Foundations for High Rise Structures

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Cover story

Skyscrapers

Broadgate Tower (Arup)
Height: 161m; 34 storeys
Status: On site, completion date 2008

1-10 Blackfriars Road (WSP)
200m; 68 storeys
At planning stage

Vauxhall tower (Arup)
180m; 49 storeys
Completion date 2009

Willis building (Whitbybird)
125m; 29 storeys
On site; completion Dec 2006

Columbus tower (WSP)
239m; 63 storeys
Going through planning; completion date 2009

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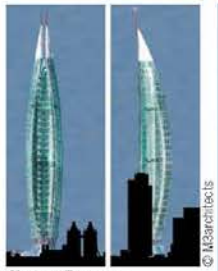
Minerva Building (Arup)
217m, 50 storeys
Planning permission granted

© Richard Rogers Partnership/Cityscape Digital Ltd

122 Leadenhall Street (Arup)
222m; 49 storeys
Detailed design; completion 2008



© M3architects

Citygate Ecotower
485m, 108 storeys
On drawing board (M3architects)

© NPS/Heron International

Heron Tower (Arup)
202m; 41 storeys
Planning permission granted

Multiplex Living Tower (The Electric Razor) (WSP)
147m; 42 storeys
At public consultation stage

Cloud busters

They are symbols of wealth and technical advancement, and one will probably be appearing soon near you. Ruby Kitching reports on the latest trend for tall buildings.

Skyscrapers are back in fashion and every city in the UK it seems is planning one. London is leading this trend with around 18 on the drawing board or on site at the moment.

Just 10 days ago, the Corporation of London granted planning permission to the 41-storey Heron Tower, the latest tall building in the wave of skyscrapers emerging in the capital. And if mayor Ken Livingstone has his way, London will see a new tall building appear on its skyline every year until 2020 (*NCE* 12 February 2004).

They are, of course, outlandish expressions of a thriving economy, but what makes this high rise boom so special is that these skyscrapers are not just rectangular blocks. The urban landscape will host a gherkin, a shard of glass or even a used-lipstick (the last being the nickname coined by *NCE* for the Columbus Tower).

City of London planning officer Peter Rees says that London is right to demand the most innovative design for its skyscrapers.

"If you're going to build tall, then it makes sense to make them interesting. What we're against is boring buildings." Irregular shaped sites, height restrictions and the developer's desire to maximise a building's volume within these constraints have dictated the unusual shape of buildings on the drawing board at the moment.

Rees wants to concentrate more "movers and shakers and highly paid professionals" in the Square Mile, raising the working population from 8,000 to 300,000 – "which is why we need to build upwards".

He adds that the "Gherkin" at 30 St Mary's Axe has done much to improve the public's perception of modern skyscrapers. "It broke the idea that a building needed to be a rectangular block and gave it more of a personality."

He acknowledges the role engineers have played in allowing more eccentric designs to develop: "Without engineers, designs would stultify."

What makes skyscrapers so special is that every detail and specification has to be honed in pursuit of economic and structural efficiency. Shaving a few centimetres off every steel element in a building can save thousands of pounds and could also increase the net floor area. Using fewer elements also reduces the number of lifts a tower crane has to make during erection, freeing it up for other operations or reducing construction time.

"I love the way you have to be a perfectionist when you design a skyscraper," exclaims Halcrow Yolles director Jonathon Hendricks. "The repetitiveness of every detail means it's worth getting it absolutely right."

WSP director Kamran Moazami, the brains behind the mighty 83-storey London Bridge Tower – a.k.a the Shard of Glass – thinks of tall buildings as "research facilities to boost technology and push structural engineering forward".

He explains that engineers pushed manufacturers to come up with higher strength concrete to achieve longer spans in tall buildings.

Developments in post-tensioned concrete slab design were demanded to achieve thinner floor depths so that hotel developers could squeeze more floors into the height of a building.

Slipform concrete technology has also gathered pace due to the demand from contractors to find an alternative to steel framed lift and stair cores.

"Most of the Canary Wharf towers of the 1990s used C50 concrete and steel framed cores. Now almost every job has a slipformed core as contractors are urged to build faster and cheaper and C80 is considered normal – they're even using C120 abroad," says Moazami.

He adds that developments in computer software have also made taller and more eccentric structures feasible.

The real beauty of skyscrapers is that they are the decathletes of the building world, where every muscle, limb and organ must be designed for optimum performance – "you don't really ever plan to demolish these buildings because they are so strong", says Moazami.

Buildings are also getting lotter. The 310m tall Shard will be almost twice the height of Tower 42, currently the tallest building in the City. This has called for a shift in skyscraper anatomy. Arup director David Glover sees engineers moving away from the traditional central core design where the concrete lift shaft provides the building's lateral stability.

He says that in buildings taller than 200m, concrete cores need

Projects: Design & On Site

Regional Development

Regional Development - NCE

Structures

Tall buildings

Manchester's record taker

Construction of the UK's tallest residential tower has just begun in Manchester. Bernadette Redfern reports.

As an address, Deansgate is probably the most desirable in Manchester. Which is why developer The Beetham Organisation was

spaces with views and light.

Starting at foundation level, the entire structure will sit on a 3m deep concrete raft.

Above this, at ground level, the first three of the tower's 48

Structures

Steel

Steely resolve

A steel basement and structural frame are turning convention on its head at a residential development in Leeds.

Convention has it that the basement walls of multi-storey residential buildings and the superstructures

steel piles," Haines says, "from whose pilecap the outer walls of the building above would spring."

This form of construction

Structures

Unity tower

Tower topper

A new Merseyside landmark is gradually being unveiled. Dave Parker reports from Liverpool.

Those lucky enough to move into the distinctive penthouse "pod" that tops Liverpool's 27

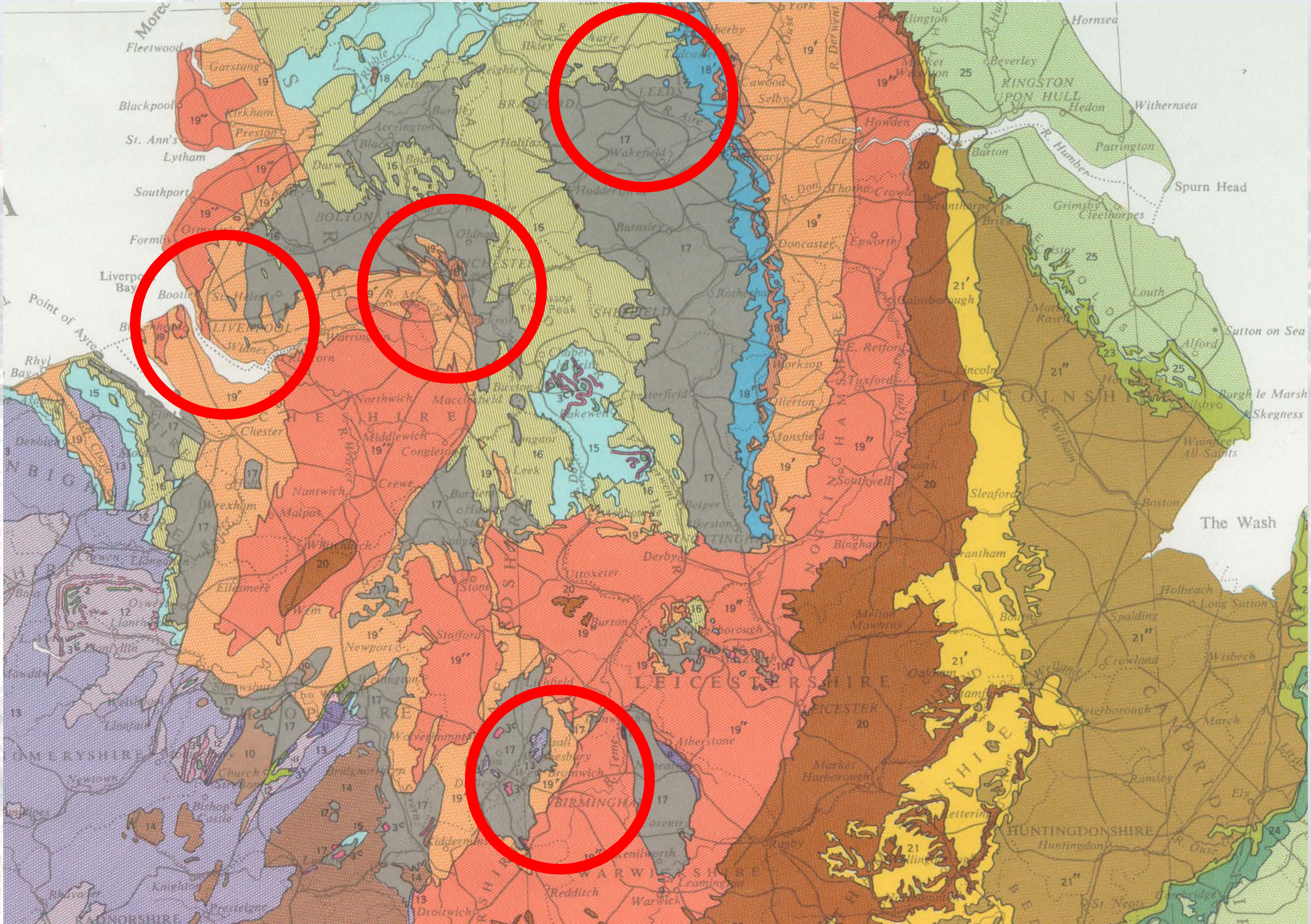
frame.

Steel and concrete are also combined imaginatively in the twin towers of the £60M Unity project.

and health and safety issues to be addressed," says Donaldson. "The slab cantilevers out up to 4m, so major temporary works were needed. We involved the Health & Safety Executive and subcontractor Efco as early as possible, and came up with a solution that worked very well in practice."

