Piles & Chalk

Lessons Learnt the Hard Way
What is Chalk?

• White
• Pure
• Soft & friable
What is Chalk?

- But
- Can be brown, red, green or grey
- Can contain clays and other minerals
- Varies in strength from soft to very hard
Best definition

- Coccolithic limestones
- Calcium carbonate in the form of calcite

- But often grades into:
- Marls - high clay content
- Calcarenites
Pure white chalks

Marl bands in the Chalk Marl

Chalkstone bands in the Chalk Marl

The White Bed, Dover
Extent of Chalk Outcrop in UK

Key
- Green: Upper Chalk (Chalk with flints)
- Red: Lower Chalk (Marly Chalk)
- Brown: Middle Chalk

There is considerable congestion of piling work in the Thames Valley downstream of London.
PILING IN CHALK

N.B. Hobbs
P.R. Healy

Directorate of Civil Engineering Services
PSA PROPERTY SERVICES AGENCY
Department of the Environment
PSA Civil Engineering Technical Guide No. 24

CIRIA CONSTRUCTION INDUSTRY RESEARCH & INFORMATION ASSOCIATION
Table 1 Classification of chalk at the Mundford site
(after Burland and Lord, 1970 and Wakeling, 1970, based on Ward,
Burland and Gallois, 1968)

<table>
<thead>
<tr>
<th>GRADE</th>
<th>BRIEF DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI*</td>
<td>Extremely soft structureless chalk containing small lumps of intact chalk</td>
</tr>
<tr>
<td>V</td>
<td>Structureless remoulded chalk containing small lumps of intact chalk</td>
</tr>
<tr>
<td>IV</td>
<td>Rubbly partly-weathered chalk with bedding and jointing. Joints 10 to 60mm apart, open to 20mm, and often infilled with soft remoulded chalk and fragments</td>
</tr>
<tr>
<td>III</td>
<td>Rubbly to blocky unweathered chalk. Joints 60 to 200mm apart, open to 3mm, and sometimes infilled with fragments</td>
</tr>
<tr>
<td>II</td>
<td>Blocky medium-hard chalk. Joints more than 200mm apart and closed</td>
</tr>
<tr>
<td>I</td>
<td>As for Grade II, but hard and brittle</td>
</tr>
</tbody>
</table>

Note:
* Added by Wakeling (1970)
Table 2  *Classification of chalk hardness* (after Dixon and Carter (32))

<table>
<thead>
<tr>
<th>Classification</th>
<th>$N$ values</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak chalk (including frost-shattered and soliflucted chalk)</td>
<td>$&lt; 20$</td>
<td>Pieces of hard chalk 25 to 50 mm (1 to 2 in.) in diameter in a matrix of putty-like chalk with a soft to firm clay consistency</td>
</tr>
<tr>
<td>Medium hard chalk</td>
<td>20 to 40</td>
<td>Similar to weak chalk but with 150 to 300 mm (6 to 12 in.) pieces of hard chalk and matrix firm to stiff</td>
</tr>
<tr>
<td>Hard chalk</td>
<td>$&gt; 40$</td>
<td>Chalk that breaks only with difficulty between finger and thumb or requires a hammer blow to break it</td>
</tr>
</tbody>
</table>
$q_b = 0.24N$ MN/m² for $N < 30$

$q_b = 0.2N$ MN/m² for $N > 40$

**Key**
- BSP. Newbury, Hobbs & Robins\(^{(38)}\)
- BSP Woolwich, Hobbs & Robins\(^{(38)}\)
- BSP Catham, Meigh\(^{(16)}\)
- West piles Portsmouth, Lord\(^{(37)}\)
- UBP Woolwich, Hobbs & Robins\(^{(38)}\)

**Figure 27**

Ultimate end bearing resistance for some driven piles of Categories 1 and 2
### Table 4

Values of ultimate bond stress for weathered and strong chalk according to $N$ value

<table>
<thead>
<tr>
<th></th>
<th>Weathered chalk</th>
<th>Strong chalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$ value</td>
<td>10  15  20</td>
<td>25  30  &gt;30</td>
</tr>
<tr>
<td>$q_s$ (kN/m$^2$)</td>
<td>35  70  105</td>
<td>170  250  250</td>
</tr>
</tbody>
</table>
Piling in Chalk
PR 11
Piling in Chalk - PR11
End Bearing

bored piles $q_u = 200N \text{ kN/m}^2$
cfa piles $q_u = 200N \text{ kN/m}^2$
driven cast-in-place piles $q_u = 250N \text{ kN/m}^2$
driven preformed piles $q_u = 300N \text{ kN/m}^2$
Piling in Chalk - PR11
Shaft Friction

Average shaft resistance (kN/m²)

Average vertical effective stress (kN/m²)

Cfa $0.45\sigma_v'$
Bored $0.8\sigma_v'$
Driven $0.8\sigma_v'$
Precast 30kPa
PG6 versus PR11 - FPS Paper

When used with engineering judgment PG6 can provide sensible solutions. When and where PR11 should be favoured needs further assessment. Until this has been established, piling contractors’ experience and knowledge must play a role in the design of the piles in chalk if a safe and economic solution is to be determined for each site.

