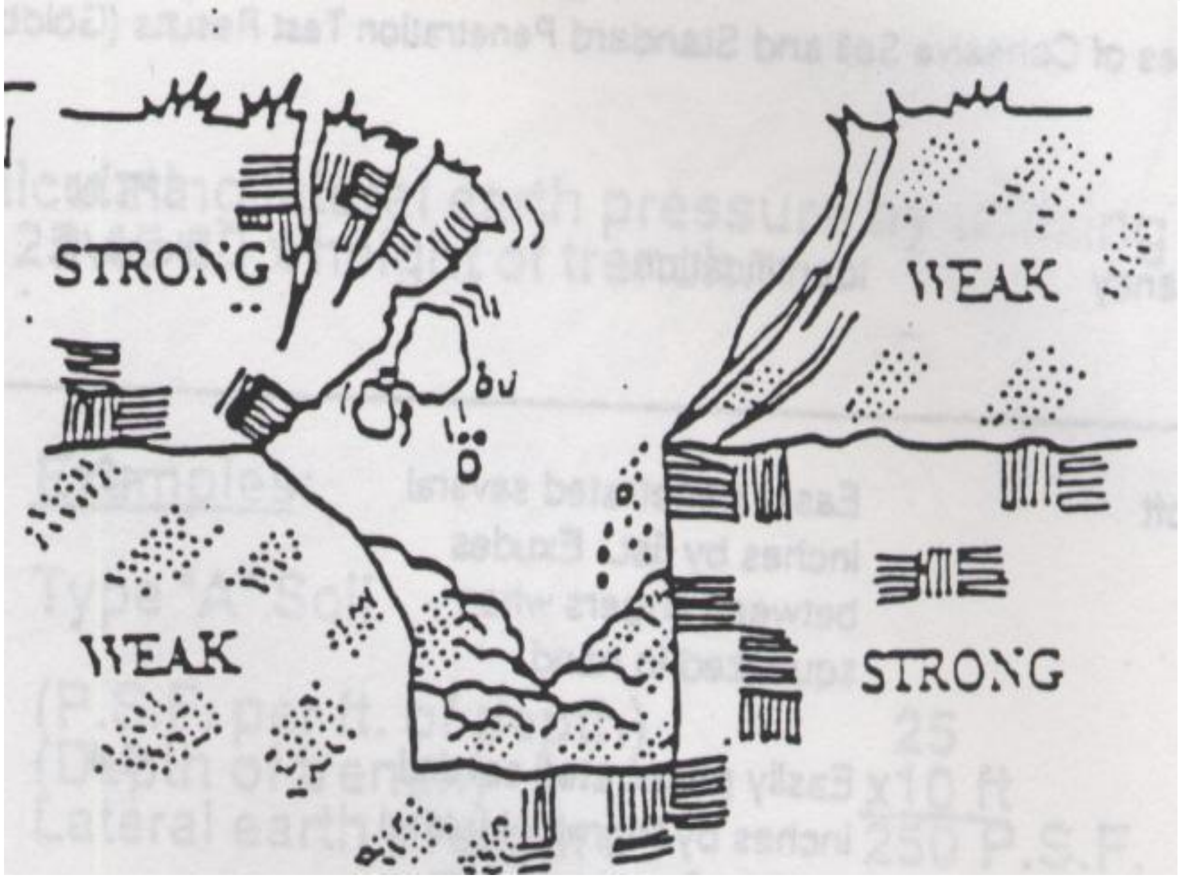
- Depth of trench
- Slope of trench wall
- Cohesive strength of soil – across fissures
- Unit weight of soil
- Position of water table
- Surface surcharge and vibrations

Mechanics of failures (3)



Soft zone failure (Lew and Thompson, 1997)

Mechanics of failures (4)

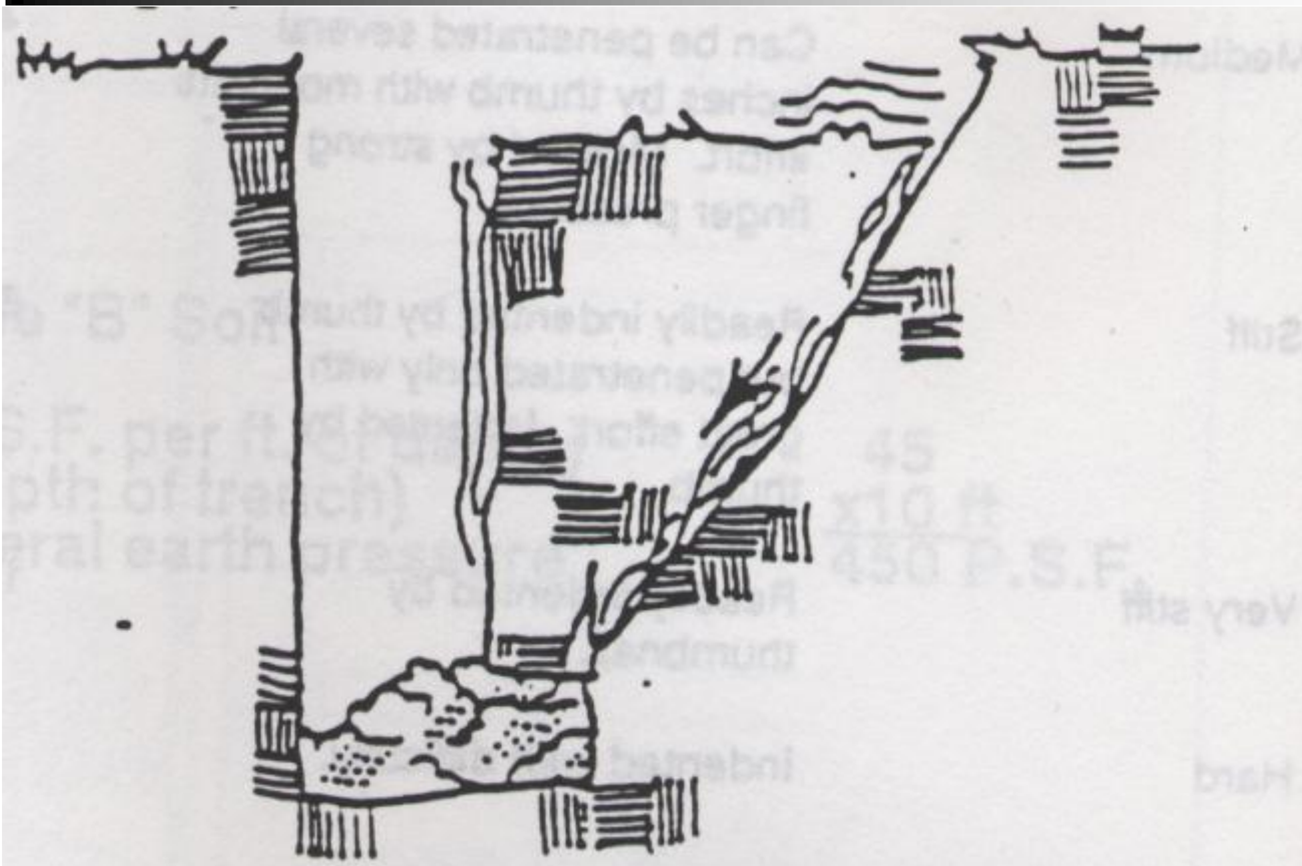


Layered soils (Lew and Thompson, 1997)

