SARF

better roads

South African Road Federation

Basic Philosophy for Chap 12

- During tender stage Tenderer prepares a proposed methodology for each aspect of the work. Thus appoint an experienced geotechnical sub contractor, preferably aided by an experienced geotechnical consultant,
- Once appointed, the Contractor updates this to a Construction Methodology, and submits to the Engineer for approval,
- The Engineer in conjunction with the Contractor refines this until an Engineer-Approved Construction Methodology is attained.
- NB: Contractor remains responsible for all aspects of the works

Alan Parrock will present sections on:

Piling
Ground Improvement
Mechanically Stabilised Earth Walls
Geosynthetics

Here goes with the first one:

Piling

Auger bored piles - are those piles formed in holes bored with an auger drilling rig, with or without use of casing.

Continuous flight auger (CFA) piles - are constructed by drilling in a continuous operation, a CFA auger into the ground and, on reaching required depth, pumping concrete or grout via a pressurised system, also in a continuous-motion, down the hollow stem as the ground-laden auger is steadily withdrawn.

Full displacement auger piles - are piles constructed by drilling a displacement auger comprising a lower tapered augered portion of the flight, a central displacement section and an upper auger section with reverse flighting and, on reaching required depth, pumping concrete or grout down the hollow stem as the auger is steadily withdrawn.

Underslurry Piles - are piles excavated either by auger or grab-excavation (resulting in circular and rectangular cross-sections, termed barrettes) under a head of bentonite/polymer slurry to prevent collapse of the pile excavation.

Screwed In Casing Auger Piles (SICAP) - are formed by screwing in a temporary casing and later removing internal material with an auger while at all times maintaining a plug at the base to prevent water ingress. Twin rotary-drive systems may be used in which casings are installed in a counter-clockwise direction with one drive head and clockwise-rotating augers with another.

Oscillator bored piles - are piles installed in holes bored by oscillating casings with hydraulic rams into the ground and removing spoil as progress is made. Casings may be temporary or permanent.

Percussion bored piles are formed by percussion driving segmental-coupled-casings and excavating soil inside the casing with a coring tool. On attaining a suitable pile depth, a dry-cast bulbous base is formed. The pile may either be formed by filling the empty bore with high slump concrete while withdrawing the temporary casing or dry mix concrete is pounded as the casing is withdrawn forming a series of bulbs along the shaft.

Cast in situ piles (DCIS Piles) are driven piles installed in holes formed by utilising a drop hammer acting on a sand/stone plug within a tube. At founding level the plug is expelled from the secured tube. A bulbous base is formed by hammering measured quantities of inserted dry mix concrete until the theoretically calculated energy required to ensure load capacity, is achieved

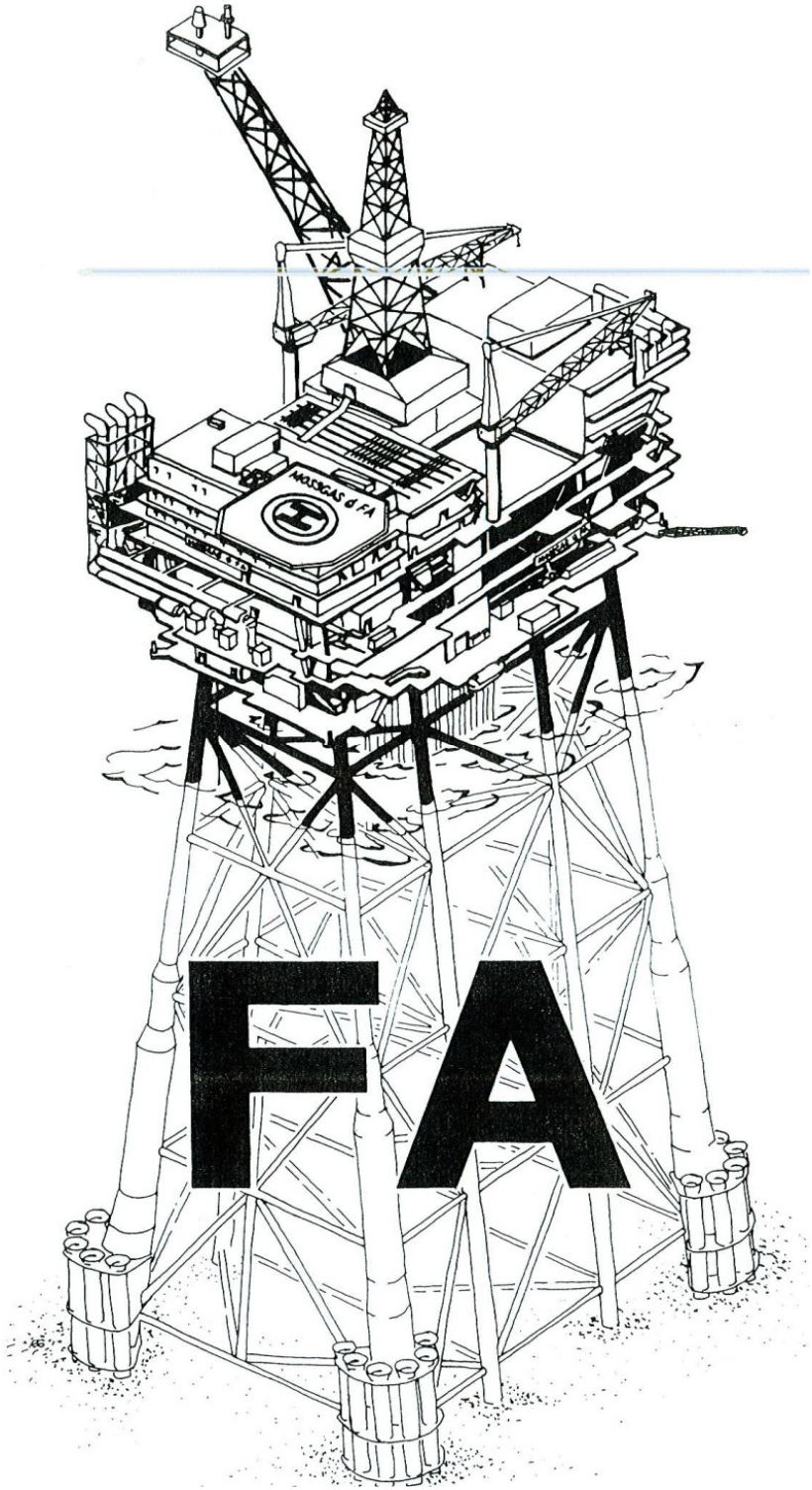
Precast piles - are driven precast reinforced concrete piles generally top driven into the ground using hydraulic or drop hammers displacing in situ soils. They are cast in any suitable cross-section such as square, hexagonal, rectangular or circular

Hollow tube steel piles - are driven steel tubes/permanent casings fitted with an end plate or rock shoe which is driven either from top or base of tube. The pile is sometimes completed by filling the installed tube with concrete and reinforcing steel. Ductile cast iron piles (DIPs) fall into this category.

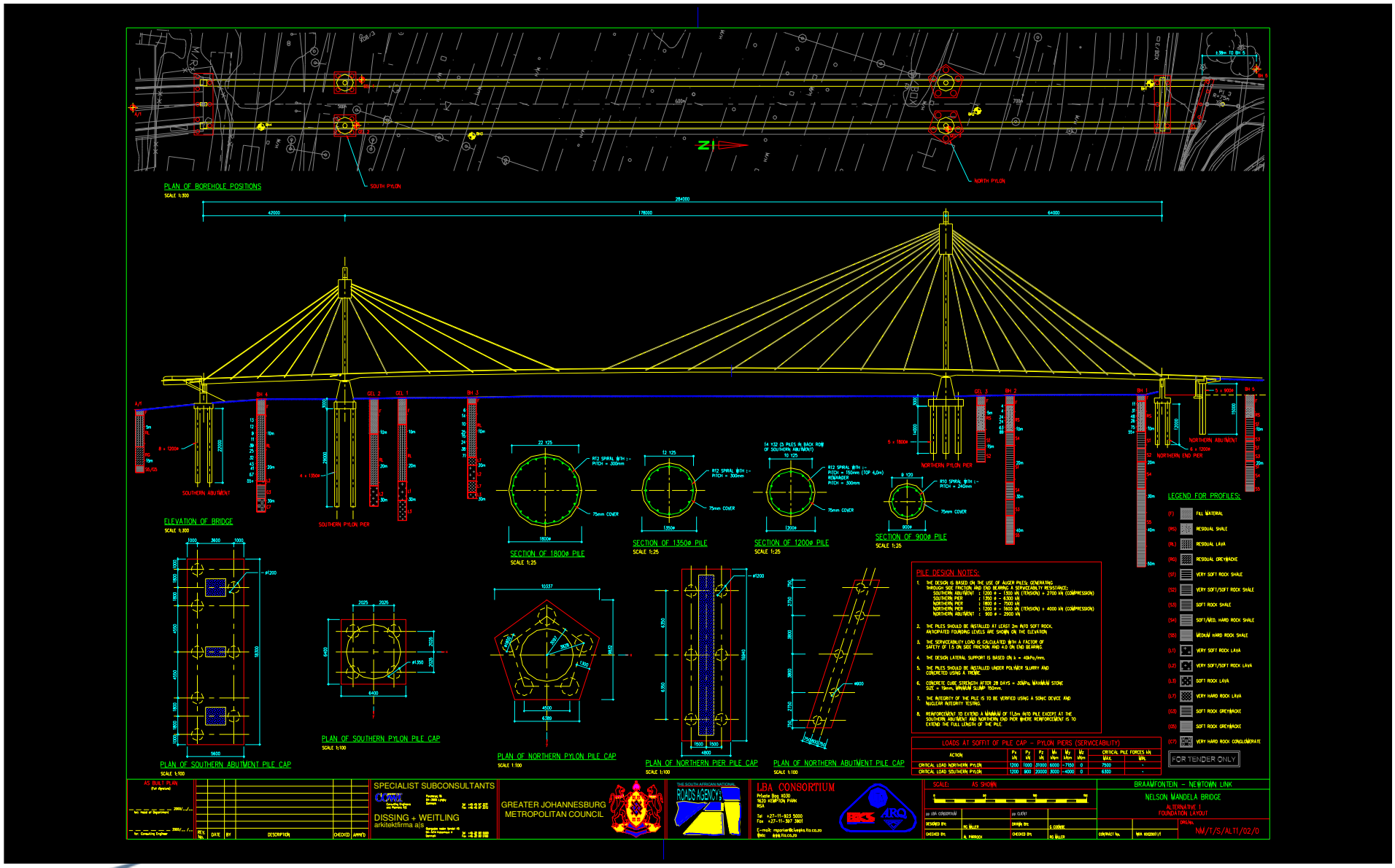
Structural Steel Section Piles - or H-piles are driven piles installed either by vibration, drop or hydraulic hammer.