Main contractor Laing O'Rourke took only four weeks to get the floor ready to take its first pour of C40/50 concrete, using a grid of built up plate girders to support

Geology of Central England



Central England (& N. Ireland)

- Sherwood Sandstone
- Mercia Mudstone

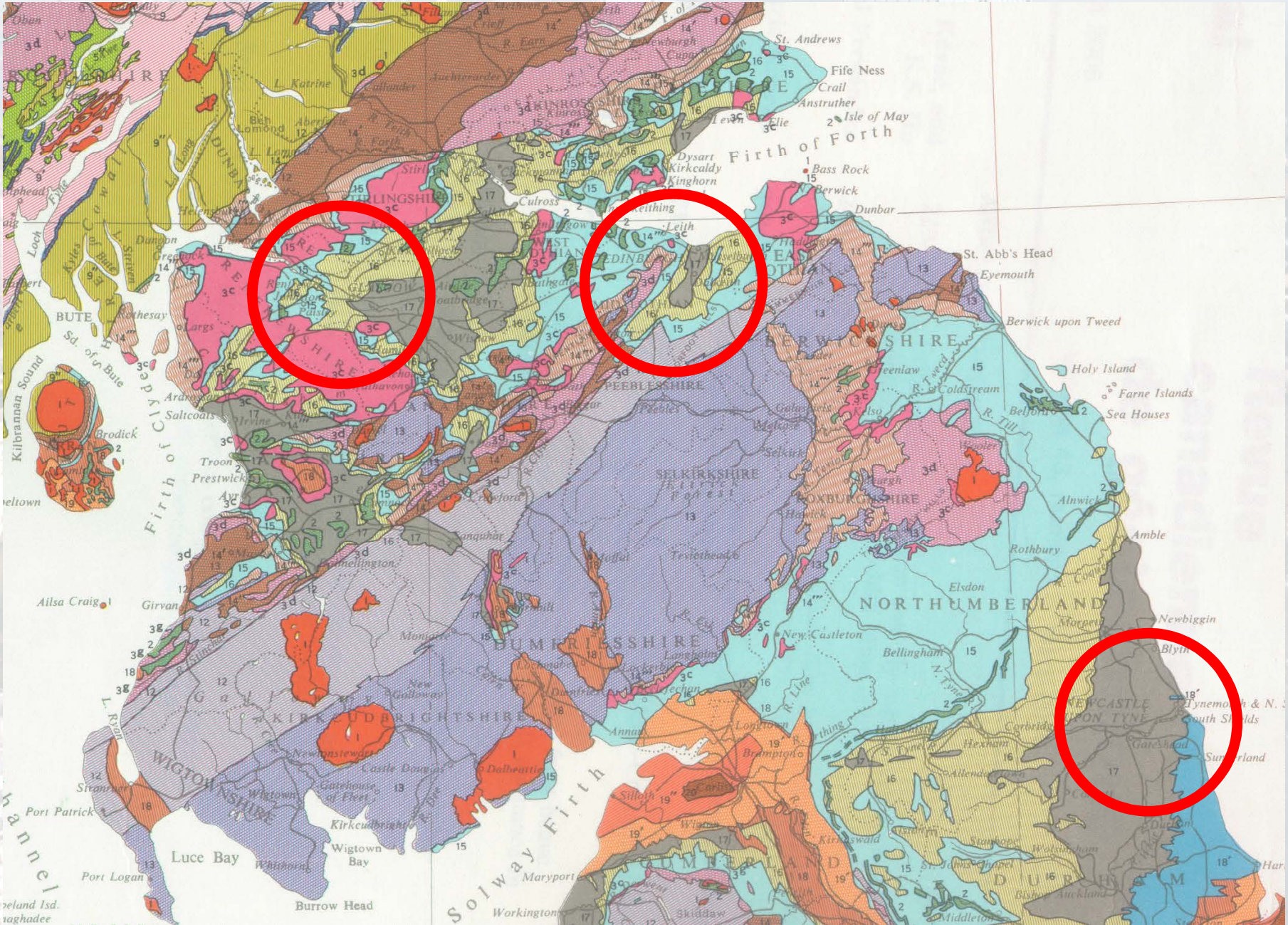
  - Birmingham
  - Manchester
  - Liverpool
  - Belfast

Northern England

- Coal Measures
- Millstone Grit
  - Leeds
  - Sheffield
  - Newcastle

Regional Development

Geology of Scotland/N. England



Scotland

- Coal Measures
- Millstone Grit
- Carboniferous Limestone

  - Edinburgh
  - Glasgow

Superficial Deposits

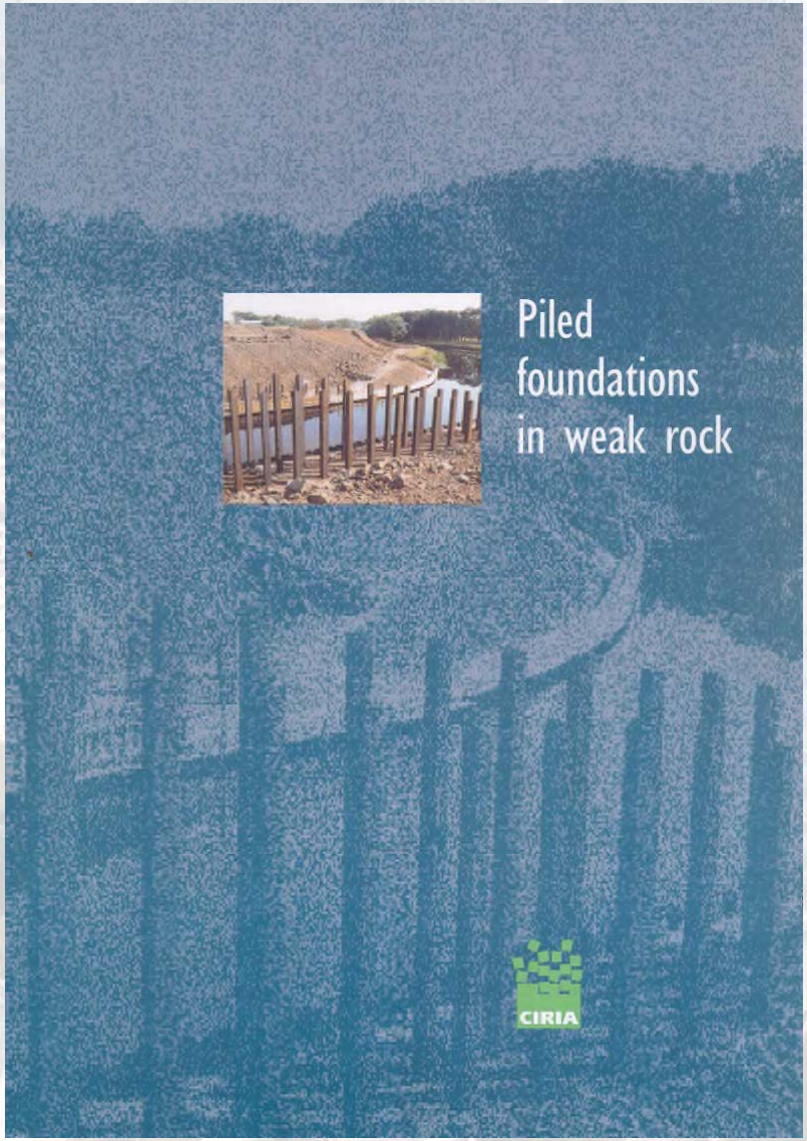
- Made Ground
- Alluvial Deposits
  - Soft Clays & Peats
  - Loose Sands
- Glacial Till/Boulder Clays
  - Over large areas of Central & Northern England, Northern Ireland & Scotland

Foundation Requirements

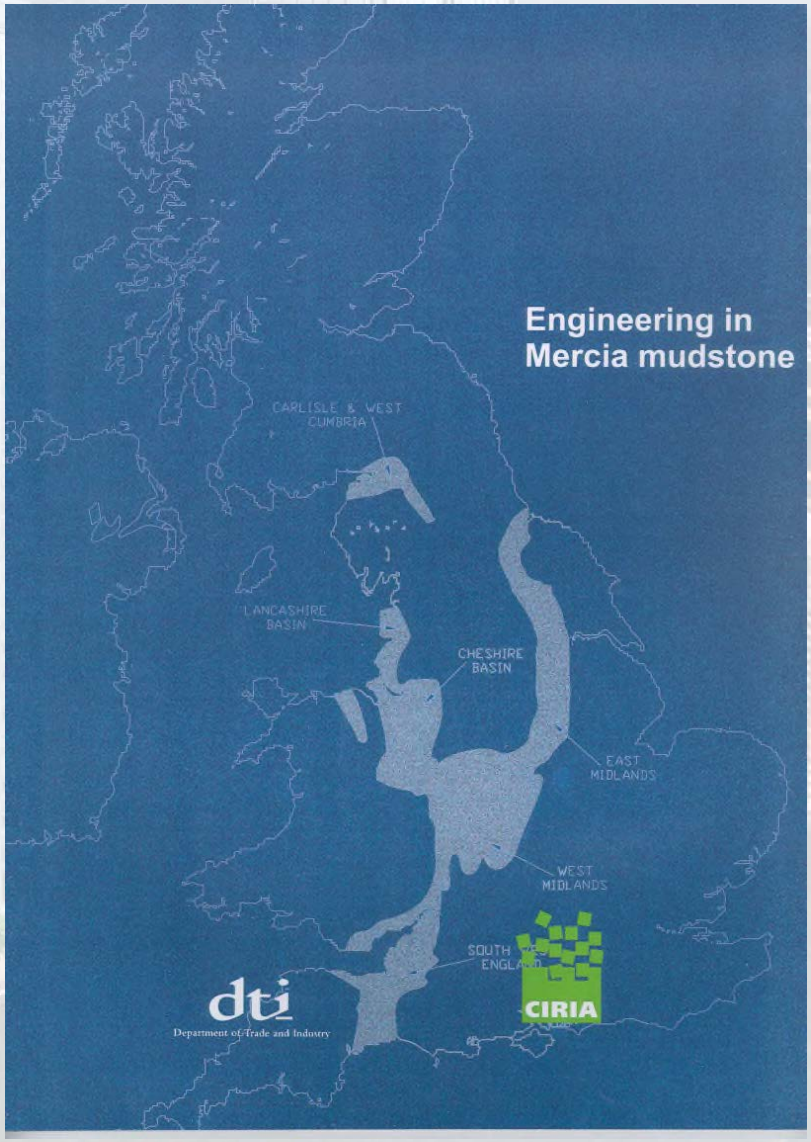
- High Rise Structures
  - High Loads
  - Deep Basements

- Usually require piled foundations
- Often need to be founded in bedrock
- Design requirements:
  - Pile diameter
  - rock socket length

Pile Design - CIRIA



Report 181



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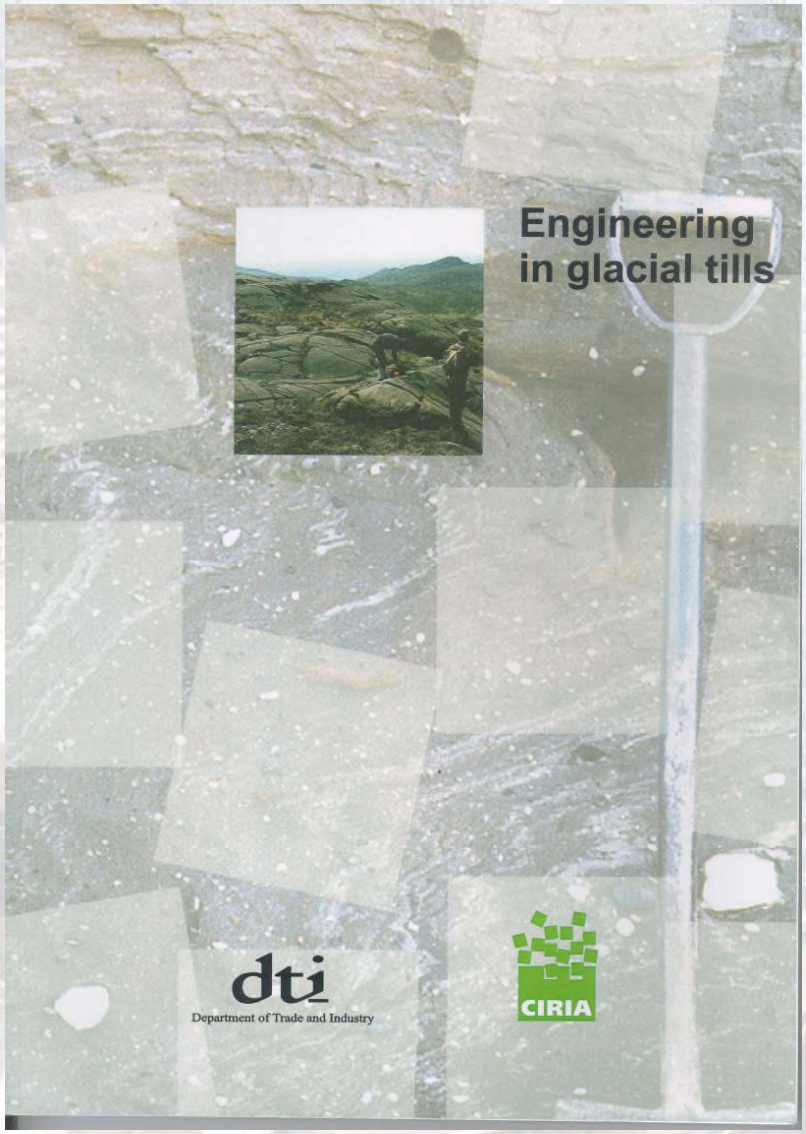
Pile Design - CIRIA