Mechanics of failures (5)

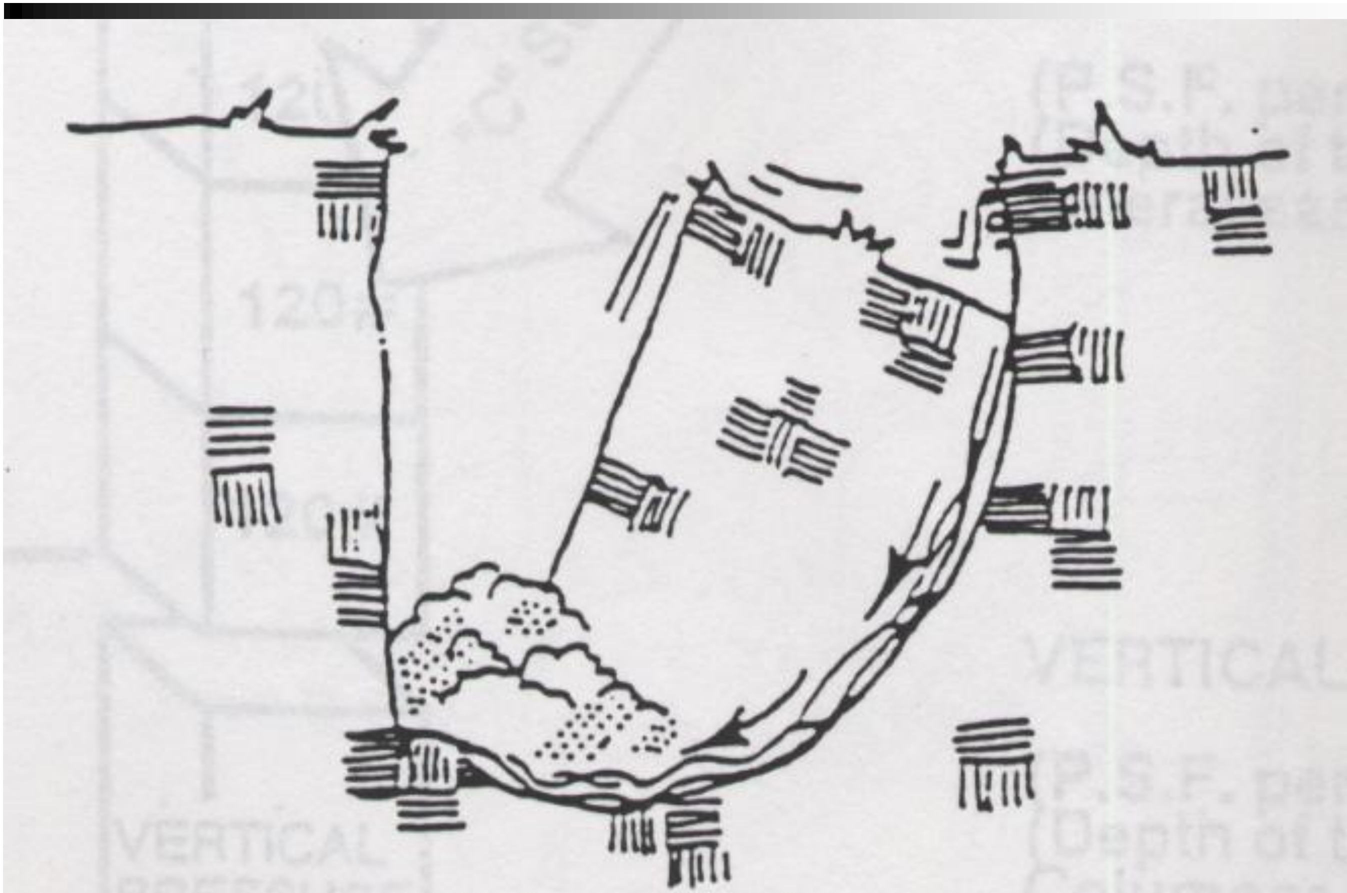
Sloughing (Air Drying) (Lew and Thompson, 1997)

Mechanics of failures (6)