Self-drilling Micropiles - provide a composite load bearing system where continuously threaded hollow bar with a diameter of less 300 mm is used as load bearing element. They are installed via rotary percussion with simultaneous flushing of the cuttings followed final grout injection under pressure to fill the annulus between the tendon and the insitu material.

- 24 x 136m long piles
- 2.44(8ft) diameter
- 500 tonne steel tubes
- 80mm wall thickness
- Installed in 100m of water
- Limestone crust
- Piling hammer 3 x D10 dozers
- Free fall for 67m at 20m/sec
- Installation 70% of fatigue life
- Grouted into the mudmat



Some pictures



O-Cell testing in a 1.8m φ pile offshore

R-515
AR 08
SOIL MEC Ground Engineering
2005 7 25

General requirements

- Approval periods
- Material quality and specifications
- Construction Equipment
- Execution of the Works
- Workmanship

Things to watch out for

- Rock hardness – Table A12.1.7-1
  - R4 -Point Load Index (PLI). Calibration between PLI and Uniaxial Compressive Strength (UCS) shall be conducted and not just accepted as 24,
  - UCS testing is only valid for samples where length = 2.5 times diameter or else a correction factor established

Things to watch out for

- Screwed in casing auger piles (SICAP)
  - Normally a plug of soil is left at the base of the piles of sufficient length to prevent material and water ingress to the pile
  - If this is breached, especially with long piles, then pressure differential between inside and outside pile causes base failure. In this case very little end bearing is present and side friction is compromised for quite a length near pile end.

Things to watch out for

- Auger underslurry piles
  - Slurry may not always remain in suspension and some usually drops under gravity to pile base,
  - This is usually sucked out under vacuum, with a centrally-located hose and suction head,
  - In certain cases much slurry muck may still be present around pile periphery, as the suction procedure concentrates at pile centre
  - This is usually detected by Cross Hole Sonic Logging (CHSL) and must be eliminated for example as detailed below, especially for end bearing piles.

Things to watch out for

- CHSL tubes
  - Coto calls for 50 or 85mm diameter tubes,
  - Special note shall be made for where pipes are joined by welding as this usually shows up as an anomaly in CHSL testing,
  - 85mm φ is preferred as this allows for ingress by NX sized drill heads (some 76mm outer diameter)

Things to watch out for

- CHSL tubes continued
  - CHSL tubes should be sealed at the base with a welded water proof plate
  - This enables core drilling to be conducted through the tube, through the bottom reaches of the pile, and into and through the rock material at the base of the pile,
  - This enables integrity of pile base and beyond to be determined,
  - If any suspect results are obtained, soft zones may be watered-jetted exiting through adjacent tubes and grouted to repair defects.

Some tips

- Precast piles
  - For optimal concreting of precast piles, plan procedure for completion by knock-off time circa 16:00 each day,
  - Steel trowel finish the upper face such that it is as smooth as the internally shuttered faces,
  - Wrap complete pile/shutter in 300 micron plastic,
  - Due to high cement content of precast piles, this plastic wrapping causes internal temperatures to rise significantly (to near 60°C) and in effect steam cures the pile overnight such that it is strong enough for removal and stacking the following morning.

Some tips

- Precast piles continued
  - If the upper face of the precast pile is not smoothed via a steel trowel as detailed above, it is somewhat rough and generates a very high friction surface,
  - During driving this increased friction of one face causes the pile to deflect significantly from vertical and in extreme circumstances snaps during driving.

Some tips

- Auger piles
  - If it is found that the action of augering and material removal causes smooth walls with low skin friction, then a convenient method to restore side wall friction is a install a single cutting tooth on auger pile tip projecting some 50 to 75mm and rapidly auger in and out the hole,
  - This effectively increases pile diameter and generates a rough wall aiding side friction.

Some tips

- Continuous Flight Auger (CFA) piles
  - Length of the CFA auger should be sufficient to reach design depth in one continuous operation, as any pauses cause rapid changes in pore pressures and flighting to commence operations results in voids or compromised pile sections,
  - Instrumentation is necessary such that all aspects of the operation are monitored and controlled between strict norms.

Some tips

- D or P concrete
  - Consideration should given to the use of Fly Ash in cement used for piling especially where Class D class is specified,
  - Lower heats of hydration and increased durability are probable benefits.

Ground Improvement

Techniques

- Geotechnical grouting
- Jet grouting
- Compaction grouting
- Dynamic Compaction (DC)
- Rapid Impact Compaction (RIC)
- Vibration compaction
- Underpinning
- Preloading
- Basal Reinforcement
- All the above require specialist sub-contractors

Examine each in more detail

- Geotechnical grouting
  - Contact grouting is the injection of grout under pressure into the interface between man-made structures and soil/rock.
  - Fissure Grouting - Fissure grouting is injection of grout under pressure into fissures, joints, fractures and discontinuities, in rock.
  - Gravity grouting is grouting carried out with no applied pressure, sometimes referred to as tremie-grouting.
  - Permeation grouting is the replacement of interstitial water or air in a porous medium with grout at injection pressures sufficiently low to prevent displacement.
  - Jet Grouting - Jet grouting is a ground improvement technique whereby in situ materials are mixed with cementitious grout by eroding the in situ material with a high velocity cementitious grout slurry, with or without compressed air/water, through an injection monitor attached to the drill string to generate a mixture of soil and cement (soilcrete).

Geotechnical grouting contd..

- Single Jet Grouting is the technique technique where a single fluid, typically neat cementitious grout, is used.

- Double Jet Grouting is the technique where one fluid, typically neat cement grout, is injected at high velocity assisted by air.

- Triple Jet Grouting is the technique where one fluid, typically water, is injected at high velocity through horizontal radial nozzle(s) and is assisted by a second "fluid", typically air delivered through a coaxial nozzle(s), to erode the in-situ soil, while a separate nozzle placed lower on the monitor delivers a third fluid, typically neat cement grout, at lower velocity to simultaneously fill the soil zone eroded by the cutting fluids (air and water).

- Compaction Grouting is a high-pressure, stiff mortar grouting technique that displaces and compacts low density soils.

Compaction techniques

- Dynamic Compaction (DC)
  - Dynamic Compaction (DC) is the process whereby density of in-situ soil is improved by dropping a large weight or pounder from great height onto the soil to be compacted. Depth of improvement is typically 6-8m.
  - Shock of the falling weight may cause damage to nearby structures/services and potential impacts must be determined.
  - Dynamic replacement is a technique whereby in situ soft/loose soils are displaced by stone columns driven into the soils by dynamic compaction. It is used in very soft cohesive with high moisture contents making compaction by conventional means impossible. The columns of stone are driven by a pounder as in Dynamic Compaction

Compaction techniques contd,,

- Rapid Impact Compaction (RIC) of in situ soils is achieved by repeatedly dropping a large weight or pounder of between 9 and 12 tonnes from a height varying from 1.0-1.5 m, at a high frequency (about 40 blows per minute, depending on machinery employed), onto ground to be compacted. Depth of improvement is typically 3-5m. RIC is carried out by impacting blows on a grid, triangular (3 prints) or square (either 4 prints or a 5-print sequence in which one is located in the middle of the 4).
- Ram size varies from 1.0-1.5 m diameter and grid size varies from 2.0-4.0m. Up to 50 blows per imprint may be required to achieve specified densification. Material may either be compacted as is or stone columns may be constructed by placing selected stone at regular intervals in the created voids and continuing compaction thereon driving stone into the substrata. Stiffness of these stone columns needs to be controlled.

Let us examine both in more detail

For DC using a typical 6m x 6m grid with one in the middle. 15 blows of a 12 tonne mass falling 18m compacting 6m deep.

Total energy input = 120 x 18 x 15 x 2 (This last number is indicative of a quarter of each corner imprint (2 x ¼ =1) plus the one in the middle)

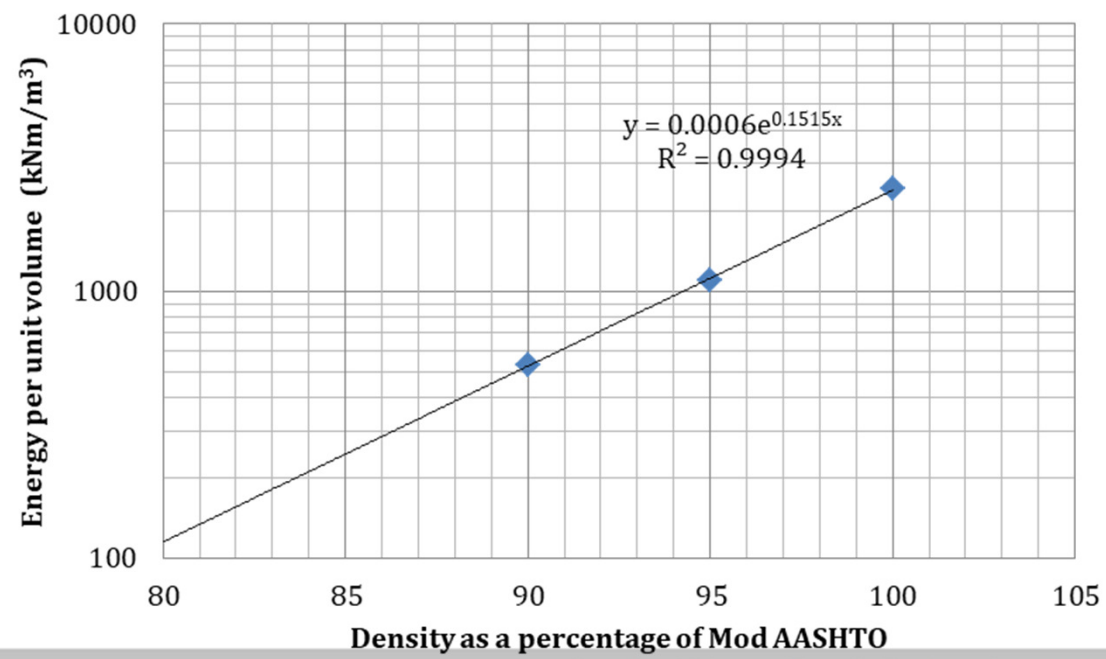
= 64 800kNm. Volume = 6 x 6 x 6 = 216m^3. Energy per unit volume = 300kNm/m^3

As per graphic alongside

This would typically generate

A density of some

86% Mod AASHTO



Let us examine both in more detail

For RIC using a typical 3.5m x 3.5m grid with one in the middle. 50 blows of a 9 tonne mass falling 1m compacting 3m deep.