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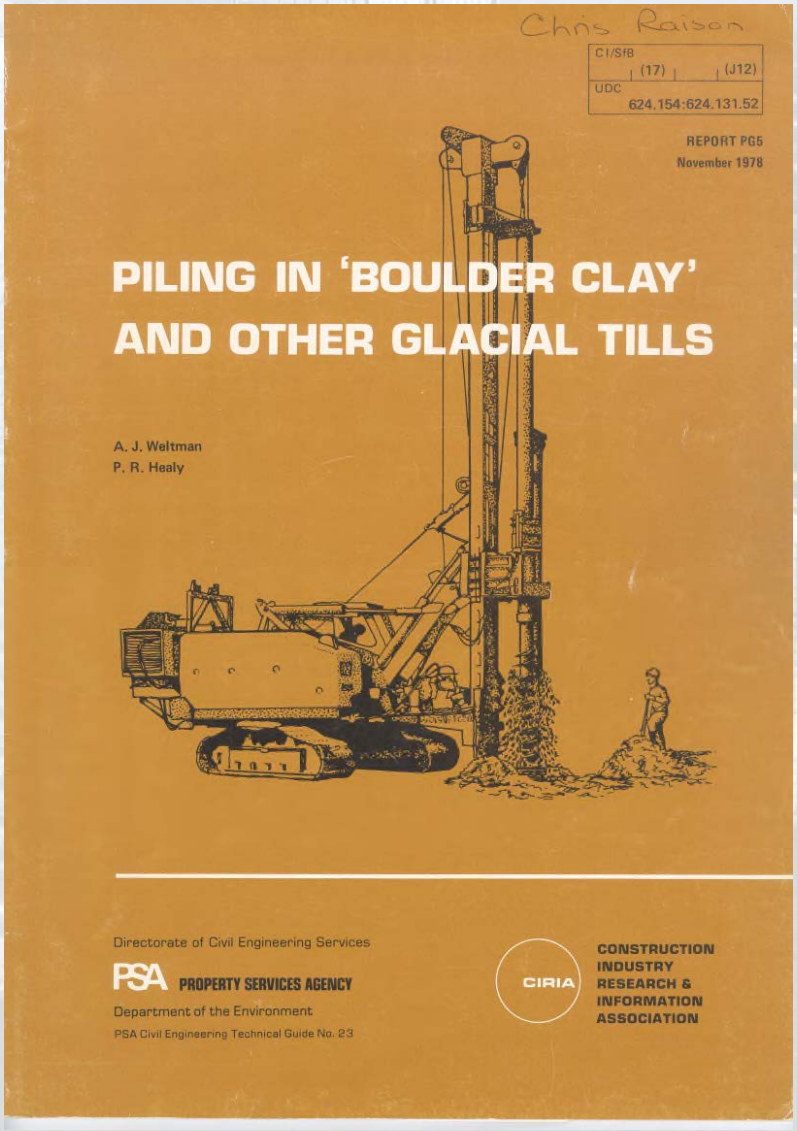

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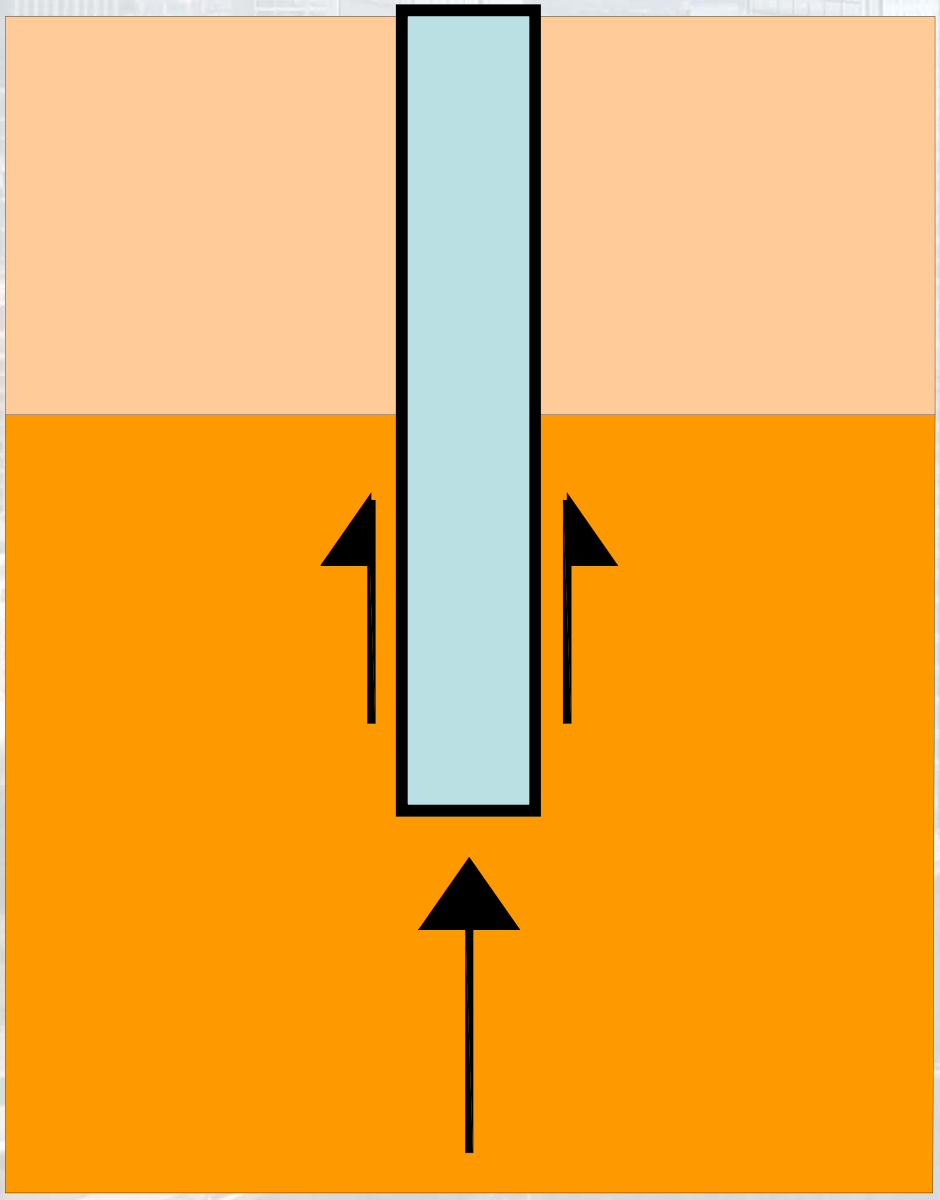
Rock Socket Design