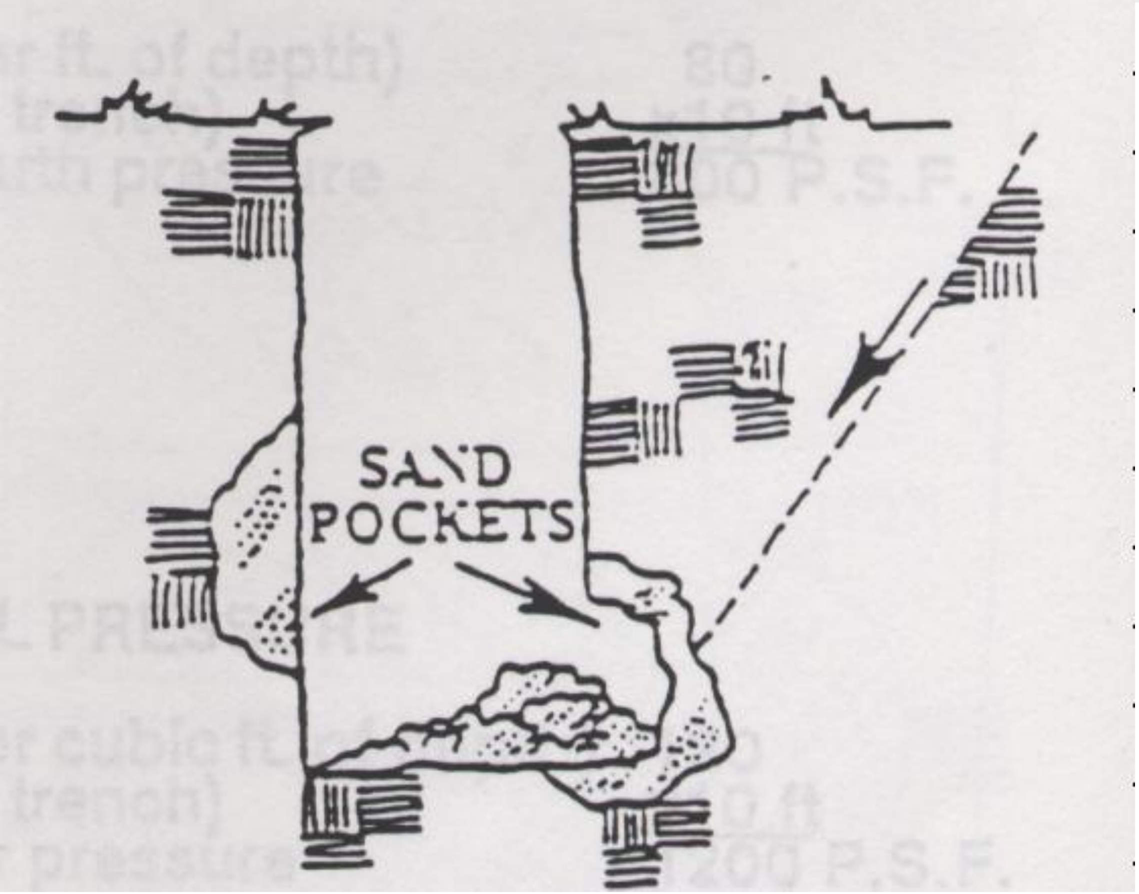
Wedge failure (Lew and Thompson, 1997)

Mechanics of failures (7)



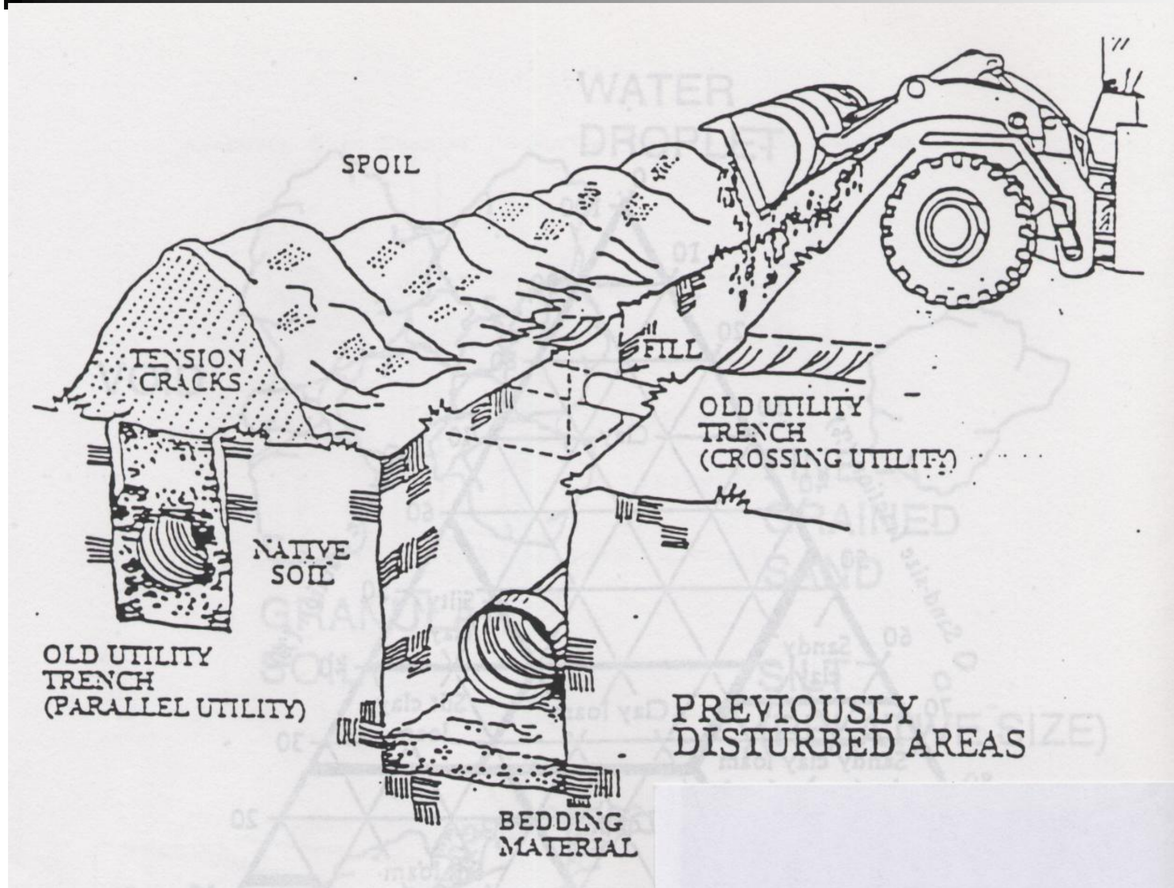
Rotational failure (Lew and Thompson, 1997)

Mechanics of failures (8)