Total energy input = 90 x 1.0 x 50 x 2 (This last number is indicative of a quarter of each corner imprint (2 x ¼ =1) plus the one in the middle)

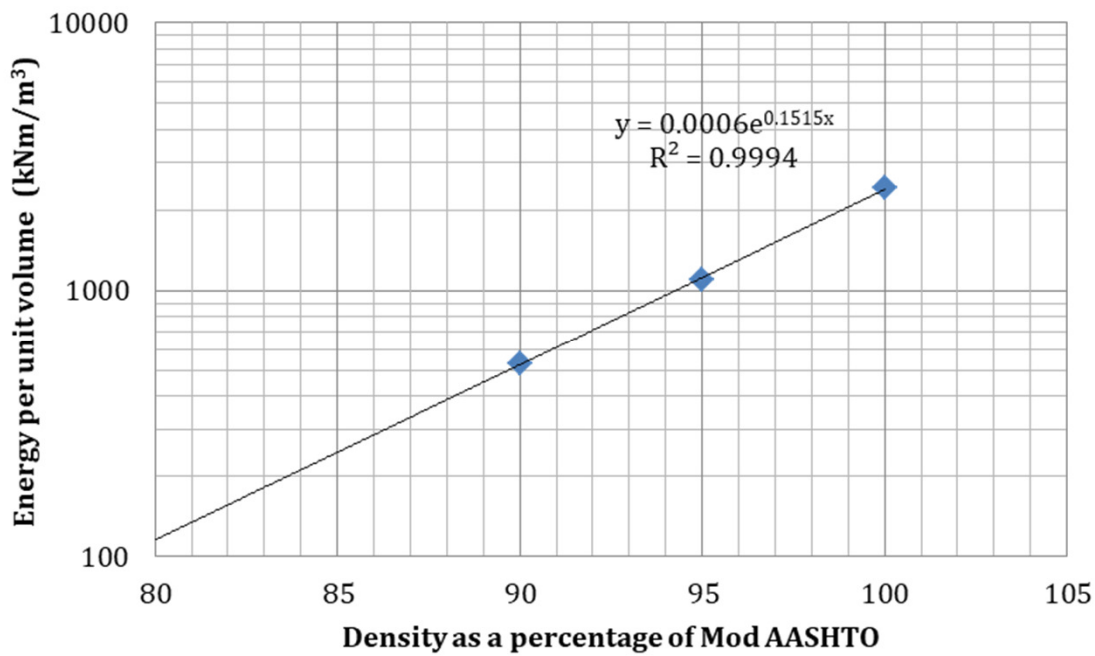
= 9 000kNm. Volume = 3.5 x 3.5 x 3 = 36.75m^3. Energy per unit volume = 244.9kNm/m^3

As per graphic alongside

This would typically generate

A density of some

85% Mod AASHTO



Thus one may deduce very similar compactive efforts with the large rig being more suited to deeper depths while the smaller one for compaction of shallower formations.

However speed of operation is critical with DC capable of a maximum of some 10 imprints per minute while RIC operates at some 40 blows per minute.

Also Oshima and Takada established that momentum (mass x velocity) is a better indicator of compaction than energy

As velocity is a function of the square root of drop height, this tends to somewhat negate large rig efficacy for intermediate depths.

- Vibration compaction
  - Vibration Compaction is the process whereby in situ soils are compacted by vibrating immersion probes inserted into the soil to increase relative density, stiffness and strength thereby reducing settlement as well as improving resistance to liquefaction. Vibration may have either horizontal or vertical amplitude and brings soil particles into a state of suspension allowing for their rearrangement and densification. Water jets assist penetration of vibrator into the ground and rearrangement of soil particles. Degree of soil improvement is largely dependent on grading of soil, natural resonant frequency and level of energy available. Vibration compaction consists of: Vibro-compaction is a technique, designed to induce compaction of granular materials at depth. The basic principle behind the process is that particles of non-cohesive soils can be rearranged by means of vibration.
  - Vibro-replacement is a technique derived by further developing the vibro-compaction process. Soils such as pure silts or mixed deposits of silt, and/or sand are improved by lateral displacement initially induced by probe insertion and further densified by the addition of coarse aggregate to create a stone column. Soil improvement relies on higher stiffness and shear strength of stone columns which act compositely with the surrounding soil.

- Underpinning
  - Underpinning is the process of staunching settlement of a structure post-construction. Underpinning may be accomplished by extending existing foundations in depth or in area to more supportive substratum or distributing load across a greater area, supplementing the support by providing additional piles or micro-piles or by ground improvement beneath existing footings.

  - Underpinning may be necessary when a) original foundations have insufficient bearing capacity/stability. Properties of material supporting the foundation may have changed (possibly through seepage or soil particle distribution or pore water dissipation), b) geotechnical characteristics misdiagnosed during investigation/design, c) Construction of nearby/adjacent structures necessitates excavation of existing foundations, d) to increase depth or load capacity of the structure It is more economical to upgrade the present structure's foundation than to construct a new one, e) earthquake, flood, drought or other natural causes have caused the structure to move, thereby requiring additional work in the form of underpinning.

- Preloading
  - Road embankment fills constructed over potentially compressible and weak ground require special construction procedures to be implemented to ensure their stability both during and post-construction. These may include slow construction or staged construction possibly with surcharge loading, generally in advance of adjacent conventional roadworks, preload monitoring is the process of measuring settlements, pore pressures and other parameters in order to ensure stability is maintained during construction by providing time for settlement and pore pressure dissipation.
  - Monitoring can consist of a) measurement of settlement of the fill embankment relative to the surrounding surface, b) pore water pressures in underlying materials subject to load, c) load cells/ earth pressure cells encompassed within constructed fill (e.g. Gloetzl cells), d) ongoing monitoring of the embankment side slopes with inclinometers.

- Basal reinforcement
  - Basal reinforcement may be required where soft deep deposits below fills make removal uneconomical or over undermined areas and karst regions where soft or voided zones require bridging. This basal reinforcement usually comprises geosynthetics in the form of polymeric or steel reinforcement to prevent embankment distress. The tensile capacity of the geosynthetic in conjunction with the fill above can be used in the repair/bridging of sinkholes or undermined areas. Void sizes up to 5m may be treated (provided the fill thickness is at least 2m thick) but specialised applications are necessary for larger voids.
  - Where the void or soft zone size exceeds 5m, steel cables are usually used in conjunction with a ring beam and appropriate matting to ensure material retention.
  - Basal reinforcement can also be addressed employing other sophisticated techniques such as included in this and other sections in this chapter, e.g. piling, compaction grouting, jet grouting, etc.

Self drilling anchors

RIC in Kenya

BSP RIC
HYUNDAI
800LC-9

BOMAG
BOMAG

JODAN
220LC-V

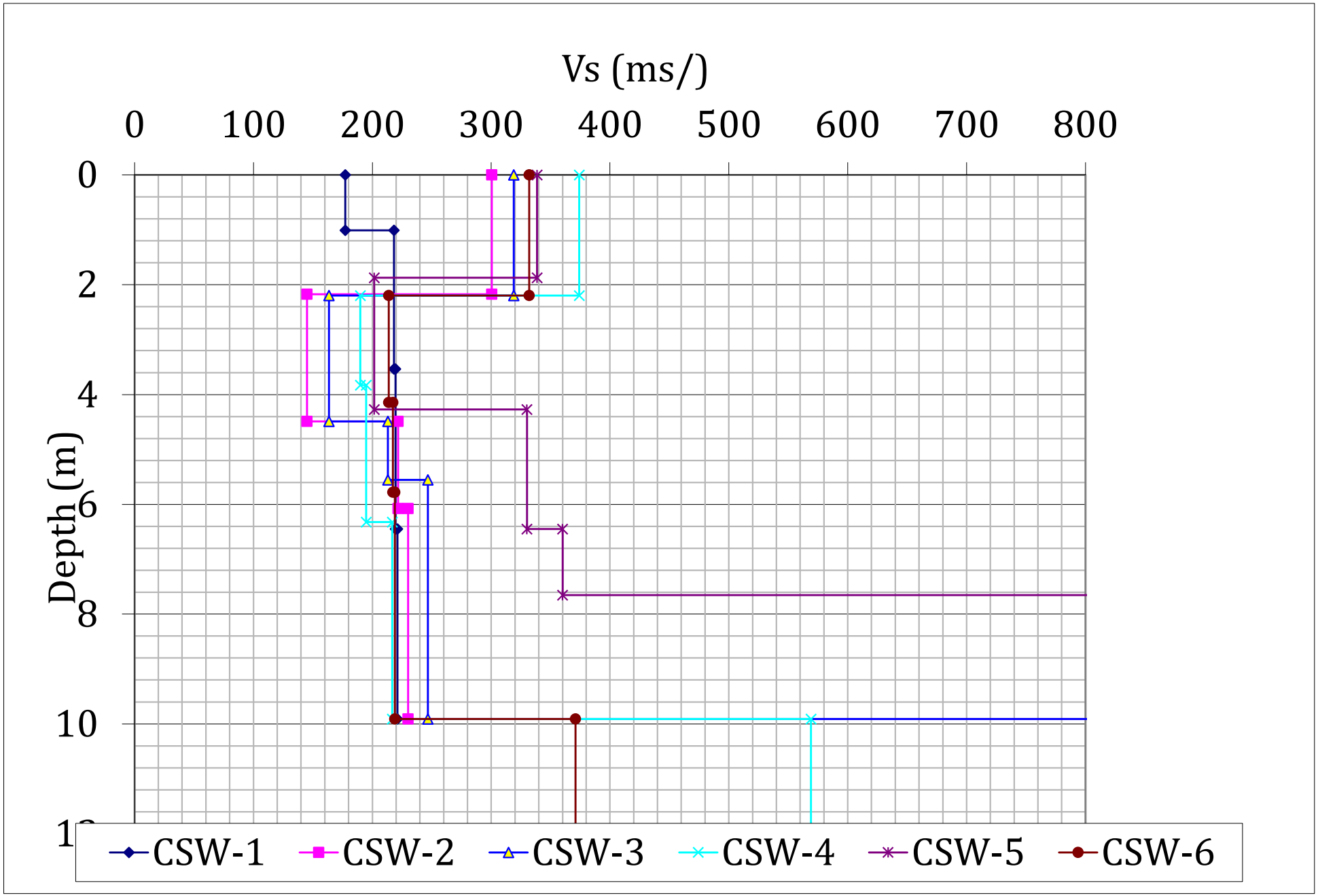
Vibratory roller compaction

Input cells		
Centrifugal force	530	kN
Frequency	1560	Vibrations/minute
Amplitude	2.85	mm
Operating speed	0.5	m/sec
Roller width	2.13	m
Layer thickness	2	m
Energy input	39.27	kNm
Volume in 1 second	2.13	m^3
Energy input/volume	18.44	kNm/m^3

Number of passes for

90%	29
93%	45
95%	61
98%	97
100%	131

Actual optimum derived from field trial was 32


Vs (ms/)
0
100
200
300
400
500
600
700
800
Depth (m)
0
2
4
6
8
10
CSW-1
CSW-2
CSW-3
CSW-4
CSW-5
CSW-6

C400-09A

RIC
RIC
RIC
CAT

Mechanically stabilised earth walls

- MSE walls and slopes
  - Concrete facings
  - Metallic reinforcement
  - Polymeric reinforcement
  - Accessories
- Gabions
  - General Boxes and Mattresses
  - Selvedges
  - Diaphragms and end-panels
  - Binding and connecting wire

Mechanically stabilised earth walls

Contractor responsible for both internal and external stability design

i. This is the single most contentious issue in MSEW
ii. In the past Contractor was responsible for internal stability
iii. Consulting Engineer responsible or overall stability
iv. However as following slides will show, it is doubted whether the expertise exists for this solution as both aspects are inter-related ie external stability conditions influence internal stability and probably vice versa.