Overburden

Weak rock



$Qs = fs \times As$

$Qb = fb \times As$

Rock Socket Design

- Shaft Friction
  - Sandstone/Siltstone/Limestone

    $f_s = a\ UCS^b$

    where $a = 0.2$ to 0.375

    and $b = 0.5$ to 0.6
  - Weak Mudstone/Shale

    $f_s = \alpha\ Cu$

    where $Cu = 5N$ or $UCS/2$

    $\alpha = 0.3$

Rock Socket Design

- End Bearing
  - Sandstone/Siltstone/Limestone

    fb = factor x UCS

    where factor = 1.5 to 4.5
  - Weak Mudstone/Shale

    fb = Nc Cu

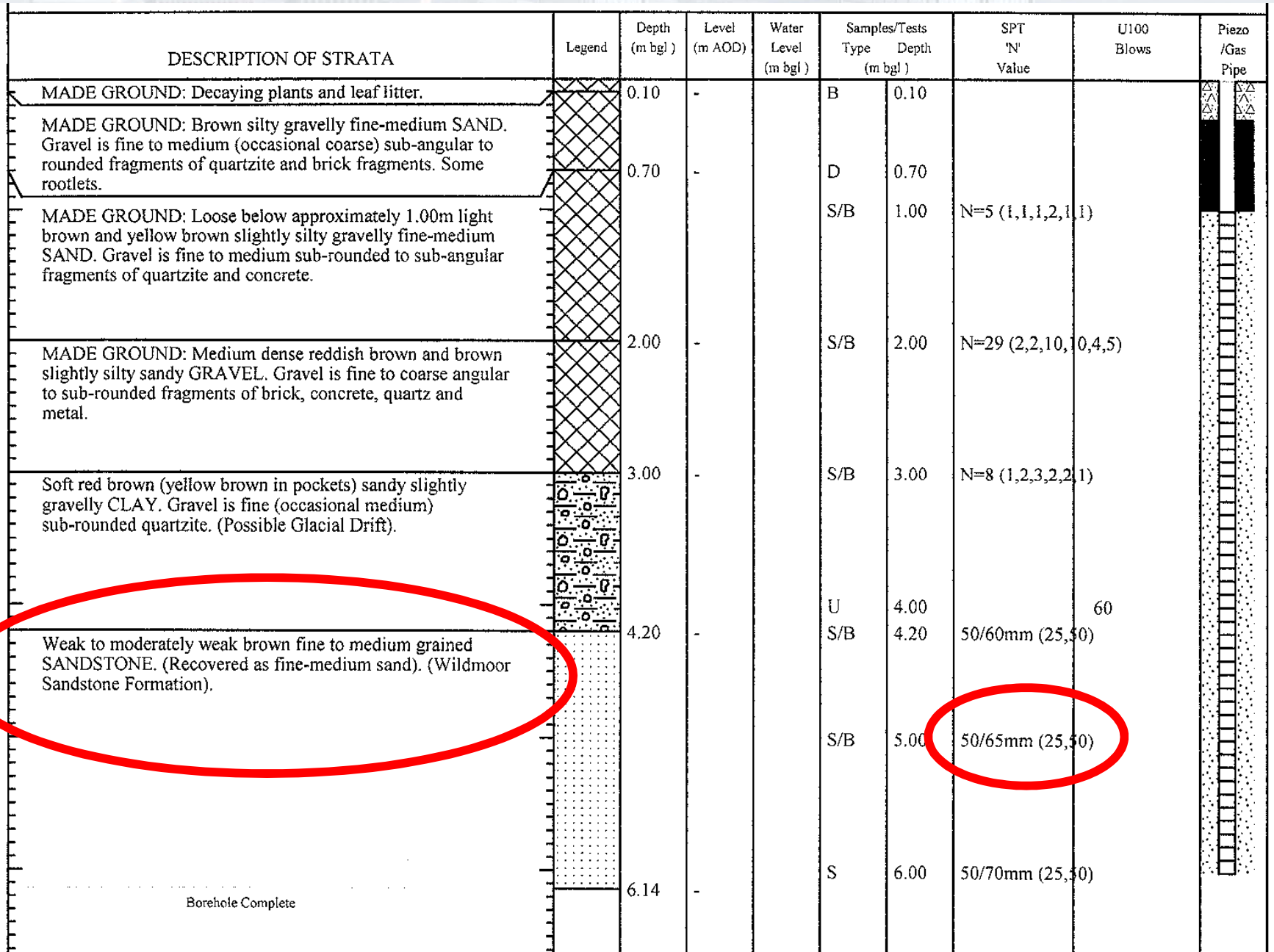
    where Cu = 5N or UCS/2

    Nc = 9

Foundation Problems

- Sandstones/Siltstones/Limestones
  - Cable tool boreholes only
  - Poor rotary core recovery in GI
  - Weathering – sandstone to sand
  - But generally straightforward
  - Pile problems
    - How long do rock sockets need to be?
    - Can piles be driven or bored to design level?

Sandstone - Short Borehole



DESCRIPTION OF STRATA	Legend	Depth (m bgl)	Level (m AOD)	Water Level (m bgl)	Samples/Tests Type	Samples/Tests Depth (m bgl)	SPT 'N' Value	U100 Blows	Piezo /Gas Pipe
MADE GROUND: Decaying plants and leaf litter.		0.10	-		B	0.10			
MADE GROUND: Brown silty gravelly fine-medium SAND. Gravel is fine to medium (occasional coarse) sub-angular to rounded fragments of quartzite and brick fragments. Some rootlets.		0.70	-		D	0.70			
MADE GROUND: Loose below approximately 1.00m light brown and yellow brown slightly silty gravelly fine-medium SAND. Gravel is fine to medium sub-rounded to sub-angular fragments of quartzite and concrete.					S/B	1.00	N=5 (1,1,1,2,1,1)		
MADE GROUND: Medium dense reddish brown and brown slightly silty sandy GRAVEL. Gravel is fine to coarse angular to sub-rounded fragments of brick, concrete, quartz and metal.		2.00	-		S/B	2.00	N=29 (2,2,10,10,4,5)		
Soft red brown (yellow brown in pockets) sandy slightly gravelly CLAY. Gravel is fine (occasional medium) sub-rounded quartzite. (Possible Glacial Drift).		3.00	-		S/B	3.00	N=8 (1,2,3,2,2,1)		
					U	4.00		60	
Weak to moderately weak brown fine to medium grained SANDSTONE. (Recovered as fine-medium sand). (Wildmoor Sandstone Formation).		4.20	-		S/B	4.20	50/60mm (25,50)		
					S/B	5.00	50/65mm (25,50)		
					S	6.00	50/70mm (25,50)		
Borehole Complete		6.14	-						

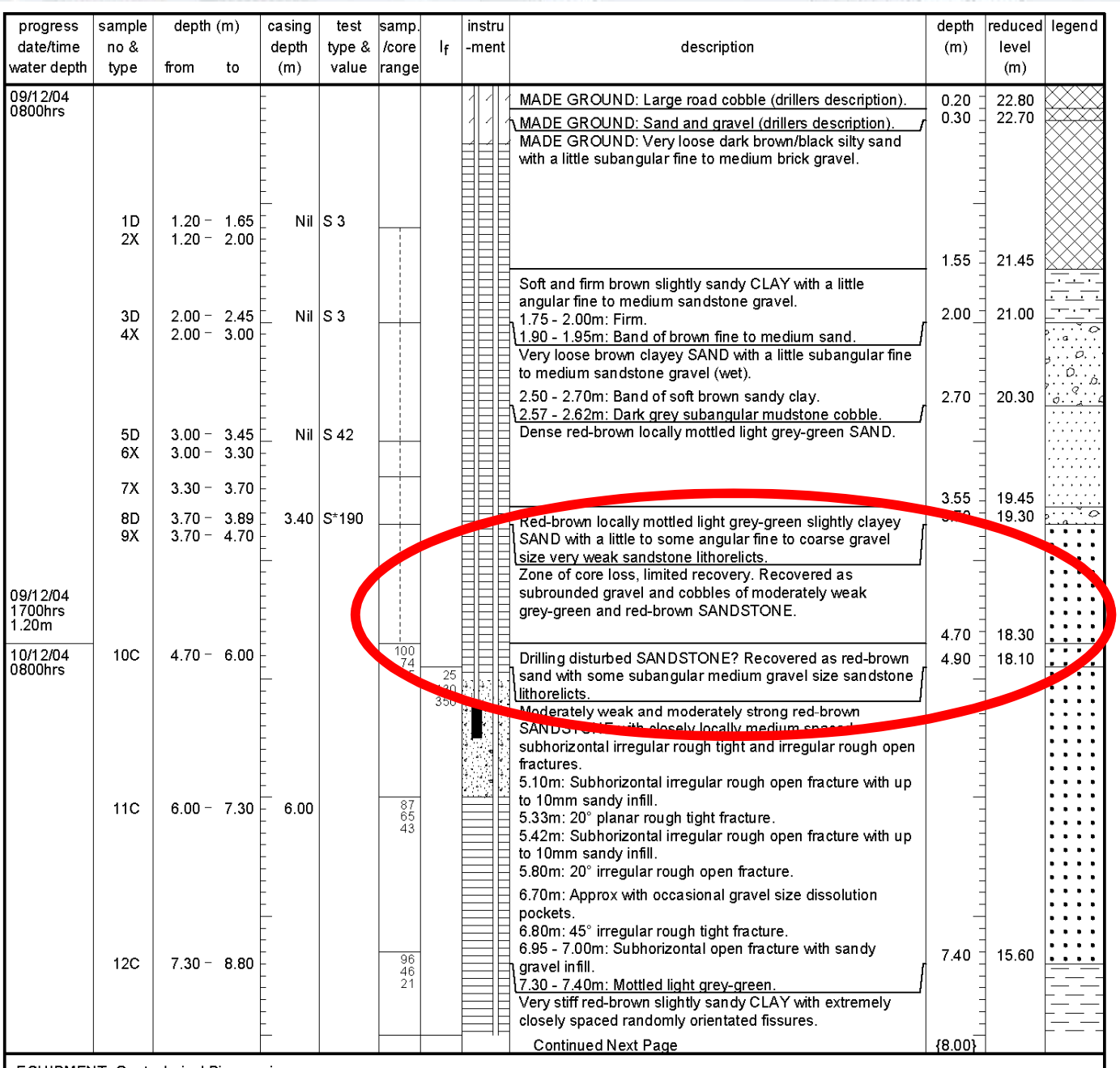
Sandstone - Short Borehole

Co-ordinates (National):	Ground level (mAOD):	Method:		
E N	16.50	CABLE PERCUSSION		
Date:	Depth of Hole:	Hole diameter:	Casing diameter:	Sheet:
04/12/02 to 04/12/02	12.20	150mm	150mm	2 of 2

Machine Number

Samples & Tests				Strata		Description of Strata	Geology	Legend	Water	Piezo Backfill
Depth (m)	No.	Type	SPT CPT 'N' value	Depth (m)	Reduced Level (m)					
8.00-8.45		S/B	64			Very dense reddish brown SAND with occasional angular gravels and cobbles. [LOWER SANDS AND GRAVELS]				
9.00-9.45		S/B	28	9.00	7.50	Medium dense reddish brown very silty fine to medium SAND. [LOWER SANDS AND GRAVELS]				
10.00-10.45		S/B	18							
11.00-11.45		C/B	121	11.10	5.40	Reddish brown silty SANDSTONE, weak to moderately weak. Recovered as angular gravel and cobble sized fragments. [UPPER MOTTLED SANDSTONE]				
12.10-12.20		C	50/75#	12.20	4.30	BOREHOLE COMPLETED AT 12.2m.				