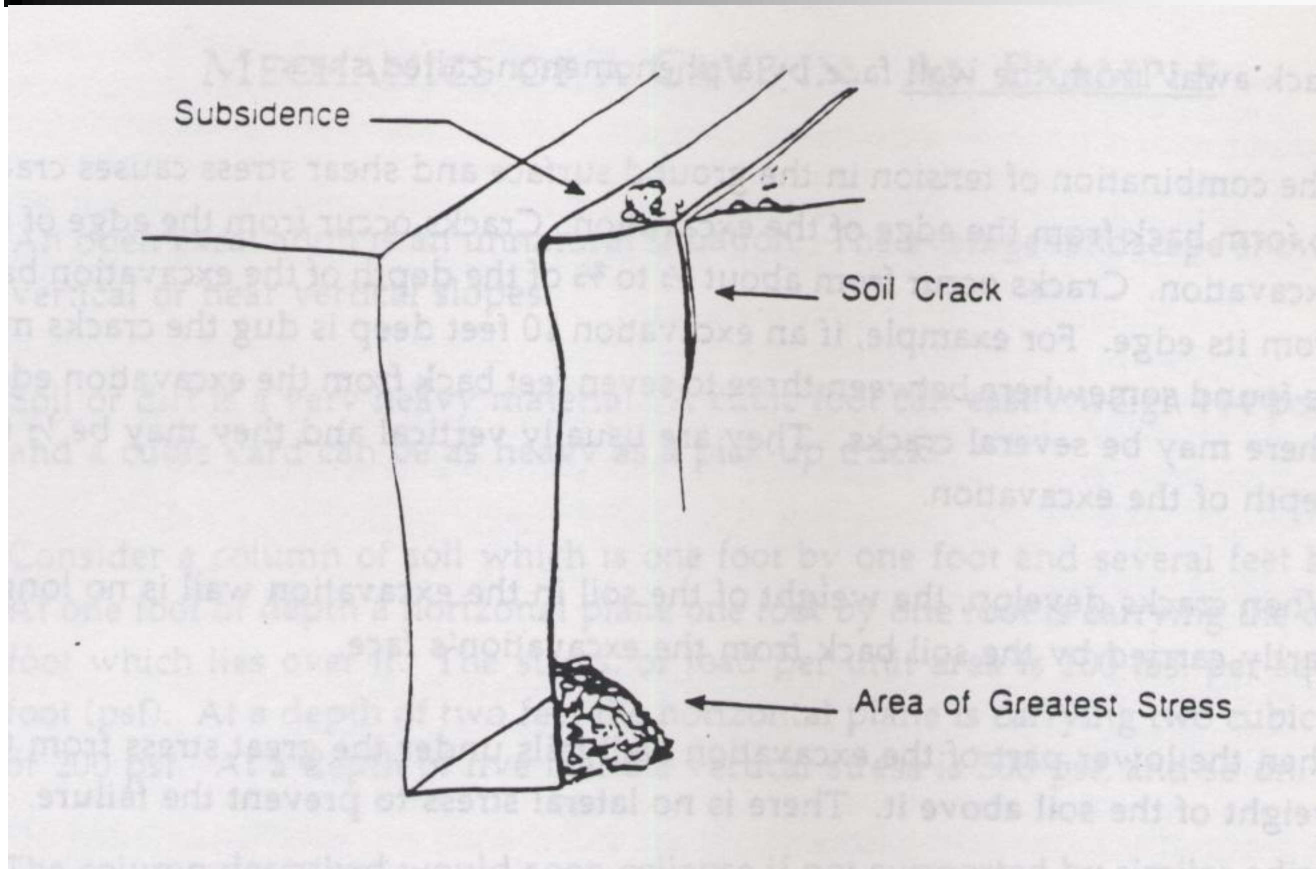
Soft pockets (Lew and Thompson, 1997)

Mechanics of failures (9)



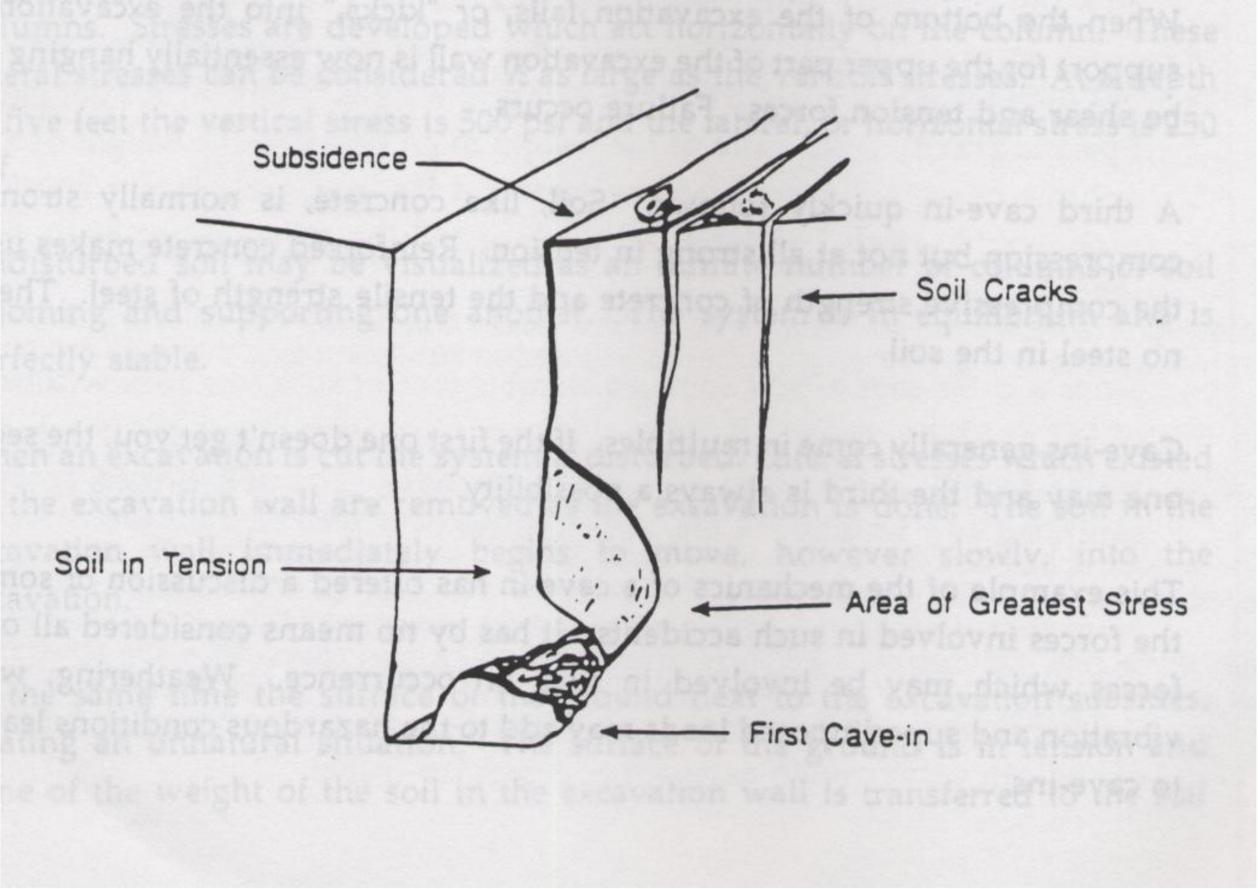
Previously disturbed areas (Lew and Thompson, 1997)

Mechanics of failures (10)