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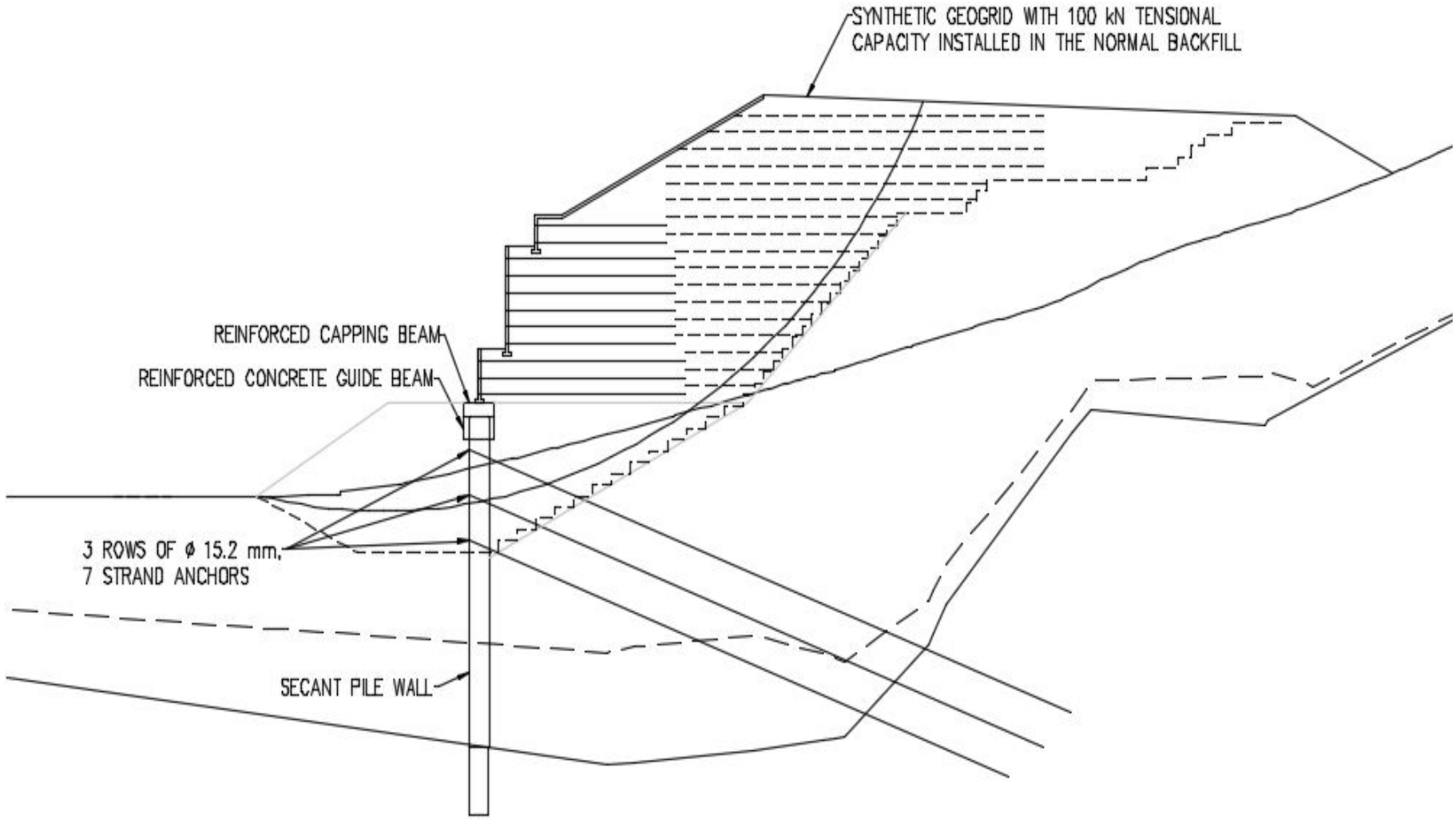
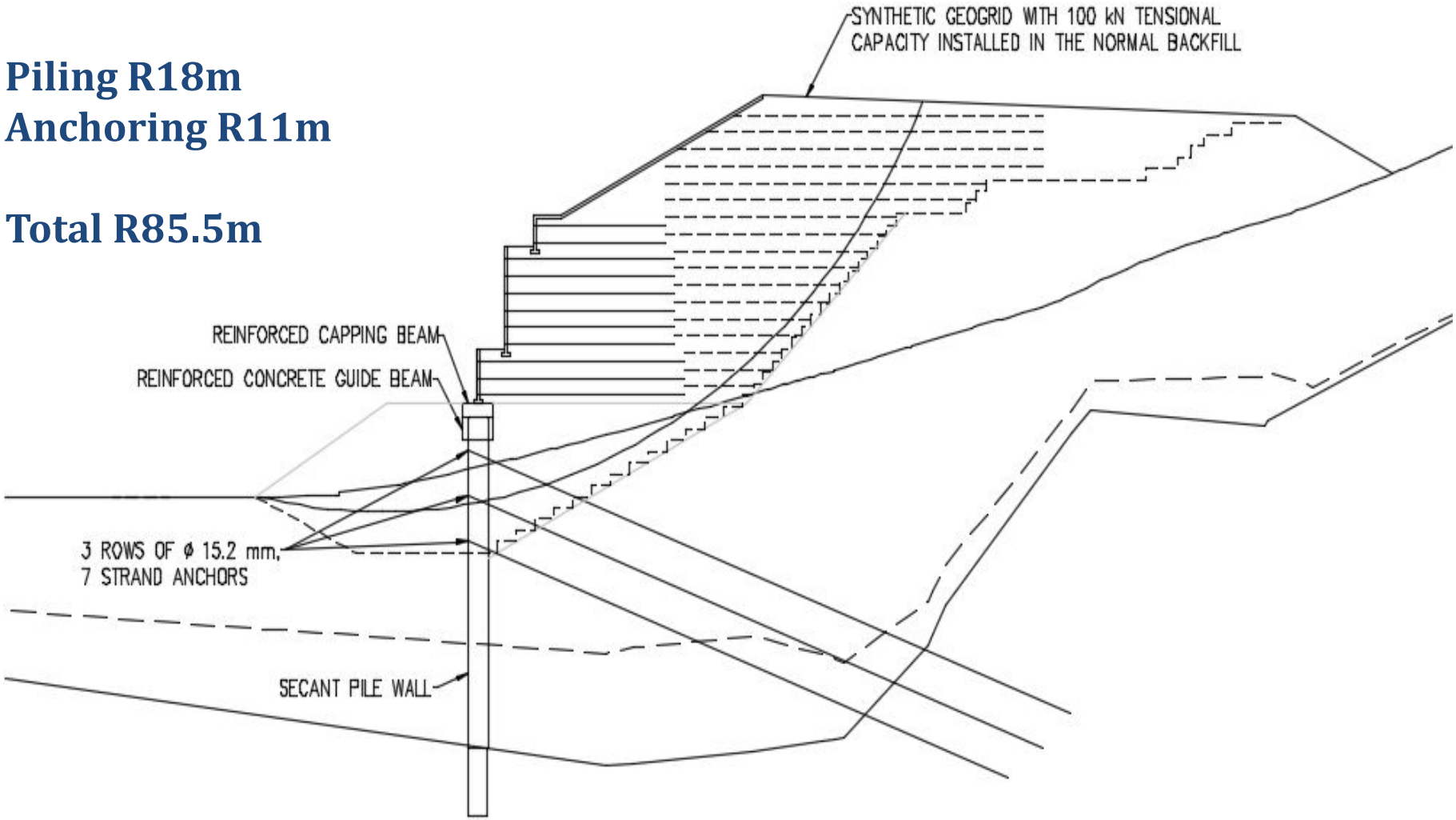

SYNTHETIC GEOGRID WITH 100 kN TENSIONAL
CAPACITY INSTALLED IN THE NORMAL BACKFILL
REINFORCED CAPPING BEAM
REINFORCED CONCRETE GUIDE BEAM
3 ROWS OF ø 15.2 mm,
7 STRAND ANCHORS
SECANT PILE WALL

Cost

Piling R18m
Anchoring R11m

Total R85.5m



Mechanically stabilised earth walls

- Type of reinforcement
  - Metallic
  - i. Strain at break about 0.1%
  - ii. Yield strength = 250MPa for mild steel
  - iii. Typically for a 311 mesh UTS = 50kN for mild steel 90kN for HT

  - Polymeric
  - i. Polyester: Strain at break some 10%
  - ii. UTS (highly variable) but some 100kN is possible
- Typically for a soil strain at failure ≈ 3%
  - i. Thus one deduces for metallic reinforcement most of load is carried by reinforcement and very little by soil, but reverses for polymeric

Mechanically stabilised earth walls

- Material for use as backfill to MSEW
  - G5A as per COTO chapter 4
  - CBR 45 at 95% Mod AASHTO density
  - 5-15% passes 0.075mm sieve
  - PI <10
  - LS <5%
- How does one achieve this
  - Bomag 212 D5
    - Properties of G5A
  - E value ≈ 70-80MPa
  - Shear wave velocity ≈ 200m/sec
  - Bearing capacity some 300kPa
  - Modulus of subgrade reaction 130kPa/mm