Sandstone - Loss of Core

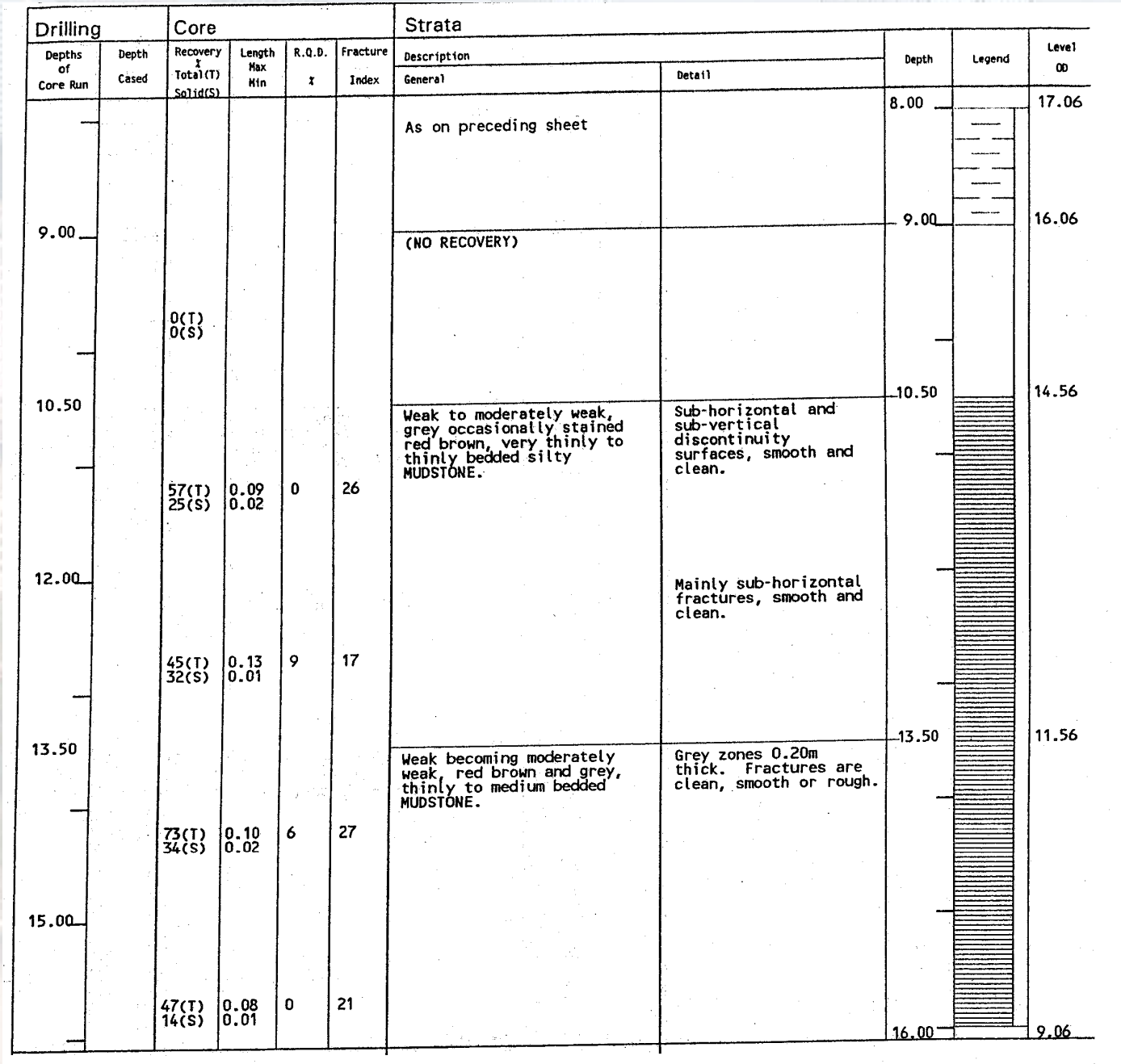


progress date/time water depth	sample no & type	depth (m) from	depth (m) to	casing depth (m)	test type & value	samp. /core range	I_f	instru -ment	description	depth (m)	reduced level (m)	legend
09/12/04 0800hrs									MADE GROUND: Large road cobble (drillers description).	0.20	22.80	
									MADE GROUND: Sand and gravel (drillers description).	0.30	22.70	
									MADE GROUND: Very loose dark brown/black silty sand with a little subangular fine to medium brick gravel.			
	1D	1.20	1.65	Nil	S 3							
	2X	1.20	2.00									
										1.55	21.45	
									Soft and firm brown slightly sandy CLAY with a little angular fine to medium sandstone gravel.			
	3D	2.00	2.45	Nil	S 3				1.75 - 2.00m: Firm.	2.00	21.00	
	4X	2.00	3.00						1.90 - 1.95m: Band of brown fine to medium sand.			
									Very loose brown clayey SAND with a little subangular fine to medium sandstone gravel (wet).			
									2.50 - 2.70m: Band of soft brown sandy clay.	2.70	20.30	
									2.57 - 2.62m: Dark grey subangular mudstone cobble.			
	5D	3.00	3.45	Nil	S 42				Dense red-brown locally mottled light grey-green SAND.			
	6X	3.00	3.30									
	7X	3.30	3.70							3.55	19.45	
	8D	3.70	3.89	3.40	S*190				Red-brown locally mottled light grey-green slightly clayey SAND with a little to some angular fine to coarse gravel size very weak sandstone lithorelicts.	[illegible]	19.30	
	9X	3.70	4.70						Zone of core loss, limited recovery. Recovered as subrounded gravel and cobbles of moderately weak grey-green and red-brown SANDSTONE.			
09/12/04 1700hrs 1.20m										4.70	18.30	
10/12/04 0800hrs	10C	4.70	6.00			100 74	25 30 350		Drilling disturbed SANDSTONE? Recovered as red-brown sand with some subangular medium gravel size sandstone lithorelicts.	4.90	18.10	
									Moderately weak and moderately strong red-brown SANDSTONE with closely locally medium spaced subhorizontal irregular rough tight and irregular rough open fractures.			
									5.10m: Subhorizontal irregular rough open fracture with up to 10mm sandy infill.			
	11C	6.00	7.30	6.00		87 65 43			5.33m: 20° planar rough tight fracture.			
									5.42m: Subhorizontal irregular rough open fracture with up to 10mm sandy infill.			
									5.80m: 20° irregular rough open fracture.			
									6.70m: Approx with occasional gravel size dissolution pockets.			
									6.80m: 45° irregular rough tight fracture.			
									6.95 - 7.00m: Subhorizontal open fracture with sandy gravel infill.			
	12C	7.30	8.80			96 46 21			7.30 - 7.40m: Mottled light grey-green.	7.40	15.60	
									Very stiff red-brown slightly sandy CLAY with extremely closely spaced randomly orientated fissures.			
									Continued Next Page	(8.00)		

Foundation Problems

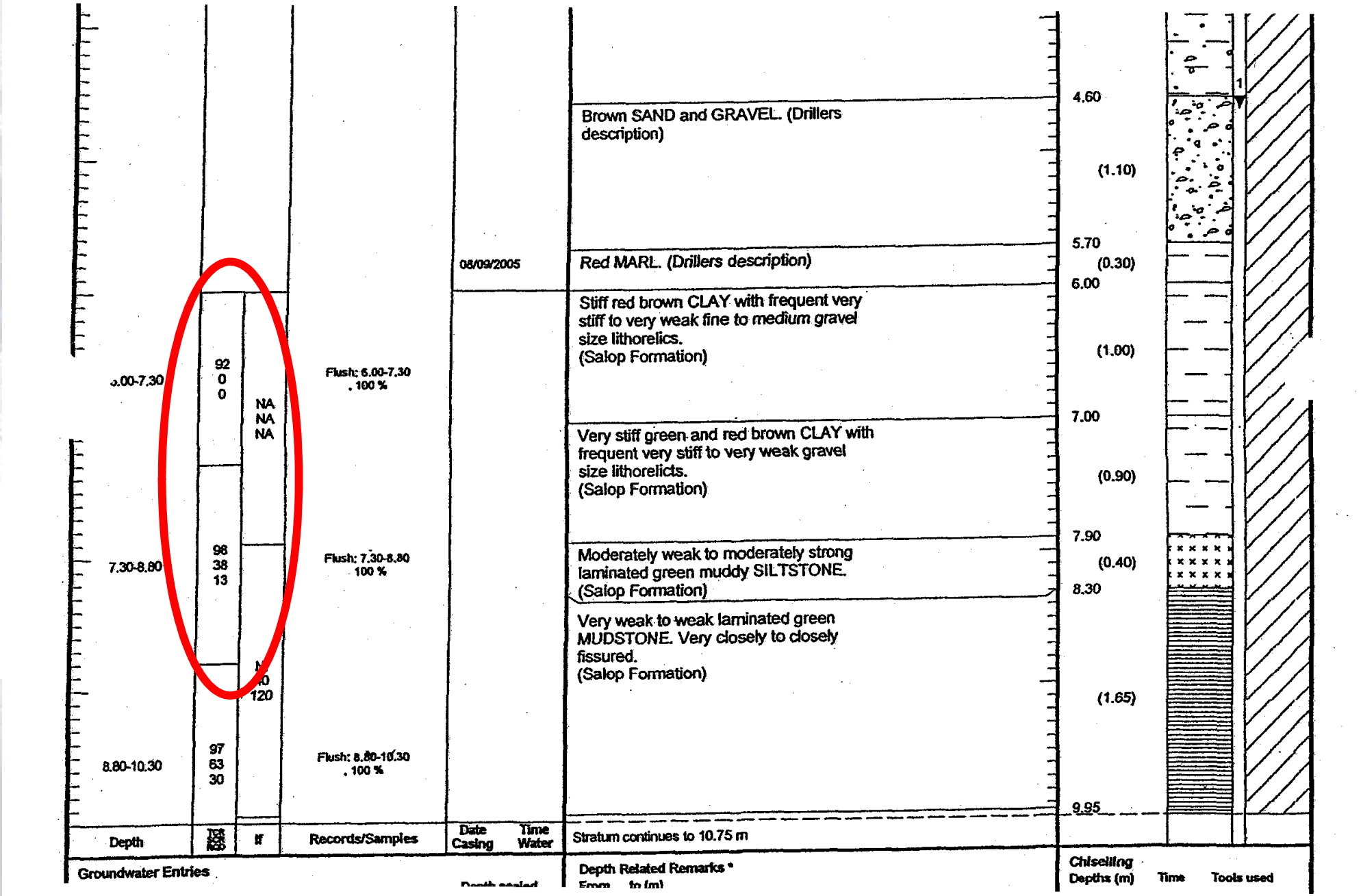
- Mudstones
  - Poor rotary core recovery in GI
  - Weathering – mudstone to clay
  - Identification of missing core
  - Pile problems
    - Smear of rock socket shaft
    - Sedimentation of slurry/spoil at base
    - How to deal with hard layers over soft?