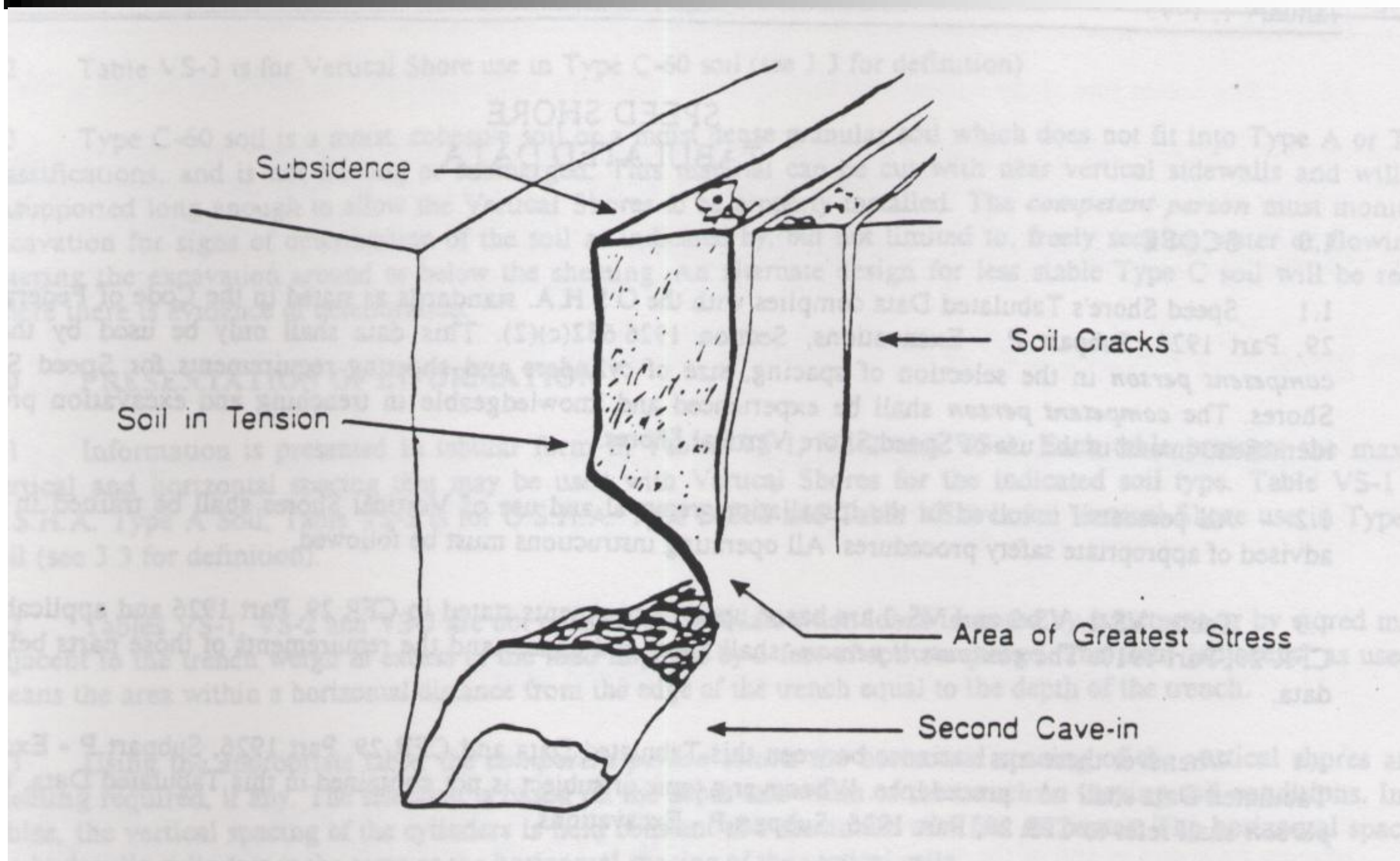
Cave in (Part A) (Lew and Thompson, 1997)

Mechanics of failures (11)



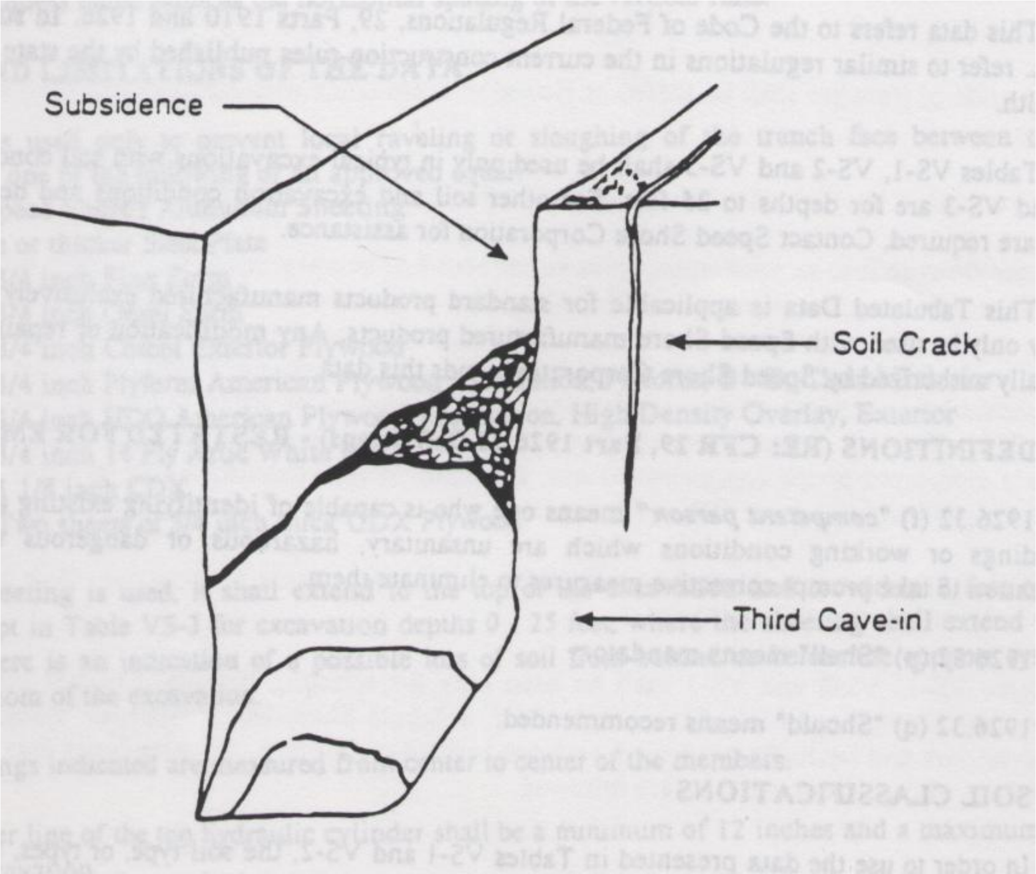
Cave in (Part B) (Lew and Thompson, 1997)