Vibratory roller compaction

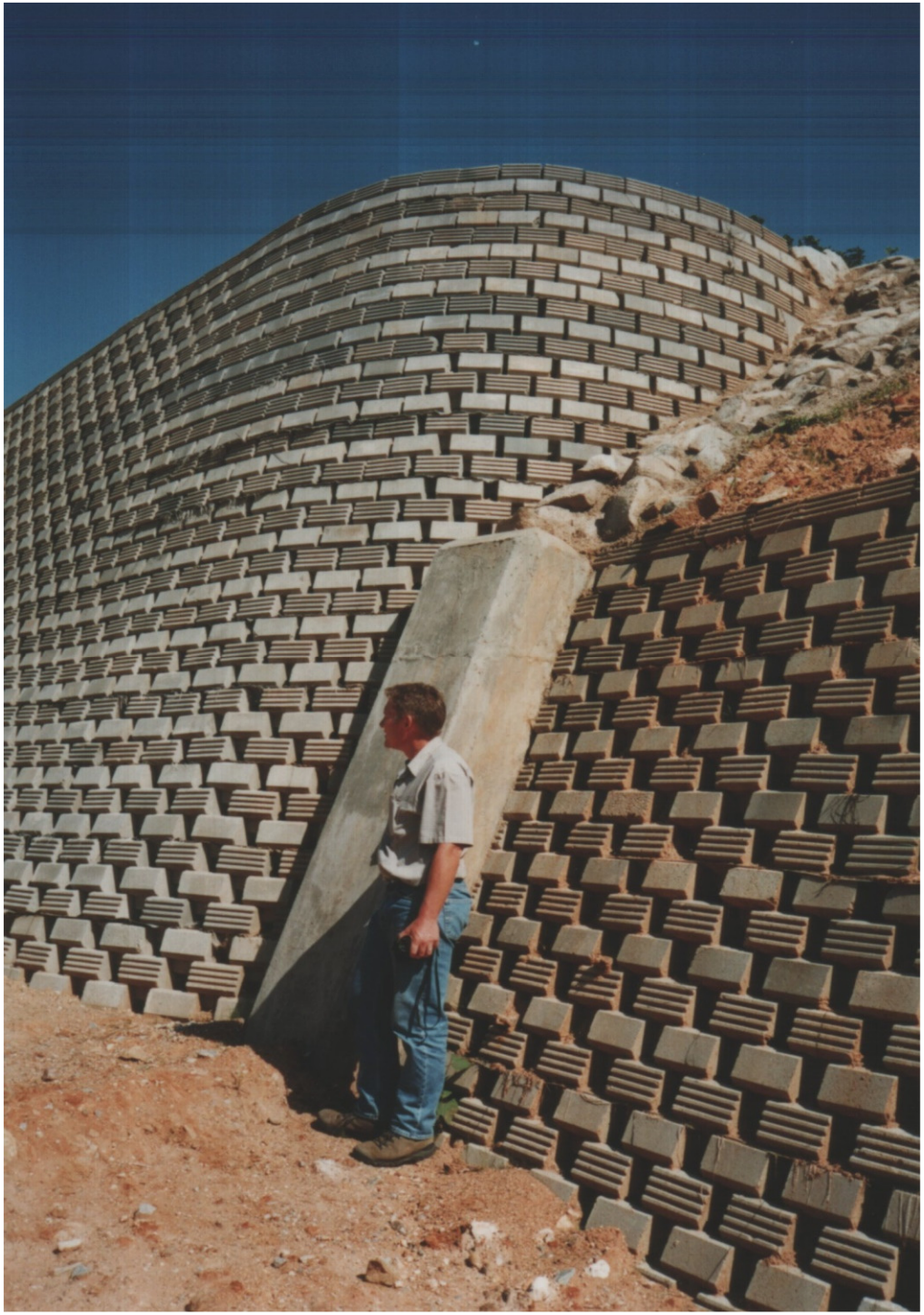
Input cells		
Static mass of vib drum	6510	kg
Centrifugal force	240	kN
Frequency	1800	Vibrations/minute
Amplitude	1.95	mm
Operating speed	0.5	m/sec
Roller width	2.13	m
Layer thickness	0.2	m
Energy input	17.78	kNm
Volume in 1 second	0.21	m^3
Energy input/volume	83.46	kNm/m^3
Number of passes for		
88%	5	
90%	6	
93%	10	
95%	14	
98%	21	
100%	29	

Mechanically stabilised earth walls

- Practical considerations
  - In using a large vibrating roller one cannot go up to the facing as it would push it over,
  - Thus stop some from 2m from facing and utilise a smaller, preferably, pedestrian roller,
  - This has not the same compactive energy as the larger one, thus many more passes are required.

Mechanically stabilised earth walls

- Back analysis of instrumented MSE structures indicates that in situ reinforcement stiffness is some 6-8 times that of in air stiffness,
- This is due to many reasons but most probably the main ones are:
  i. compacted material is dilatant on initial shear and thus generates large confining stresses,
  ii. In air testing of geosynthetics induces the same force throughout the specimen whilst insitu, various portions of the geosynthetic will be loaded differently,
  iii. The geosynthetic ensures that only small strains will occur and this imparts a much higher stiffness to the geosynthetic and surrounding soil.



Mechanically stabilised earth walls: difference between vertical and 70 degree wall

Wall angle	Ka
90	0.28
80	0.21
70	0.15
60	0.10
100	0.35
110	0.46

CAT
924G

Geosynthetics

- Geosynthetic Materials - collective term for geogrids, geotextiles and geocells made from a synthetic or natural polymer, in the form of a sheet, a strip or a three-dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications
- Geotextiles - are planar soil and polymeric (synthetic or natural) textile material, which may be nonwoven, knitted, woven knitted or stitch-bonded fibres or yarns, used in contact with /or other materials in geotechnical and civil engineering applications.

Geosynthetics

- Geogrids - are planar, polymeric structures consisting of a regular open network of integrally connected, tensile elements, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents.
- Geonets - are a geosynthetic consisting of parallel sets of ribs overlying and integrally connected with similar sets at various angles.
- Geomembranes - are continuous flexible sheets or rolls manufactured from one or more synthetic materials. They are relatively impermeable and are used as liners for fluid or gas containment and as vapour barriers.
- Geocomposites - are geosynthetics made from a combination of two or more geosynthetic types. Examples include geotextile-geonet; geotextile-geogrid; geonet- geomembrane; or a geosynthetic clay liner (GCL). Prefabricated geocomposite drains or prefabricated vertical drains (PVDs) are formed by a plastic drainage core surrounded by a geotextile filter.

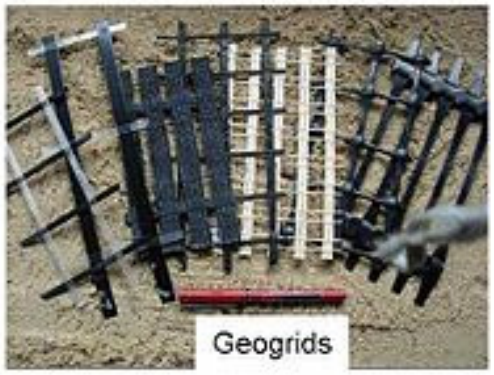
Geosynthetics

- Geosynthetic clay liners (GCLs) - are geocomposites, prefabricated with a bentonite clay layer typically incorporated between a top and bottom geotextile layer or geotextile bonded to a geomembrane or single layer of geotextile. Geotextile-encased GCLs are often stitched or needle-punched through the bentonite core to increase internal shear resistance. When hydrated, they are effective as a barrier for liquid or gas and are commonly used in landfill liner applications often in conjunction with a geomembrane.
- Geopipes - are perforated, slotted or solid-wall polymeric pipes used for drainage of liquids or gas (including leachate or gas collection in landfill applications). In some cases the perforated or slotted pipe is wrapped with a geotextile filter.

Geosynthetics

- Geocells - are three-dimensional, permeable, polymeric (synthetic or natural) honeycomb or similar cellular structure, made of linked strips of geosynthetics. Strips are joined together to form interconnected cells that are in-filled with soil and sometimes concrete. In some cases 0,5 to 1,0 m wide strips of polyolefin geogrids are linked together with vertical polymeric rods used to form deep geocell layers called geomattresses.
- Geofoam - blocks or slabs are created by expansion of polystyrene foam to form a low-density network of closed, gas-filled cells. Geofoam is used for thermal insulation, as a lightweight fill or as a compressible vertical layer to reduce earth pressures against rigid walls.
- Geosynthetic Cementitious Composite Mats (GCCMs) - is a flexible, concrete impregnated fabric that hardens on hydration to form a thin, durable waterproof and fire resistant concrete layer. It is used in concrete channel lining, slope protection, bund lining, remediation of existing concrete structures and culvert lining.