Mudstone - Poor Recovery

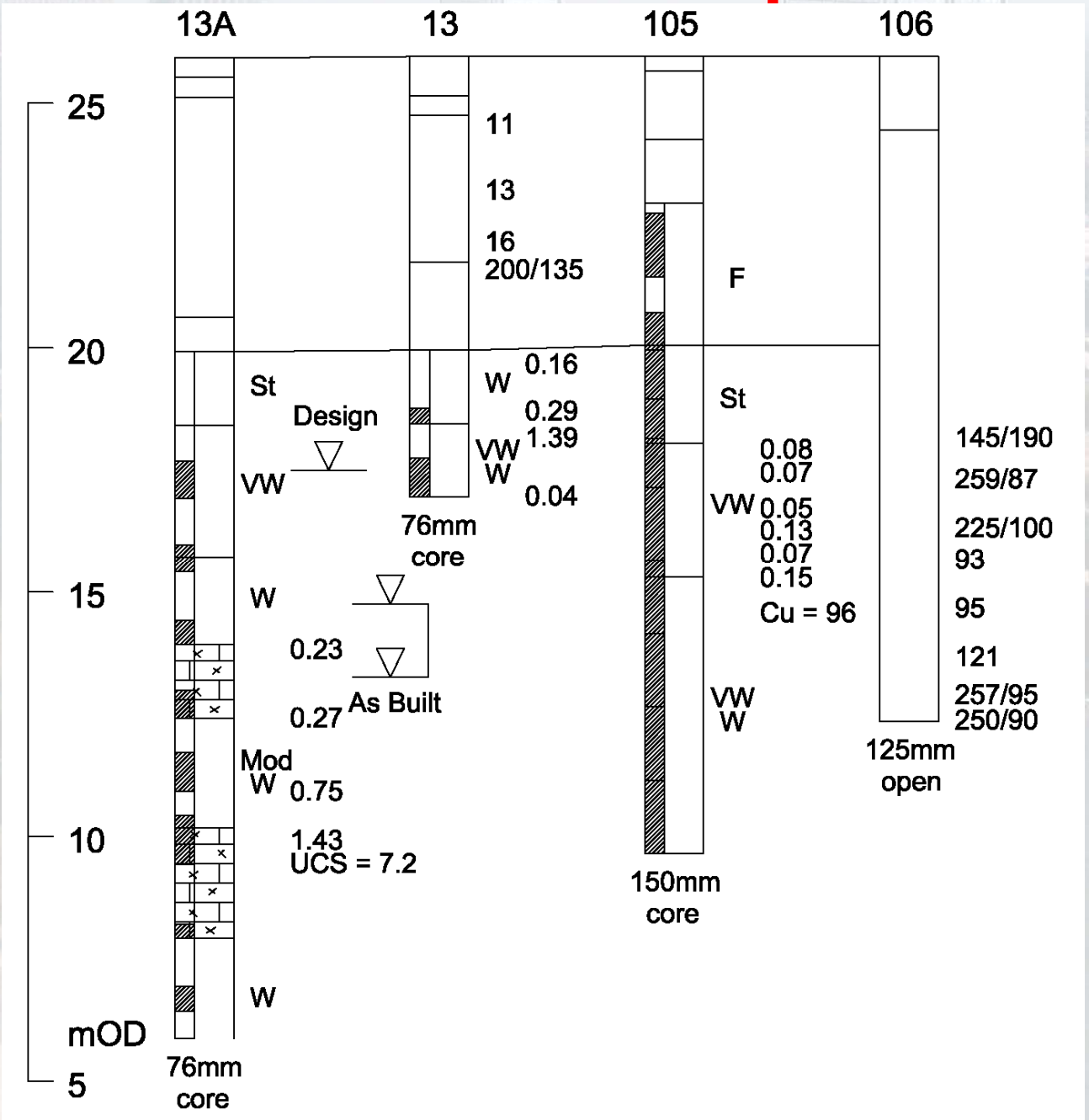


Drilling		Core				Strata				
Depths of Core Run	Depth Cased	Recovery % Total(T) Solid(S)	Length Max Min	R.Q.D. %	Fracture Index	Description General	Description Detail	Depth	Legend	Level OD
						As on preceding sheet		8.00		17.06
9.00								9.00		16.06
		0(T) 0(S)				(NO RECOVERY)				
10.50								10.50		14.56
		57(T) 25(S)	0.09 0.02	0	26	Weak to moderately weak, grey occasionally stained red brown, very thinly to thinly bedded silty MUDSTONE.	Sub-horizontal and sub-vertical discontinuity surfaces, smooth and clean.			
12.00										
		45(T) 32(S)	0.13 0.01	9	17		Mainly sub-horizontal fractures, smooth and clean.			
13.50								13.50		11.56
		73(T) 34(S)	0.10 0.02	6	27	Weak becoming moderately weak, red brown and grey, thinly to medium bedded MUDSTONE.	Grey zones 0.20m thick. Fractures are clean, smooth or rough.			
15.00										
		47(T) 14(S)	0.08 0.01	0	21			16.00		9.06

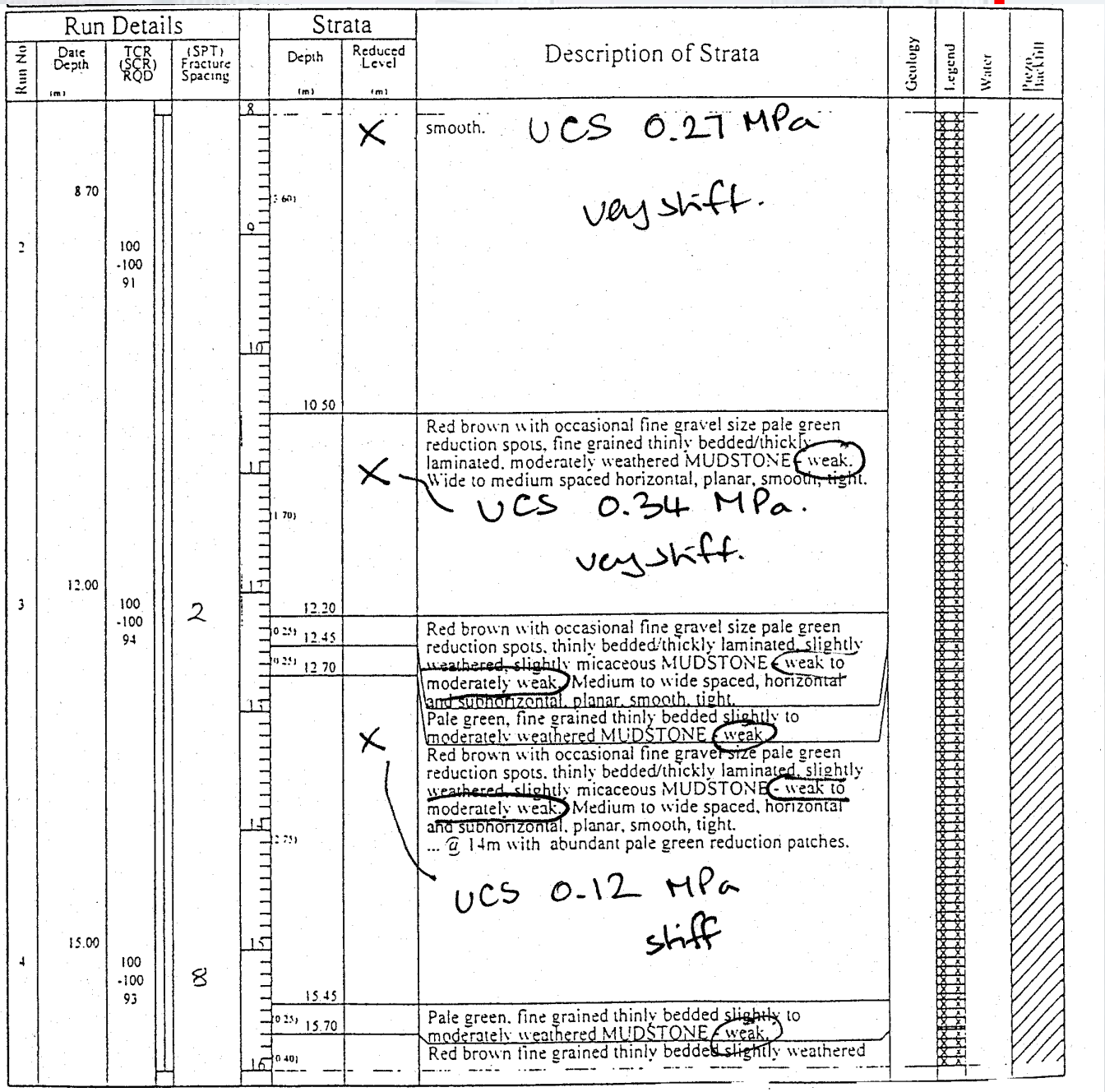
Mudstone - Better Recovery



Mudstone - Comparison



Mudstone - Poor Description

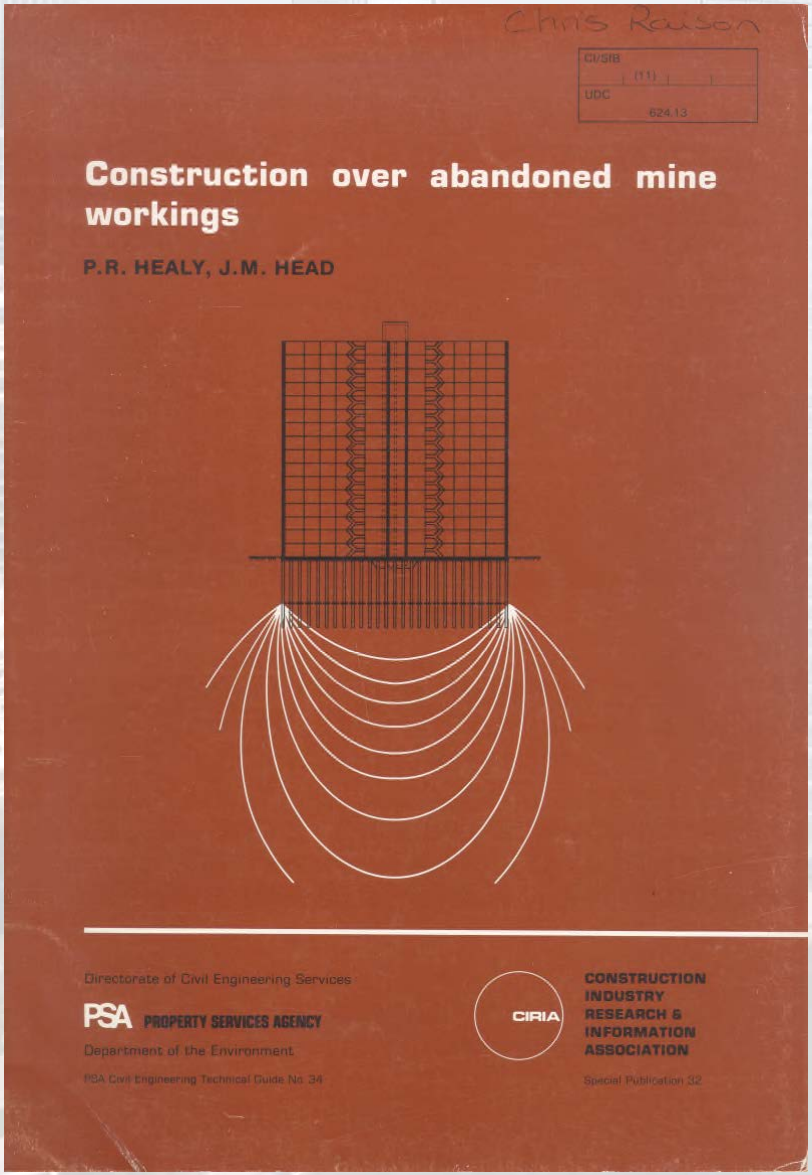


Run Details				Strata		Description of Strata	Geology	Legend	Water	Piezo/ backfill
Run No	Date Depth (m)	TCR (SCR) RQD	(SPT) Fracture Spacing	Depth (m)	Reduced Level (m)					
				8		smooth. UCS 0.27 MPa very stiff.				
2	8.70	100 -100 91		9 (9.60) 10.50						
						Red brown with occasional fine gravel size pale green reduction spots, fine grained thinly bedded/thickly laminated, moderately weathered MUDSTONE - weak. Wide to medium spaced horizontal, planar, smooth, tight. UCS 0.34 MPa. very stiff.				
3	12.00	100 -100 94	2	12 (1.70) 12.20						
				(0.25) 12.45		Red brown with occasional fine gravel size pale green reduction spots, thinly bedded/thickly laminated, slightly weathered, slightly micaceous MUDSTONE - weak to moderately weak. Medium to wide spaced, horizontal and subhorizontal, planar, smooth, tight.				
				(0.25) 12.70		Pale green, fine grained thinly bedded slightly to moderately weathered MUDSTONE - weak.				
				13 (2.75)		Red brown with occasional fine gravel size pale green reduction spots, thinly bedded/thickly laminated, slightly weathered, slightly micaceous MUDSTONE - weak to moderately weak. Medium to wide spaced, horizontal and subhorizontal, planar, smooth, tight. ... @ 14m with abundant pale green reduction patches. UCS 0.12 MPa stiff				
4	15.00	100 -100 93	8	15 15.45						
				(0.25) 15.70		Pale green, fine grained thinly bedded slightly to moderately weathered MUDSTONE - weak.				
				16 (0.40)		Red brown fine grained thinly bedded slightly weathered				