Mechanics of failures (12)



Cave in (Part C) (Lew and Thompson, 1997)

Mechanics of failures (13)



Cave in (Part D) (Lew and Thompson, 1997)

Research – Excavation failures (1)

- **296 Summaries of OSHA fatality investigations, 1997-2001 (Arboleda & Abraham, 2004 in Plog, Materna, Vannoy, & Gillen, 2006):**
  - **94% of cave-ins - no protective systems in place**
  - **84% of companies (248) had received at least one prior OSHA citation. Smaller contractors (less than 50 employees) and small projects (costs below $250 000) tended to have higher death rates**
- **44 case files from OSHA inspections of fatal trench collapses, 1997-99 (Deatherage *et al.,* 2004 in Plog, Materna, Vannoy, & Gillen, 2006):**
  - **29 cases (66%) - failure to provide trench protection**
  - **23 cases (52%) - lack of daily inspections by competent person**
  - **23 cases (52%) - no training provided**

Research - Excavation failures (2)

- Other contributing conditions were:
  - Spoil pile within 610mm of edge - 18 cases (41%)
  - Rain / Standing water - 15 cases (34%)
- 2002 survey of contractor members of the National Utility Contractors Association on use of trench boxes and safety practices - 151 respondents (Hinze, 2005 in Plog, Materna, Vannoy, & Gillen, 2006):
  - Identified problems with trench boxes, including not using them when they are onsite
  - Taking other shortcuts that violate the OSHA standard and put workers at risk

Research - Excavation failures (3)

Trenching-related fatalities, USA (Pachico, 2004):

- 1992-2002 (384 No. = 35 / Year):
  - Event leading to injury:
    - Cave-in 274 (71%)
    - Struck by falling object 18 (5%)
  - Main occupations:
    - Labourers 201 (52%)
    - Plumbers / Pipe fitters 33 (9%)
- 2003 (57 no.):
  - Event leading to injury:
    - Cave-in 38 (67%)
  - Main occupations:
    - Labourers 33 (58%)
    - Supervisors / Managers 9 (16%)

Research - Excavation failures (4)

Trenching / Excavation related fatals and non-fatals, California, January 93-June 04:

- Type of event (162 No.)
  - Struck by 63 (39%)
  - Caught in or between 55 (34%)
  - Fall from elevation 13 (8%)
  - Electrical shock 5 (3%)
  - Struck against 5 (3%)
  - Unknown, not reported, and other 21 (12%)

Economics of excavation H&S

Lew and Thompson (1997):

- Cost of trench collapses is about 7% to 8% of the cost of construction
- Cost of prevention is less than this
- Cost of properly shoring the walls of a trench and training employees in safe excavation procedures is less than it does to not protect it and train

Hazards (1)

- **Health:**
  - Vibrating equipment such as paving breakers
  - Noise
- **Safety:**
  - Collapse of sides
  - Struck by falling objects including earth
  - Struck or run over by construction vehicles or plant
  - Falls into excavations
  - Falls from plant, materials, or ladders
  - Collapse of structures that have been undermined
  - Contact with electricity
  - Gas explosion
- **Ergonomic:**
  - Bending and twisting the back
  - Use of body force

Hazards (2)

- Repetitive movements
- Over exertion
- Reaching away from the body

Ground movement (1)

Ground type markedly affects the probability, timing, and the extent and nature of collapse. However, the following increase the risk of collapse:

- Loose, uncompacted granular soils such as sand or gravel
- Excavations through different strata i.e. a weak layer lower down can undermine more stable layers above
- The presence of ground water and the effect on the excavation sides of run-off surface water running into the excavation
- Made up ground
- Proximity to earlier excavations
- Loose blocks of fractured rock
- Weathering e.g. rain, drying out etc.
- Vibration from plant, equipment, road and rail traffic

Ground movement (2)

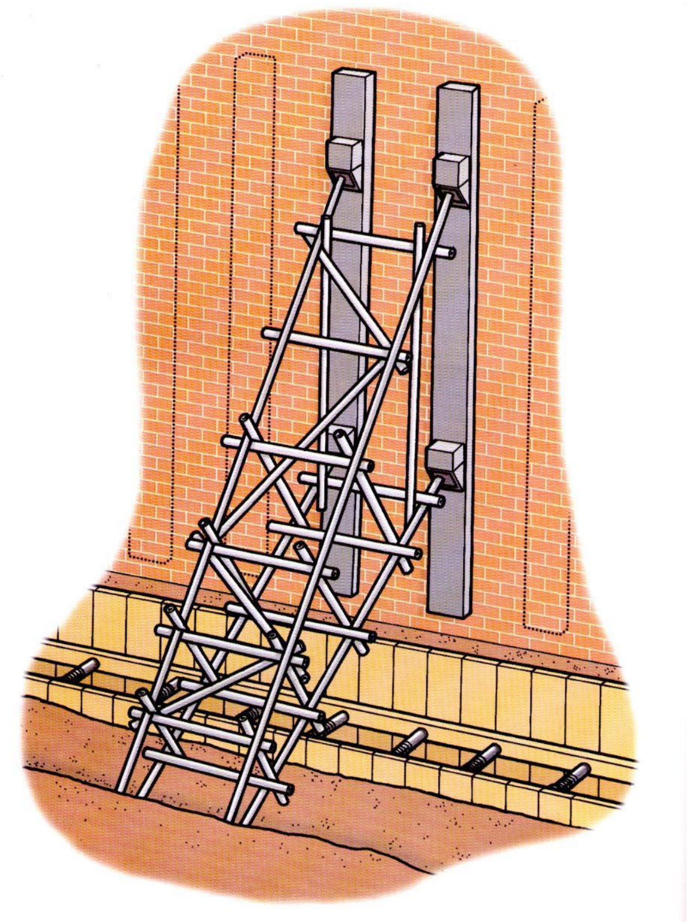
- Surcharging of stored materials, and plant and equipment and
- Proximity of loaded foundations
- Damage to the support system by personnel
- Undercutting of the road pavement structure or kerbs