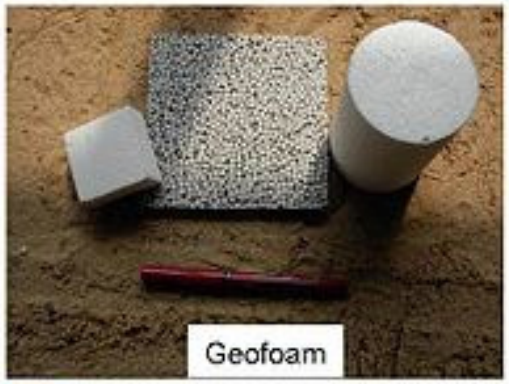
Geotextiles


Geogrids

Geonets

Geomembranes

Geosynthetic Clay Liners

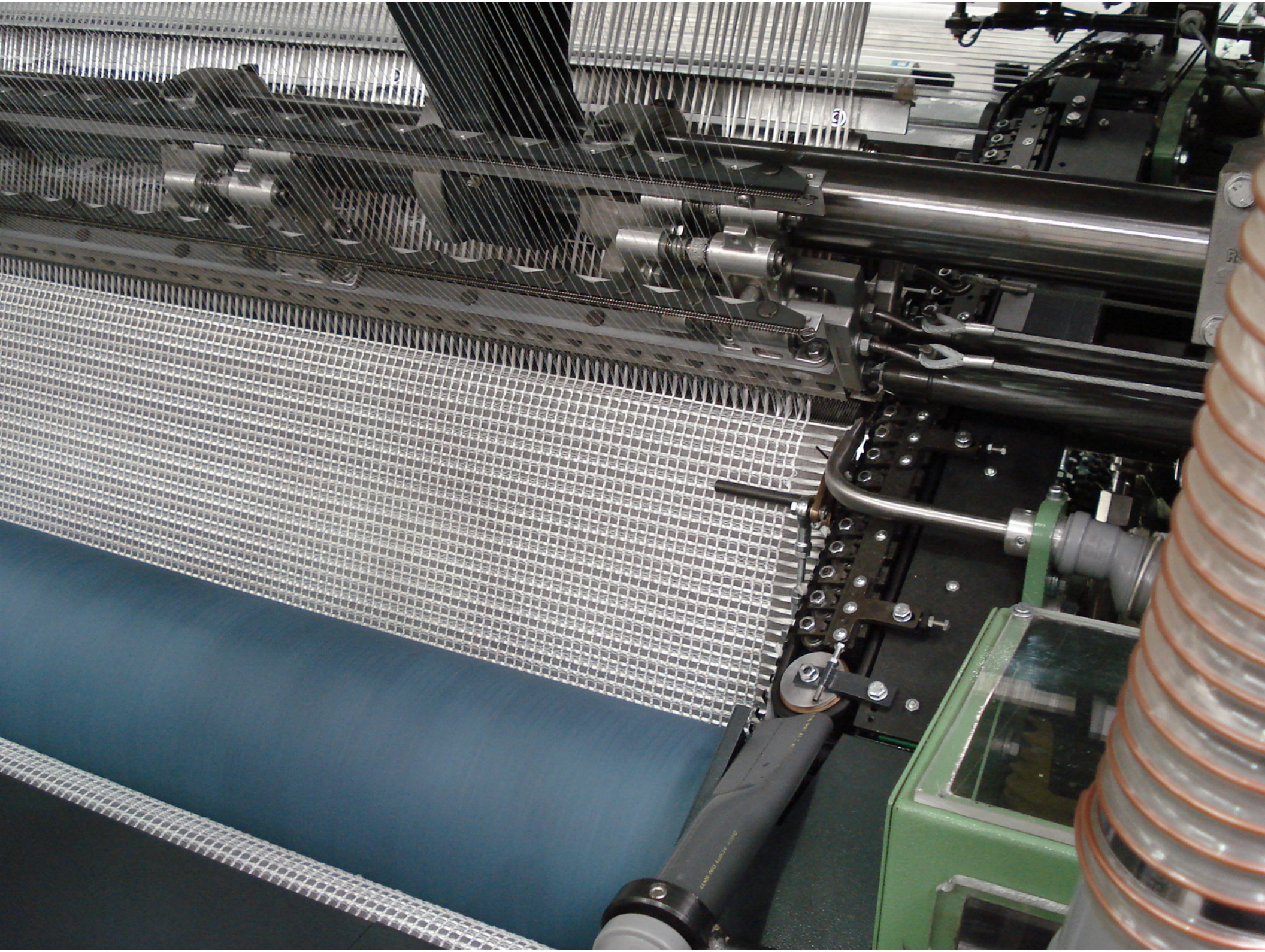

Geofoam

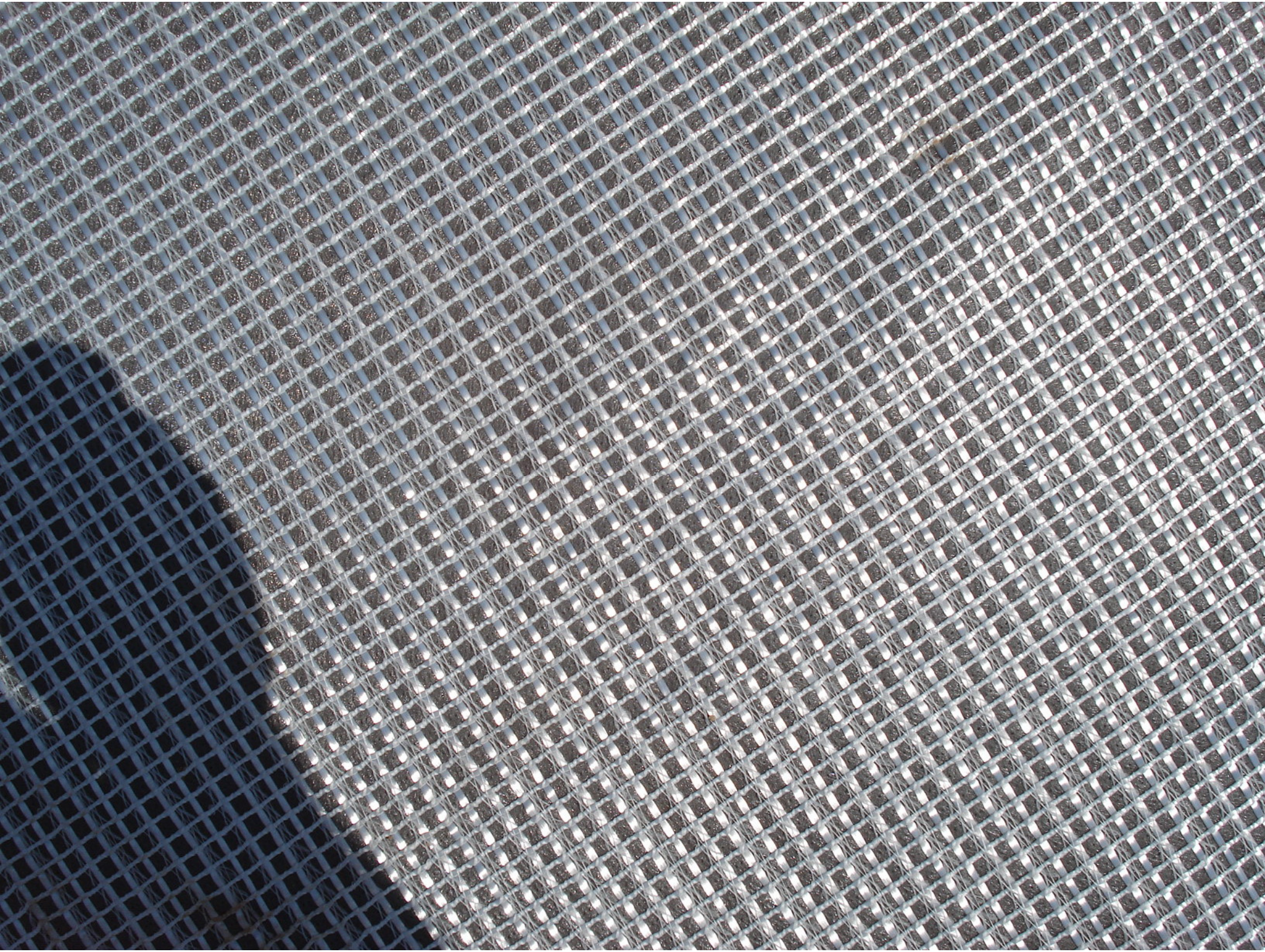
Geocells

Geocomposites

Geosynthetics

Local manufacture





Geosynthetics

- a) Barrier. As a barrier to prevent migration of liquids or gases.
- b) Containment. To contain soil or sediments to a specific geometry and prevent their loss. The contained fill takes the shape of the inflated at-rest geometry of the geosynthetic container.
- c) Drainage (also known as transmission). To collect and transport fluids.
- d) Filtration. To allow passage of fluids from a soil while preventing the uncontrolled passage of soil particles.
- e) Protection. As a localised stress reduction layer, to prevent or reduce damage to a given surface or layer.
- f) Reinforcement. To resist stresses or contain deformations in geotechnical structures.
- g) Separation. To provide separation between two dissimilar geotechnical materials, to prevent intermixing.
- h) Surficial erosion control. To prevent surface erosion of soil particles due to surface water run-off and/or wind forces.
- i) Frictional interlayer. As a friction interlayer to increase or reduce friction across the interface.

Road embankment underlain by sinkholes

Typical calculation for a sinkhole taken from BS 8006

Type of condition:		yes/no
	Plane strain conditions	n
	Axisymmetric conditions	y

D	5	Design diameter of the void
H	2	Height of the embankment
θ_d	31	Angle of draw of the embankment fill, which is approximately equal to its peak friction angle.
d_s/D_s	0.015	Maximum allowable differential deformation occuring at the surface of the embankment or pavement
ε_{max}	0.0964	Maximum allowable strain in the reinforcement

(11.4.4.5) Reinforcement tensile properties

Note: For extensible reinforcement (e.g. polymeric) the tensile load T_{rs} in the deflected reinforcement is given by:

f_{fs}	1.0	
f_q	1.0	
λ	0.67	Coefficient depending on whether the reinforcement support is to function as a one-way or two-way load shedding system
γ	20	
w_s	10	
ε	0.0964	The strain in the reinforcement which is less than or equal to ε_{max}
T_{rs}	138.37	Tensile load in the reinforcement per meter "run"

Alan Parrock's Boere method as a hand check on the reality of the above

i. For a simply supported beam $M=wl^2/8$, a continuous beam $M=wl^2/12$ while for a plate spanning a void $M \approx wl^2/20$.

ii. In the previous example w= 2x20=40, l=5m, thus moment = 40x25/20=50kNm

iii. For a regular section in bending, lever arm la from the centre of the compression block to the edge of the tension flange (geosynthetic) la=0.75 x 2 = 1.5m and as M=T/la, T may be calculated as 1.5m 50 =75kN

iv. Deflection of a simply supported beam $\delta=5wl^4/384EI$, where $I = bd^3/12 = 5x40x5^4/384x50x0.67 = 9.7mm$ where E of backfill material is estimated at 50MPa.

v. Thus although not comparable to results obtained previously δ=30mm T =138kN, order of mag is maintained