GROUND ENGINEERING APRIL 2000
A Case History - Frogmore Garage
Geological Map

Alluvium
Valley Gravel
Brickearth
Glacial Gravel
Upper Chalk
Site Layout
Initial Site Investigation

- Window sample boreholes
- SEDI auger boreholes
- Revealed made ground over alluvium over glacial gravels
- Two boreholes showed soft clay
PROJECT: Frogmore Garage, Park Street, Frogmore, Hertfordshire
CLIENT: Barratt North London
BORING METHOD: SEDI Auger
BOREHOLE No 10
Date: 12/11/97

GROUND WATER:
Ground water encountered at a depth of 1.10 m

REMARKS:
SVS = Soil Vapour Survey by FID
50 mm diameter fully slotted standpipe installed to 3.00 m with gas valve head fitted

<table>
<thead>
<tr>
<th>Samples No</th>
<th>Type</th>
<th>Depth m</th>
<th>SVS ppm</th>
<th>Legend</th>
<th>Depth m</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>0.30</td>
<td></td>
<td></td>
<td>0.40</td>
<td>Made ground (200 mm of concrete over brick rubble with occasional gravel)</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>0.80</td>
<td>10 - 50</td>
<td></td>
<td>0.90</td>
<td>Soft/ firm organic peaty silty sandy CLAY with wood fragments and occasional fine gravel</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>4.50</td>
<td>&lt;10</td>
<td></td>
<td>4.60</td>
<td>Greyish brown becoming orange-brown silty sandy GRAVEL</td>
</tr>
</tbody>
</table>
# Borehole No 11

**Client:** Barratt North London  
**Boring Method:** SEDI Auger  
**Date:** 12/11/97

**Ground Water:**  
Ground water encountered at a depth of 3.90 m

**Remarks:**  
SVS = Soil Vapour Survey by FID  
50 mm diameter fully slotted standpipe installed to 3.50 m with gas valve head fitted

<table>
<thead>
<tr>
<th>Samples</th>
<th>Type</th>
<th>Depth m</th>
<th>SVS ppm</th>
<th>Legend</th>
<th>Depth m</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
<td>Made ground (100 mm of tarmac over grey silty locally sandy clay with gravel, dead roots, concrete fragments and organic material - slightly malodorous)</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>0.80</td>
<td>10 - 50</td>
<td></td>
<td>1.20</td>
<td>Made ground (pale greyish brown clayey silty sandy gravel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;10</td>
<td></td>
<td>2.25</td>
<td>Brown silty sandy GRAVEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;10</td>
<td></td>
<td>2.90</td>
<td>Soft white silty CLAY with occasional flint</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>3.50</td>
<td></td>
<td></td>
<td>3.90</td>
<td></td>
</tr>
</tbody>
</table>
BOREHOLE
No 14

GROUND WATER:
Ground water encountered at a depth of 1.00 m

REMARKS:
SVS = Soil Vapour Survey by FID
50 mm diameter fully slotted standpipe installed to 3.00 m with gas valve head fitted

<table>
<thead>
<tr>
<th>Samples No</th>
<th>Type</th>
<th>Depth m</th>
<th>SVS ppm</th>
<th>Legend</th>
<th>Depth m</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td>Made ground (200 mm of concrete over black sandy clay with brick fragments)</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>3.80</td>
<td></td>
<td>3.50</td>
<td>3.80</td>
<td>Pale brown CLAY</td>
</tr>
</tbody>
</table>

Greyish brown becoming orange-brown silty sandy GRAVEL
4.5 **Upper Chalk**

A pale brown clay encountered within Borehole No 14 is thought to possibly represent the top of the Upper Chalk in the area.
The granular soils should be capable of supporting the envisaged light loads by means of spread foundations. However, the presence of a high water table may preclude the use of strip footings in some locations and piled foundations or some form of ground improvement may have to be adopted.
For the ground conditions encountered at this site, it is considered that either a driven or bored type of pile would be appropriate. Consideration should be given to the effect of noise and vibrations associated with the installation of driven piles, which could render their use unacceptable.