Foundation Problems

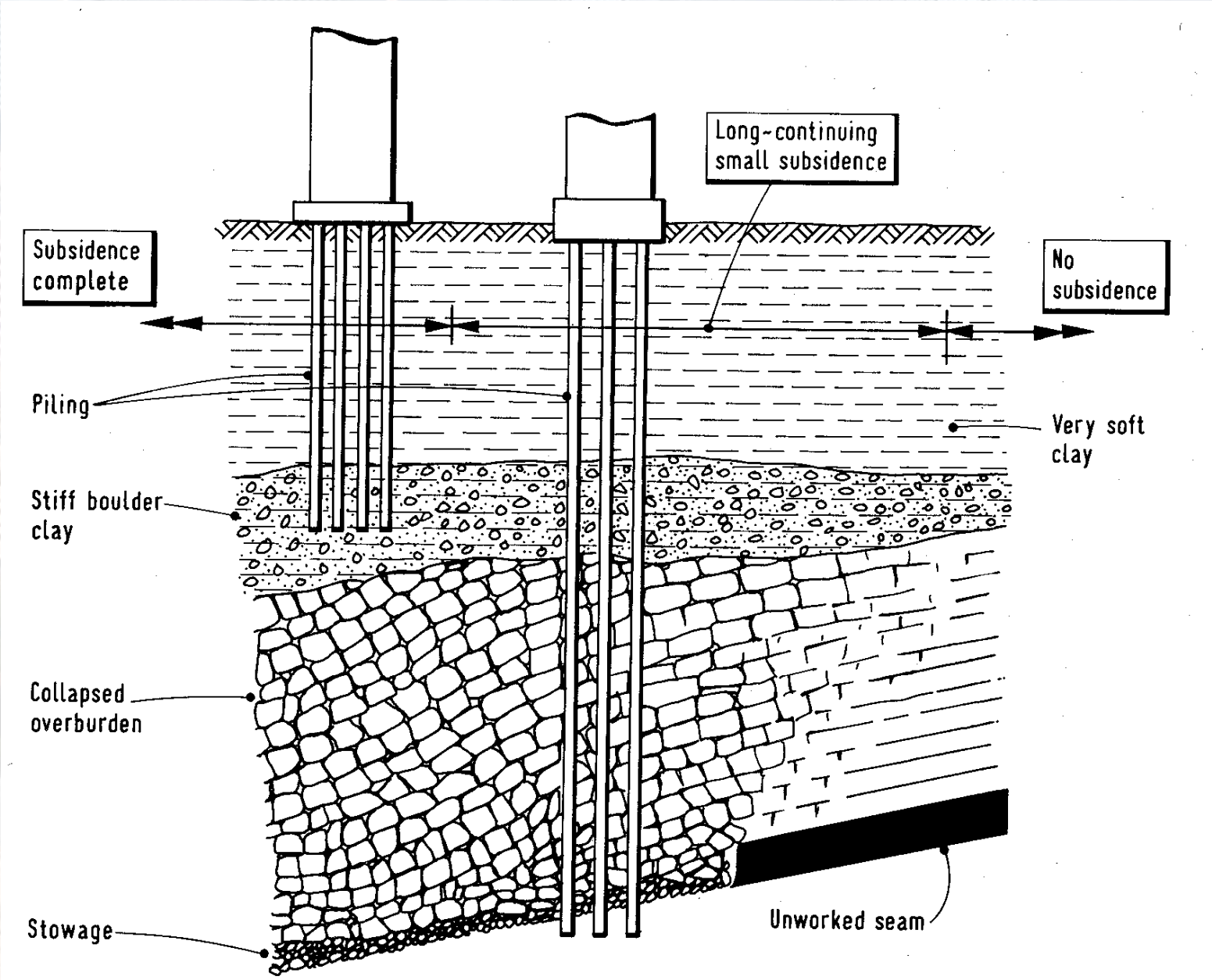
- Coal Measures
  - Mix of sandstone, siltstone & mudstone
  - Usually highly variable
  - Added problem of layers of coal, old workings or even voids