Container terminal pavement

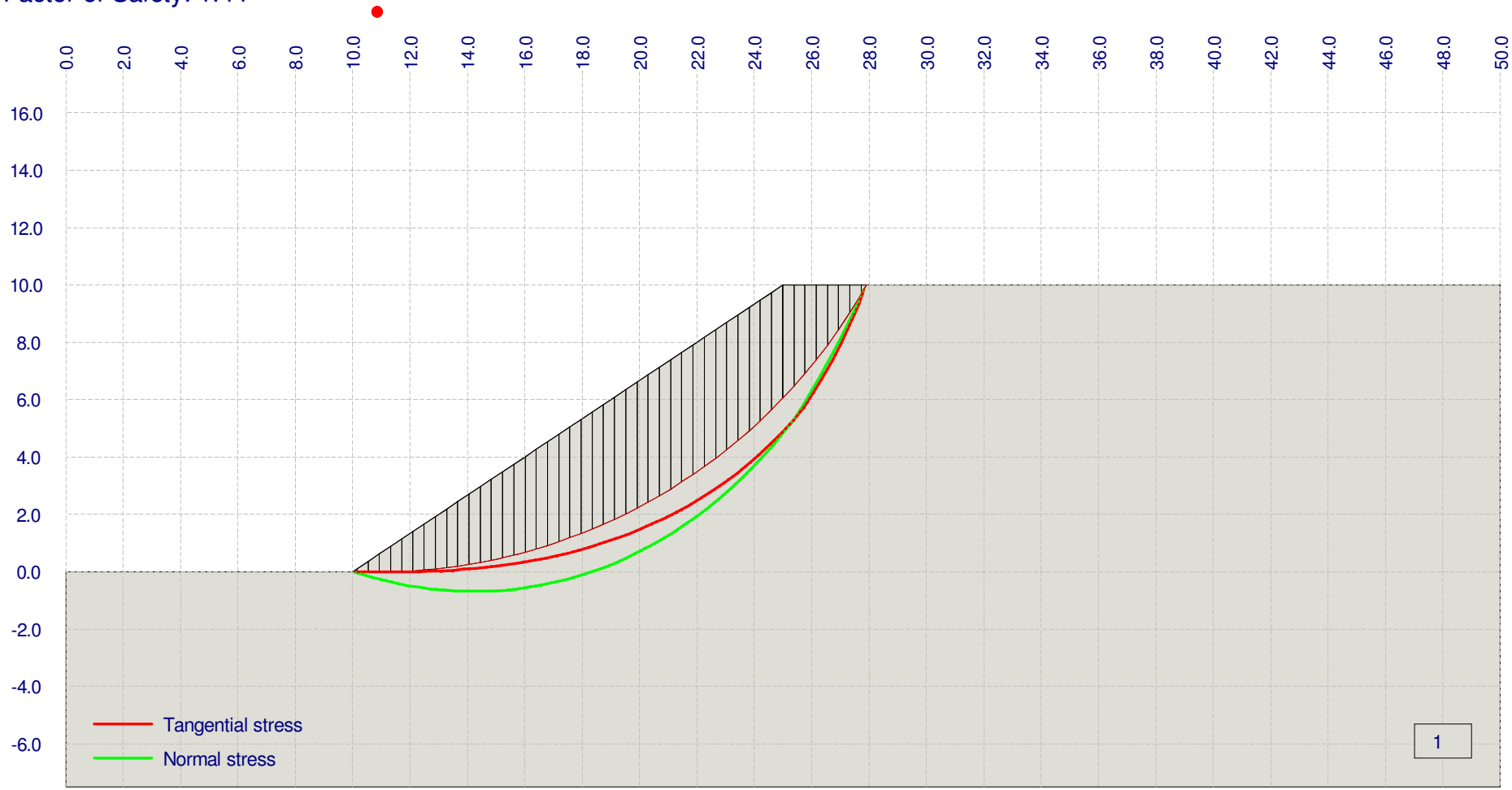
Demand for geosynthetics (millions m^2)

Region	2007	2012	2017
North America	923	965	1300
Western Europe	668	615	725
Asia/Pacific	723	1200	2330
Central SAmerica	124	160	220
Eastern Europe	248	305	405
Africa/Mideast	115	155	220
Total	2801	3400	5200

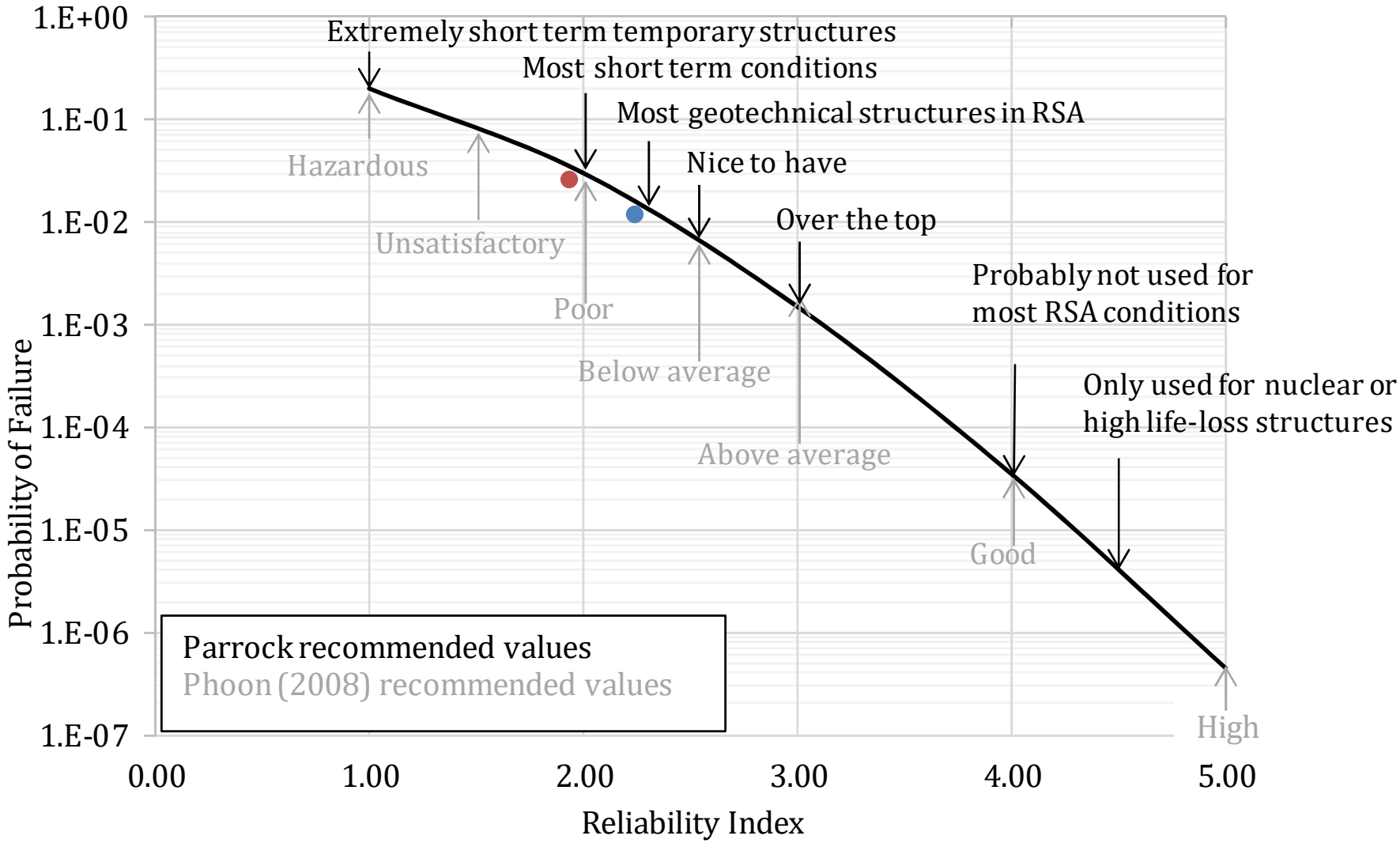
Geosynthetics- some tips

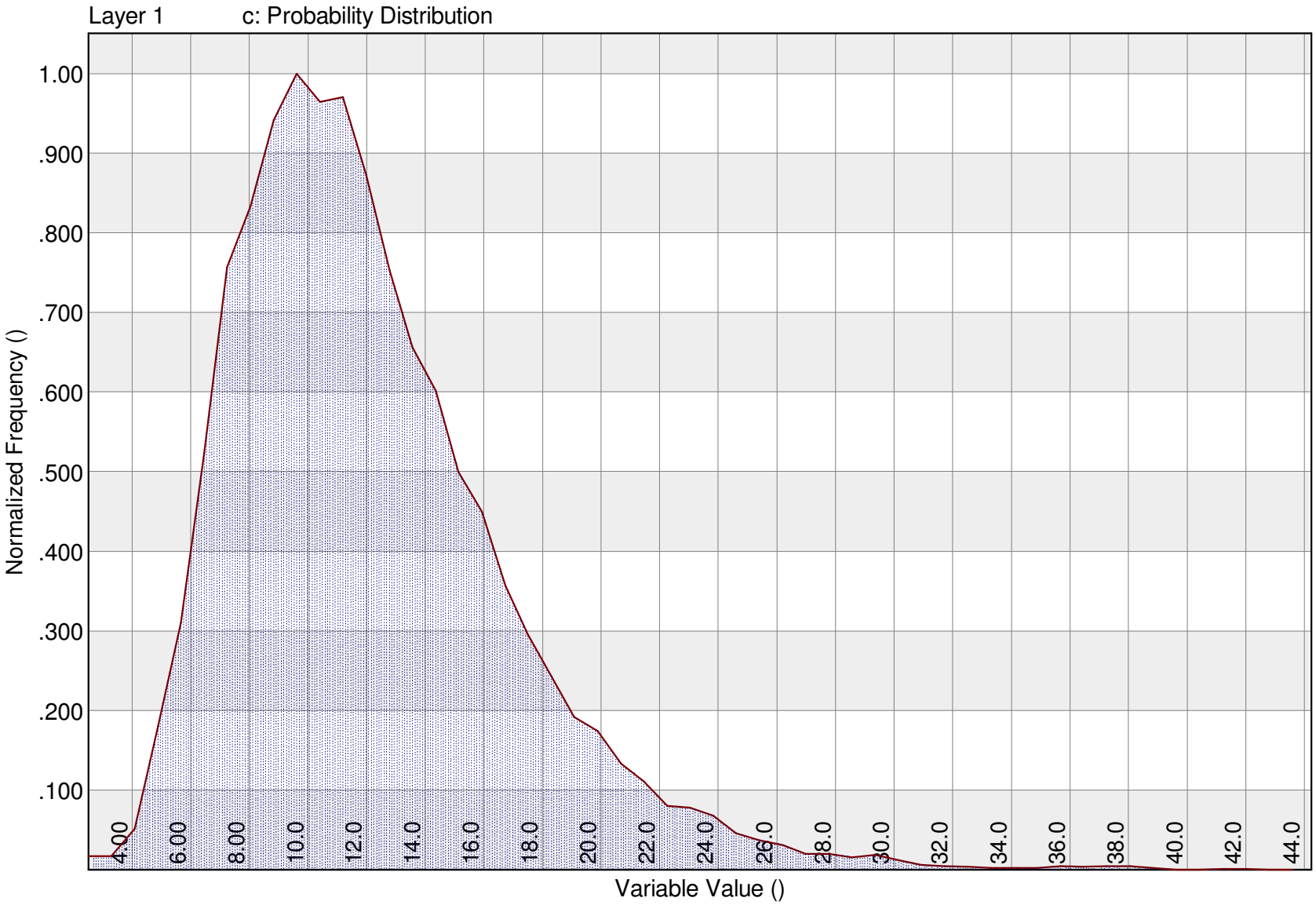
- Jean Louis Briaud – then president of the ISSMGE, stated at the ICSMGE held in Alexandra Egypt in 2009 that geosynthetics were the most important recent addition to Soil Mechanics. As an aid to road building in RSA they are just as important,
- When laying geosynthetics as a tensile layer, it usually helps to aid tensioning that a small trench (about the layer thickness deep), is excavated at 2/3 of the length from the face, The fabric as pulled over this and anchored at the end. Backfill for the layer above is placed and additional tension and anchorage is provided to the fabric as it settles into the trench,
- A frictional interlayer, when filled with some 20mm thick coarse river sand, 0.5m wide along the lengths of the fabric and some 2m at the ends, is usually sufficient to ensure continuity, and transmit tensile forces,
- If a tensile system is necessary at fill base, it acts as a multi-purpose, mechanism to a) enhance FOS as it contributes to the resisting moment, b) is able to span over soft spots or voids and c) acts as horizontal drainage layer. This us usually best accomplished using 2 layers of mutually-perpendicular fabric separated by a thin (100-150 mm thick) gravel layer of some G6 consistency .