If loadings are to be relatively light, the use of relatively short driven cast in-situ piles bearing within the Glacial Gravel be considered. A precast segmental type of pile would probably be the most appropriate as it would allow for variations in pile length. It should be noted that for driven piles terminated within the sand at relatively shallow depths, the working load may well exceed the ultimate skin friction and consideration will therefore need to be given to pile settlement characteristics.

In the event of adverse environmental factors associated with the installation of driven piles then consideration could be given to the adoption of a bored pile solution. Again, relatively short bored piles bearing within the Glacial Gravel may be considered for the lighter column loads.

A borehole investigation will be required to provide data to assist in the design of piled foundations.
Mistakes No. 1 & 2

- No comment about the ‘possible Chalk’ at shallow depth in two out of fourteen boreholes
- No discussion about thin gravel or underlying soft clay and the effect on foundations
Site Investigation
Deep Borehole Site Investigation

- Cable tool boreholes

- Revealed made ground over alluvium over medium dense glacial gravels over highly weathered and weathered Chalk
**GROUND WATER**

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Depth (m)</th>
<th>SPT N</th>
<th>Legend</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>0.50</td>
<td>0.20</td>
<td></td>
<td>Tarmac over concrete</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>1.30</td>
<td>20</td>
<td></td>
<td>Made ground (rock rubble in a sandy clay matrix)</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>1.50</td>
<td></td>
<td></td>
<td>Soft dark brown peaty CLAY with occasional gravel</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>2.30</td>
<td>22</td>
<td></td>
<td>Medium dense brown sandy flinty GRAVEL</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>3.30</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>D</td>
<td>3.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>4.30</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>4.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>5.30</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>D</td>
<td>5.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>6.80</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>D</td>
<td>7.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>B</td>
<td>8.30</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>D</td>
<td>8.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>9.80</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:** Excavating inspection pit to 1.00 m for 1 hour 30 minutes. Water added to assist drilling from 1.20 m to 8.20 m. Ground water struck at 0.80 m rose to 0.20 m after 20 minutes, at 1.30 m rose to 0.65 m after 20 minutes, at 8.20 m rose to 6.20 m after 20 minutes, and at 11.20 m rose to 5.60 m after 20 minutes. 50 mm diameter perforated standpipe installed to 4.00 m.
Geological Section

Approximate level of soft clay in boreholes 11 and 14
SPT Profile in Gravels
SPT Profile in Chalk
2.1 Summary of Previous Investigation

The ground conditions were found essentially to comprise made ground over weak alluvial soils over gravel. In the lower part of the site, towards the northwestern corner, the made ground was found to be thin and the site had been raised elsewhere by the placing of up to about 2 m to 3 m of made ground. Ground water was encountered at shallow depths.
4.3 Glacial Gravel

The made ground and alluvium were found to be underlain by Glacial Gravel. This stratum mainly consists of dark grey and brown sandy gravel and was found to extend to depths of between 7.20 m and 7.40 m. Beneath this stratum, in Borehole Nos 15 and 16, coarse flinty gravel with flint cobbles and bands of weathered chalk was encountered and found to extend to a depth of about 10.20 m.

The SPTs indicate the gravel stratum to be in a generally medium dense condition.

4.4 Upper Chalk

The Upper Chalk was found to underlie the Glacial Gravel and was proved to the full depth investigated.

The following strength classification has been used to categorise the chalk on the appended borehole records.

<table>
<thead>
<tr>
<th>SPT 'N' Value (cone)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>Highly Weathered</td>
</tr>
<tr>
<td>20 to 30</td>
<td>Weathered</td>
</tr>
<tr>
<td>30 to 40</td>
<td>Moderately Sound</td>
</tr>
<tr>
<td>&gt;40</td>
<td>Sound</td>
</tr>
<tr>
<td>&gt;50</td>
<td>Very Sound</td>
</tr>
</tbody>
</table>

On this basis the chalk has been assessed as initially highly weathered above about 12.0 m below existing ground level, weathered to a depth of about 14 m, and moderately sound thereafter. The chalk was found to include occasional flints.
The investigation has revealed the presence of relatively nominal thicknesses of fill materials and alluvium which overlie up to 7.2 m of medium dense gravel and then the Upper Chalk. It is likely that the underground fuel storage tanks, both those currently in use and the disused cement filled tanks, which are located along the Park Street frontage, will be removed. This will typically result in relatively large excavations to depths of about 3 m. Such activities will result in the disturbance of the soils beneath a significant proportion of the proposed flats which will preclude the use of a shallow spread foundation solution. Beneath the footprint of the proposed townhouses, the presence of ground water at shallow depths will similarly preclude the formation of shallow foundation excavations. In each case, therefore, it is considered that a piled foundation solution will prove to be the most feasible option.