CIRIA Guidance

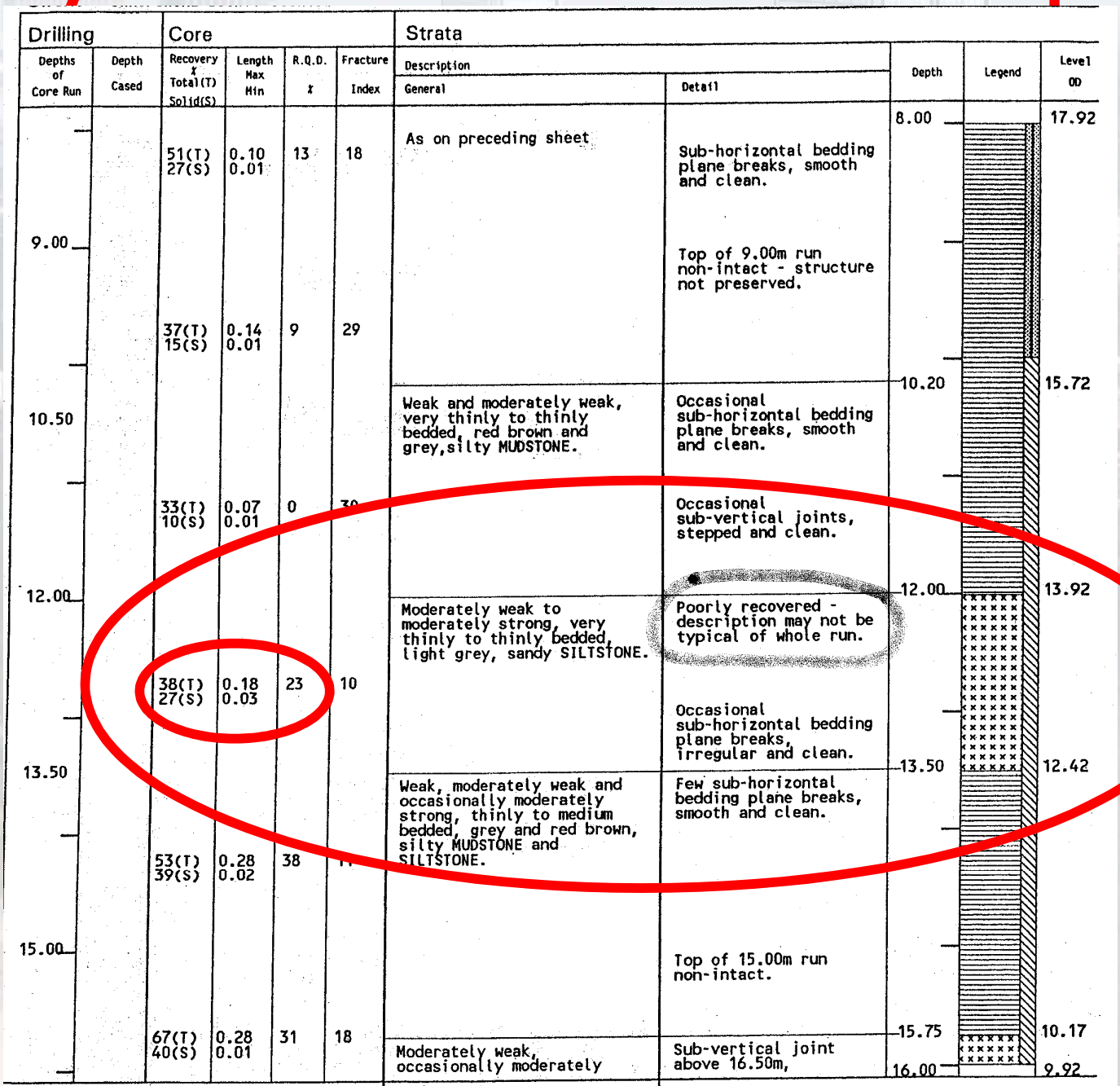


Report SP32

Mine Workings



Rotary Core - Poor Description

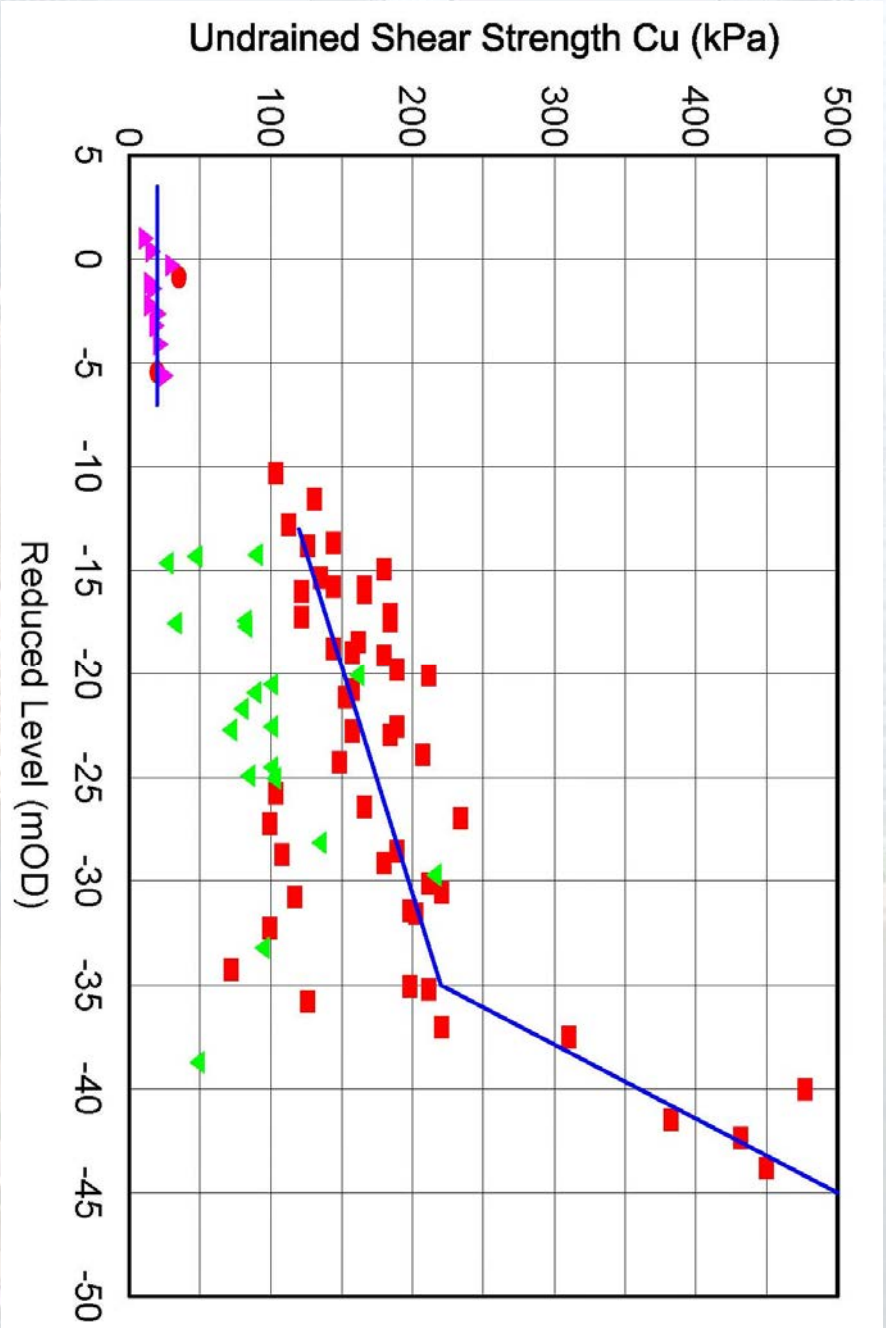


Drilling		Core				Strata				
Depths of Core Run	Depth Cased	Recovery % Total(T) Solid(S)	Length Max Min	R.Q.D. %	Fracture Index	Description General	Description Detail	Depth	Legend	Level OD
						As on preceding sheet	Sub-horizontal bedding plane breaks, smooth and clean.	8.00		17.92
		51(T) 27(S)	0.10 0.01	13	18					
9.00							Top of 9.00m run non-intact - structure not preserved.			
		37(T) 15(S)	0.14 0.01	9	29					
						Weak and moderately weak, very thinly to thinly bedded, red brown and grey, silty MUDSTONE.	Occasional sub-horizontal bedding plane breaks, smooth and clean.	10.20		15.72
10.50										
		33(T) 10(S)	0.07 0.01	0	30		Occasional sub-vertical joints, stepped and clean.			
12.00						Moderately weak to moderately strong, very thinly to thinly bedded, light grey, sandy SILTSTONE.	Poorly recovered - description may not be typical of whole run.	12.00		13.92
		38(T) 27(S)	0.18 0.03	23	10		Occasional sub-horizontal bedding plane breaks, irregular and clean.	13.50		12.42
13.50						Weak, moderately weak and occasionally moderately strong, thinly to medium bedded, grey and red brown, silty MUDSTONE and SILTSTONE.	Few sub-horizontal bedding plane breaks, smooth and clean.			
		53(T) 39(S)	0.28 0.02	38	11					
15.00							Top of 15.00m run non-intact.			
		67(T) 40(S)	0.28 0.01	31	18			15.75		10.17
						Moderately weak, occasionally moderately	Sub-vertical joint above 16.50m,	16.00		9.92

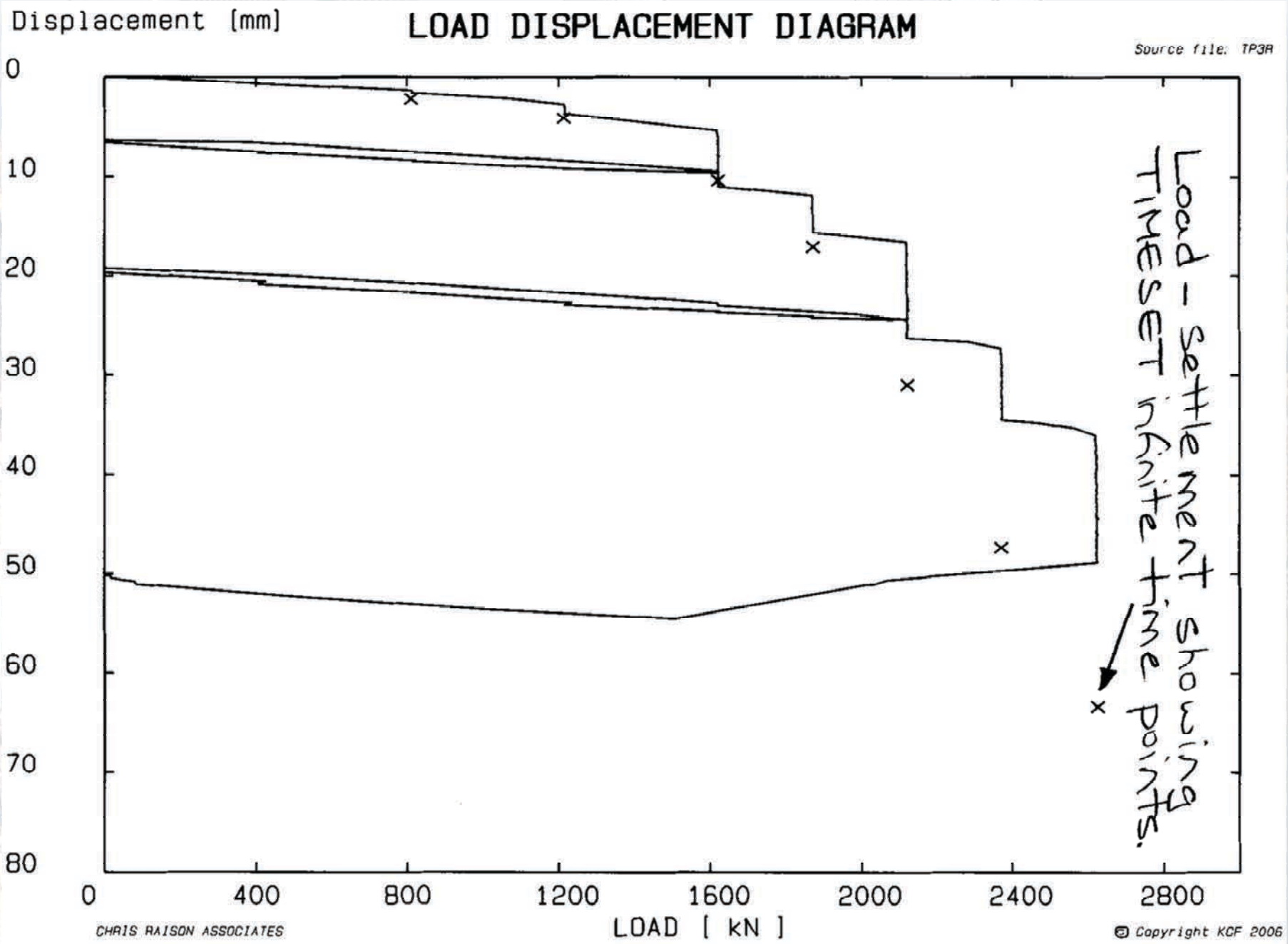
Foundation Problems

- Glacial Till & Boulder Clay
  - GI sampling and testing very difficult
  - Often only SPT data possible
  - Conflict between insitu & laboratory
  - How to determine shaft friction?

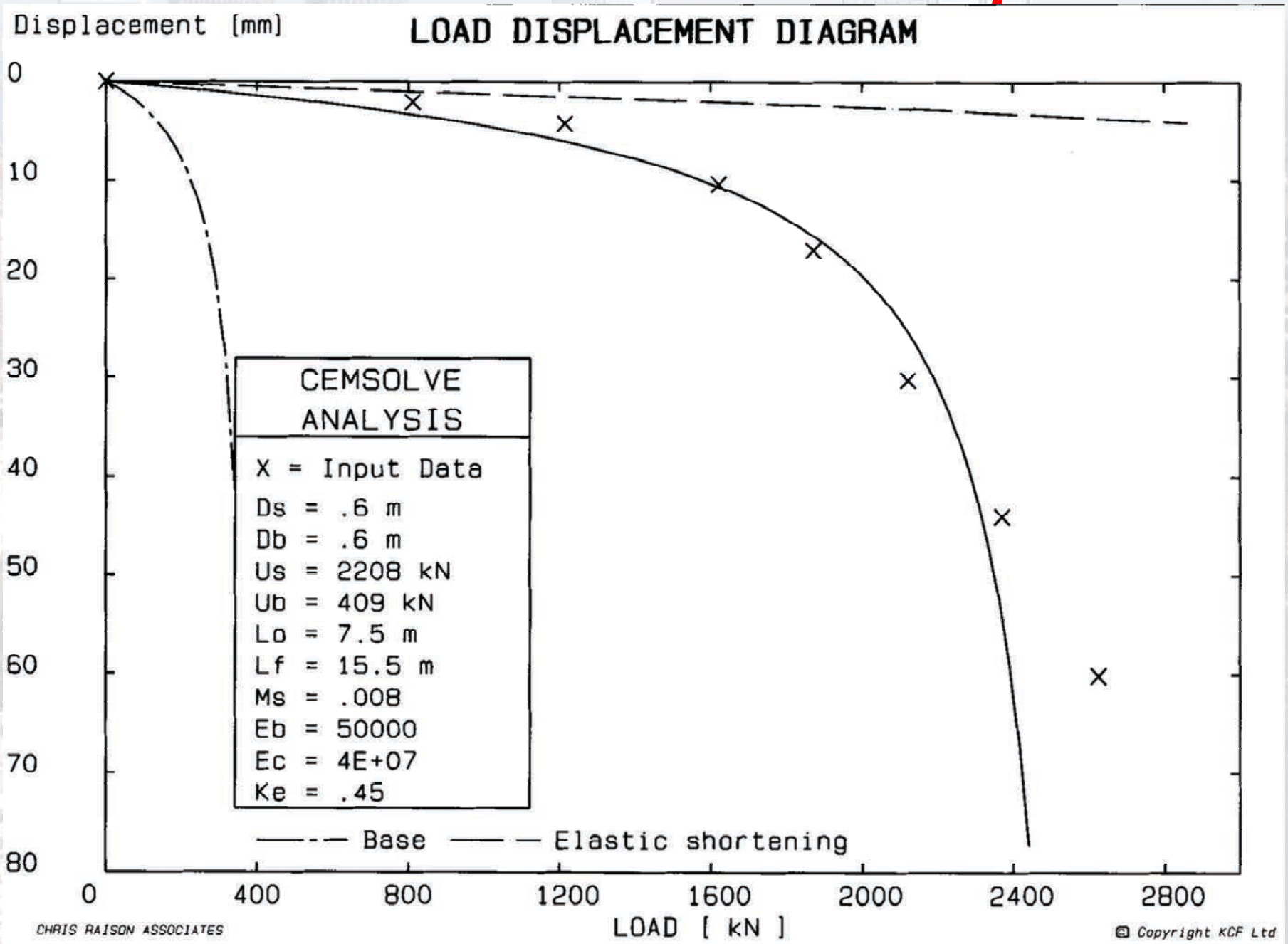
Glacial Till – SPT vs QUT



Pile Test - Load vs Settlement



Pile Test -Back Analysis



Foundations for High Rise

- London Development
  - Pile loads usually large
  - Good pile performance required

BUT

  - Ground conditions relatively simple
  - Site investigation has few difficulties
  - Easy to establish soil & strength profile
  - Pile foundations generally straightforward
  - Effects on ground understood

Foundations for High Rise

- Regional Development
  - Pile loads usually large
  - Good pile performance required

BUT

  - Ground conditions often more complex
  - Often weak variable rock or Glacial Till
  - Site investigation has major difficulties
  - Require high quality core
  - Establishing ground profile is difficult
  - Establishing strength profile is difficult

Foundations for High Rise

- Regional Development
  - Piling works are more complex
  - Can piles be installed to required depth?
  - Does piling affect interface properties?
  - Design calculations are the simplest task