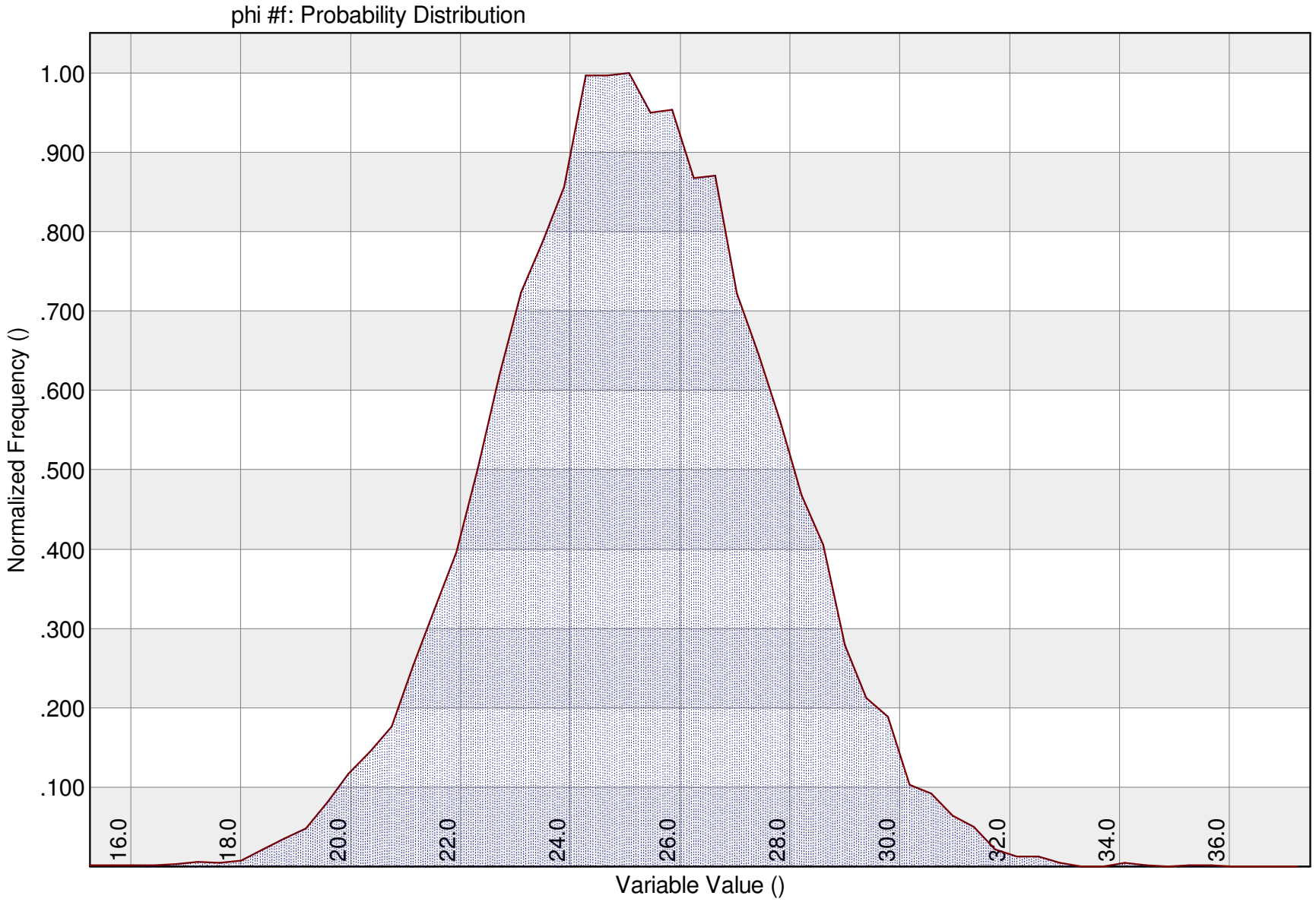
Factor of Safety: 1.44

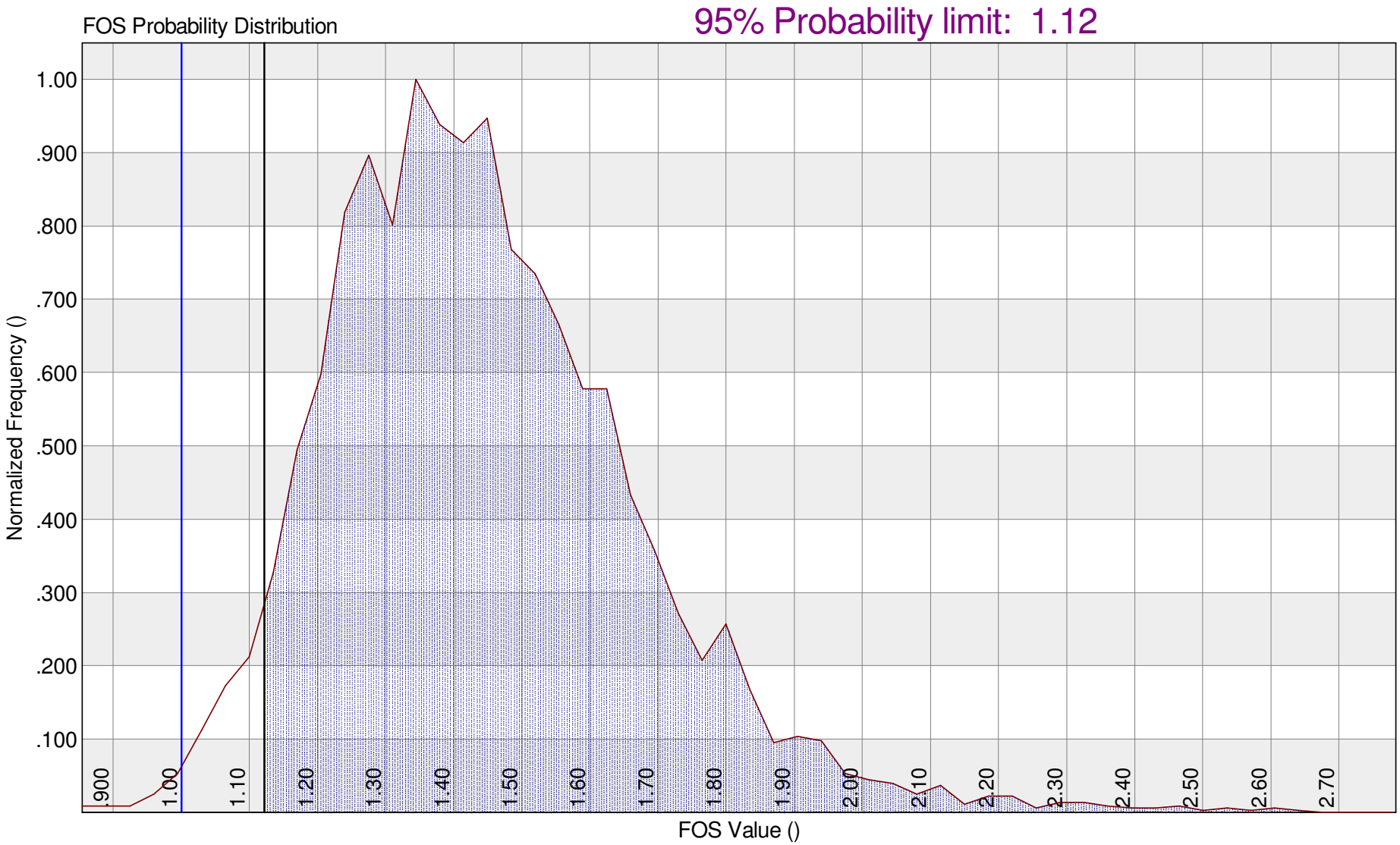


Analysis	Material Types	Variable	Value	SRF	ΔF
1		c+		1.64	0.40
2		c-		1.24	
3		φ+		1.55	0.22
4		φ-		1.33	
Average				1.44	
σ				0.23	
COV				0.16	
Lognormal Distribution		RI		2.24	
		P[f] (%)		1.2%	
Normal Distribution		RI		1.93	
		P[f] (%)		2.7%	


1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
Probability of Failure
0.00
1.00
2.00
3.00
4.00
5.00
Reliability Index
Extremely short term temporary structures
Most short term conditions
Most geotechnical structures in RSA
Nice to have
Over the top
Probably not used for most RSA conditions
Only used for nuclear or high life-loss structures
Hazardous
Unsatisfactory
Poor
Below average
Above average
Good
High
Parrock recommended values
Phoon (2008) recommended values


Layer 1
c: Probability Distribution
Normalized Frequency ()
1.00
.900
.800
.700
.600
.500
.400
.300
.200
.100
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
36.0
38.0
40.0
42.0
44.0
Variable Value ()


phi #f: Probability Distribution
Normalized Frequency ()
1.00
.900
.800
.700
.600
.500
.400
.300
.200
.100
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
36.0
Variable Value ()


FOS Probability Distribution
95% Probability limit: 1.12
Normalized Frequency ()
1.00
.900
.800
.700
.600
.500
.400
.300
.200
.100
.900
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
2.10
2.20
2.30
2.40
2.50
2.60
2.70
FOS Value ()

Thank you all

Alan Parrock