Poor trenching practices

Lew and Thompson (1997):

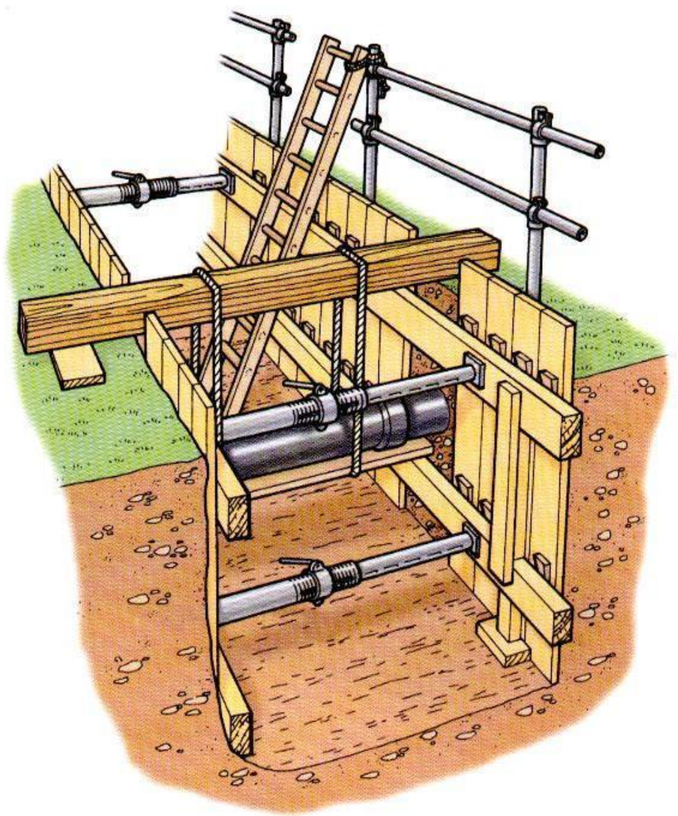
- No plan
- Not ordering the necessary materials
- Untrained workers
- Untrained ‘competent’ person
- Trenching ahead of supports
- Working outside or supports or trench box
- Installing supports from the bottom

Stability of adjacent structures and services



Shoring of building with excavation at base of building (HSE, 1999)

Traditional ground support – Trench sheets (1)



Timbered excavation with ladder access and supported services (HSE, 1999)

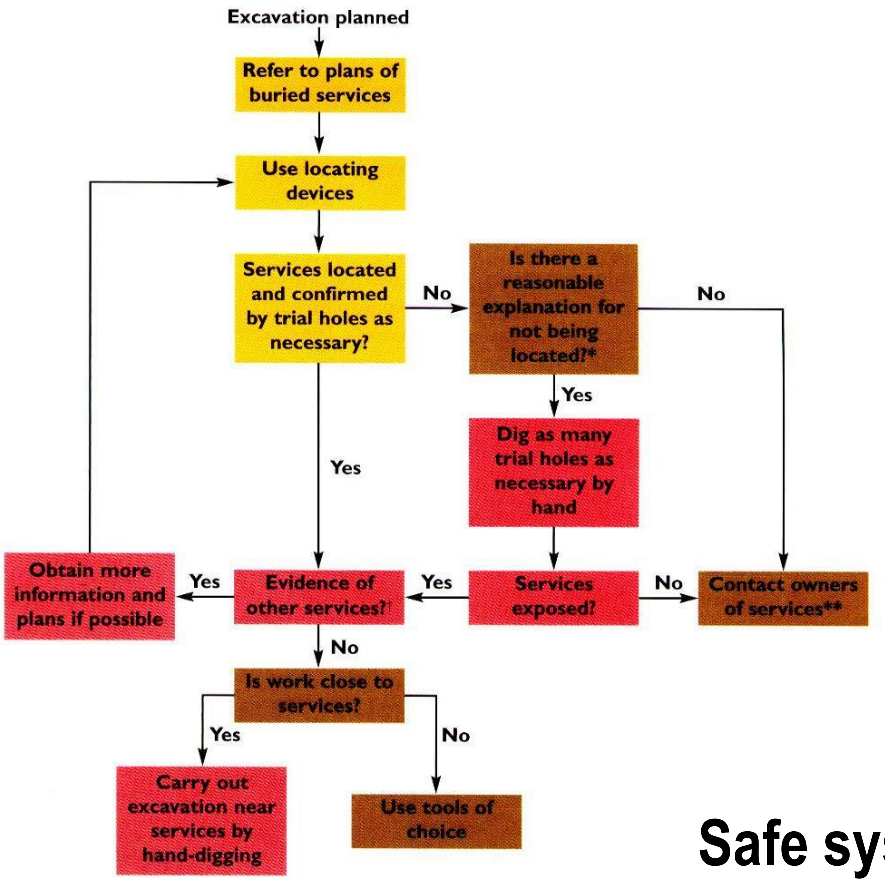
Traditional ground support – Trench sheets (2)

Culvert construction within a trenched sheeted excavation, Umhlanga (Smallwood, 2007)

Traditional ground support – Trench sheets (3)

Culvert construction within a trenched sheeted excavation, Umhlanga (Smallwood, 2007)

Underground services – safe system of work



Safe system of work flow diagram (HSE, 2000)

Location devices (1)

- **Hum detectors:**
  - Receiving instruments which detect the magnetic field radiated by electricity cables which have a current flowing through them
  - Do not respond to:
    - Cables where little or no current flowing
    - Direct current cables
    - Well-balanced high-voltage cables that generate relatively little field
- **Radio frequency detectors:**
  - Receiving instruments which respond to low-frequency radio signals which may be picked up and re-emitted by long metallic pipes and cables
- **Transmitter-receiver instruments:**
  - A small portable transmitter or signal generator can be connected to a cable or pipe or placed very close to it so that the signal is introduced into it
  - The receiver can then detect the signal

Location devices (2)

- **Metal detectors:**
  - **Conventional detectors will usually locate flat metal covers, joint boxes, but may well miss round cables or pipes**
- **Ground probing radar:**
  - **Method capable of detecting anomalies in the ground**
  - **When the anomalies can be plotted into a continuous line, doing so may indicate a cable**