5.1 Piled Foundations

For the ground conditions encountered at this site, it is considered that a bored pile installed by means of a continuous flight auger (cfa) would be the most appropriate type, since it will obviate the need for temporary casing through the granular soils which would be necessary with conventional bored or augered piles. In addition, adverse environmental factors, such as providing a conduit for the downwards migration of contaminants, would not arise. Consultation with the EA should be sought before any pile type or method of construction is finally adopted.
Mistakes No. 3, 4 & 5

- No consideration of the ‘possible Chalk’ at shallow depth found in the original SI
- No discussion about gravel with layers of Chalk below about 7.5m depth
- No warning about possible solution features in the Chalk
The following table of ultimate coefficients may be used for the preliminary design of straight-shafted bored piles installed using cfa techniques, based upon the measured SPT / Depth relationship illustrated in the Appendix.

<table>
<thead>
<tr>
<th>Ultimate Skin Friction</th>
<th>$kN/m^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Made Ground G.L. - 1.5 m</td>
<td>Ignore</td>
</tr>
<tr>
<td>Sandy Gravel 1.5 m - 7.5 m</td>
<td>20</td>
</tr>
<tr>
<td>Upper Chalk 7.5 m - 12.0 m</td>
<td>Increasing linearly from 100 to 250</td>
</tr>
<tr>
<td>12.0 m - 15.0 m</td>
<td>250 (limit)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ultimate End Bearing</th>
<th>$kN/m^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Upper Chalk 12.0 m - 15.0 m</td>
<td>Increasing linearly from 4800 to 7200</td>
</tr>
</tbody>
</table>

Different factors of safety, or load factors, for shaft friction and end of bearing are normally applied to these values, depending on the method of pile construction.
Mistake No. 6

• Why give so much detail about piling yet fail to give warnings about the highly weathered surface of the Chalk or about the possibility of solution features
Problems During Piling

- 350mm diameter Cfa piles were designed by the contractor
- Typical length about 10m
- Problems with slumping concrete during construction
- A number of piles needed re-drilling
- More SI was carried out to investigate
Cfa Piling

Diagram showing Cfa Piling:
- Spoil
- Reinforcing cage
- Concrete
Cfa Piling
Geological Section

Chalk is at a similar level in 15a but is weaker than in 15.
Chalk is at a much higher level and is weaker.
Geological Section

Chalk is at a much higher level

Chalk at high level is much weaker than in borehole 16

Lower gravels in 16 may be infill material
Geological Section

Chalk is at a slightly higher level.

Chalk at high level is generally weaker than in borehole 17.
Geological Section

Chalk level is shown to be very variable across the site.
SPT Profile in Gravels

Generally confirms the original boreholes but shows a greater range and local variation.
SPT Profile in Chalk

Generally confirms the original boreholes but shows a greater range and local variation.

Chalk is very weak at higher levels.
Conclusions from Additional SI

- Additional SI carried out confirmed that there were major differences in Chalk level and strength
- Piling contractor believed ground conditions were different
- Engineer and Client concluded that original SI was false
Conclusions from Additional SI

• Engineer & Client lost confidence
• Claimed that SI data was false and SI report advice was therefore misleading and wrong
• Client blamed SI contractor for all the piling problems and commenced claim
Reassessment of Additional SI

• Interface between gravels and Chalk very irregular

• Chalk strength very low at higher levels

• But

• SPT values at depth were generally similar to the original boreholes
Reassessment of Additional SI

- Variations in Chalk level and strength can be explained by a variable weathering profile and the presence of a number of solution features
- Collapsed swallow holes or infilled solution pipes
Figure 25  Schematic illustration of common dissolution feature types developed in calcium carbonate rich chalks (based on Applied Geology, 1993)
Solution Features - Sink Hole
Solution Features
Solution Features - Solution Pipe
Solution Features
Mistake No. 7

- The SI contractor did not recognise that the piling problem was almost certainly due to solution features
- But neither did the piling contractor, Engineer or Client
- The opportunity to solve the problem was missed
The Claim

- On site discussions concluded that much more expensive driven steel cased piles were required rather than continuing with the Cfa option.
- The claim was started on the believe that the original SI had been falsified.
- Everything was blamed on the SI contractor.
The Claim

- The reality was that no one recognised the possibility of solution features
- Both the piling contractor and Engineer should have been aware of the risk
- In my view the piling contractor and Engineer were equally culpable
The Claim

- The SI contractor was found negligent for not including a warning in his report.
- He lost the case, was blamed for everything and had to pay.
Conclusions

• Always include a warning about solution features (and mine workings) when dealing with Chalk
• Do not include throw away comments
• Do not give advice where it has not been asked for particularly in areas where you are not a specialist