Safe digging practices

- Excavate after a location device has been used to determine the position and route
- Trial holes using suitable hand tools to confirm the position of any buried services
- Hand-held power tools and mechanical excavators are the main causes of danger – do not use close to services
- Hand tools can also be a common source of injury
- Excavate alongside the service rather than directly above it:
  - Final exposure by horizontal digging
  - Insulated hand tools when hand digging near electrical cables
  - Use spades and shovels (curved)
  - Only use picks, pins, or forks to free lumps of stone
  - Do not use picks in soft clay or other soft soils

Research - Barriers (1)

34 Interviews (Plog, Materna, Vannoy, & Gillen, 2006):

- Attitude:
  - Casual attitude on the part of employers and workers
  - Workers believe a cave-in will not happen to them – consequently willing to enter an unprotected trench
  - Workers also believe that a cave-in can be outrun
- Lack of training:
  - Lack of appropriate training for competent persons and workers
  - In preferred language
  - Contractors inexperienced and ignorant regarding trenching hazards
- Insufficient enforcement
- Costs:
  - Cost of trenching equipment - transportation, installation, and storage, are excessive
  - Competitive bidding

Research - Barriers (2)

- **Other:**
  - **Overly complicated regulations**
  - **Lack of certification or a training standard for competent-person training providers**
  - **Workers' compensation insurance system(s), for not providing adequate financial incentives for employers to create exemplary H&S programs; also for not holding employers financially responsible for unsafe conditions resulting in serious injury or death, for instance, through substantially higher premiums**

Research - Interventions

34 Interviews (Plog, Materna, Vannoy, & Gillen, 2006):

- Training and outreach:
  - Management, supervisors, and workers
  - OSHA excavation standard
  - Reasons for using protective equipment
  - Information regarding trench shielding methods
- Regulatory action:
  - Increasing OSHA fines
  - Increasing enforcement of the OSHA multi-employer citation policy
  - Mandating certification of competent person trainers
  - Prosecuting willful offenders
  - Making protective systems a bid item per lineal foot (meter)
  - Linking revocation of contractor licenses to OSHA trenching violations
- Technology improvements - developing lighter-weight shielding would help bring down the cost of transporting and installing

Culture

Lew and Thompson (1997):

- **Total commitment to trench safety and the elimination of trench deaths**
- **Trench cave-ins are not accidental**
- **Trench cave-ins are preventable**
- **Team work to evolve sensible solutions**
- **Competent person**

Appointment of a competent person

Lew and Thompson (1997):

- Knows the Constitution, OH&S Act, Construction Regulations, and Excavation Regulation
- Proficient in soil classification and the use of soil testing
- Knowledgeable in the proper use of trench safety equipment
- Has the ability to recognise unsafe conditions, the authority to stop work when unsafe conditions exist, the ability to abate the unsafe condition, restarting work in a safe economic manner

Design, procurement, and construction

Lew and Thompson (1997):

- Geo-technical information
- Pre-tender site inspection
- Pre-tender trench safety plan (and H&S plan)
- Review of pre-tender trench safety plan (and H&S plan)
- Pre-construction discussion and approval of trench safety plan (and H&S plan) and review of financial provision for trench safety
- Trench safety inspection
- Revision of trench safety plan (and H&S plan)

Pre-planning

- What types of soil will be found?
- What are the soil moisture conditions?
- Has the soil previously been disturbed?
- How large will the excavation be?
- How long will the excavation be open?
- What kinds of weather can we expect?
- What kinds of equipment will be on the job?
- Will the excavation be near structures?
- Is traffic control needed near the excavation?
- What sources of vibration will be nearby?
- Will water be a problem?
- What kind of shoring? How much?
- Underground installations?

Visual tests (1)

- **Observe samples of soil that are excavated and soil in the sides of the excavation. Estimate the range of particle sizes and the relative amounts of the particle sizes:**
  - Soil that is primarily composed of fine-grained material is cohesive material
  - Soil composed primarily of coarse-grained sand or gravel is granular material
- **Observe soil as it is excavated:**
  - Soil that remains in clumps when excavated is cohesive
  - Soil that breaks up easily and does not stay in clumps is granular

Visual tests (2)

- Observe the side of the opened excavation and the surface area adjacent to the excavation:
  - Crack-like openings such as tension cracks could indicate fissured material
  - If chunks of soil spill off a vertical side, the soil could be fissured
  - Small spills indicate moving ground and can pose potentially hazardous situations
- Observe the area adjacent to the excavation to identify previously disturbed soil i.e. evidence of existing utility and other underground structures
- Observe the opened side of the excavation to identify layered systems. Examine layered systems to identify if the layers slope toward the excavation. Estimate the degree of slope of the layers

Visual tests (3)

- Observe the area adjacent to the excavation and the sides of the opened excavation for evidence of surface water, water seeping from the sides, or the location of the water table level
- Observe the area adjacent to the excavation and the area within the excavation for sources of vibration that may affect the stability of the excavation face

(Oregon OSHA, 2006)

Manual tests (1)

- **Plasticity test:**

  Shape a sample of moist soil into a ball and try to roll it into threads about 3.2mm in diameter. Cohesive soil will roll into 3.2mm threads without crumbling

Manual tests (2)

- **Dry strength test:**
  Hold a dry soil sample in your hand. If the soil is dry and crumbles on its own or with moderate pressure into individual grains or fine powder, it's granular. If the soil breaks into clumps that are hard to break into smaller clumps, it may be clay combined with gravel, sand, or silt.

Manual tests (3)

- **Thumb penetration test:**
  This test roughly estimates the unconfined compressive strength of a sample. Press your thumb into the soil sample. If the sample resists hard pressure, it may be Type A soil. If it's easy to penetrate, the sample may be type C.

Manual tests (4)

- **Pocket penetrometers:**
  Offer more accurate estimates of unconfined compressive strength. These instruments estimate the unconfined compressive strength of saturated cohesive soils. When pushed into the sample, an indicator sleeve displays an estimate in tons per square foot or kilograms per square centimeter.

(Oregon OSHA, 2006)

Key points

- Risk management
- Excavation results in ‘columns of earth’ that were supporting each other and the ‘to be exposed sides’ being removed
- H&S culture
- Competency
- Financial provision and other resourcing
- The cost of excavation ‘accidents’ exceeds the cost of excavation H&S
- Planning
- A multi-stakeholder issue - clients, project managers, designers, quantity surveyors, and contractors
- Client BRAs, H&S specifications, and designer reports should facilitate the development of H&S plans, and H&S files

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Links

- **www.achasm.co.za**
- **www.sacpcmp.org.za**
- **www.mandela.ac.za/construction**