Concrete Basements

Guidance on the design and construction of in-situ concrete basement structures

ASELB 29 April 2016

Charles Goodchild
CEng., MICE, MStructE
Principal Structural Engineer
MPA - The Concrete Centre

The whole lecture usually takes 90 mins.

The talk is aimed at commercial basements but the principles are applicable to domestic basements, water retaining structures, etc.

It is necessary to understand the background before kicking on with the structural design.

Concrete Basements

Introduction/background
Planning a basement
• Types & Waterproofing strategy
• Site Constraints
Ground movements & Methods of construction
Materials
Structural design
• Loads
• ULS
• SLS
• Example
Specification and construction
Case studies

Concrete Basements

Introduction/background
Planning a basement
• Types & Waterproofing strategy
• Site Constraints
Ground movements & Methods of construction
Materials
Structural design
• Loads
• ULS
• SLS
• Example
Specification and construction
Case studies

Then: BS 8007:1987

Then: BS 8102:1990

ASELB 29 April 2016
Concrete Basements

Then: CIRIA 139/140  1995

Then: Design & Construction of Deep Basements: 2004

What’s new(ish) in basements (and water retaining structures)?

- Eurocodes
- Withdrawal of BS 8110, BS 8007 etc
- Revision to BS 8102
- New information:
  - CIRIA C660
  - CIRIA C580
  - ICE Reducing the Risk of Leaking Substructure: A Clients’ Guide
- Debate
  - S Alexander, TSE Dec 06
  - B Hughes, TSE Aug 08?
  - ICE project 0706 on reinforcement to control cracking (report Feb 2010)

EN1992-3

CIRIA C660

BS8102
Concrete Basements

Introduction/background
Planning a basement
- Types & Waterproofing strategy
- Site Constraints
Ground movements & Methods of construction
Materials
Structural design
- Loads
- ULS
- SLS
- Example
Specification and construction
Case studies

Basement design requires:
- an holistic approach
- an understanding of both the ground and the structural behaviour
- formal consideration of construction methods
- communication:

Wants
Clients want:
- short construction times
- low costs
- low risk and uncertainty
Architects want:
- Dry walls and base - with no impact on space planning
- Simple shapes - unless it’s shapes they are defining
- Large holes - often at points of maximum in-plane stress
- No columns - but if you put any in, they will clad them to twice the size
- Narrow beams between holes (not appreciating they will act more like props)
Contractors want:
- Bottom up Construction - simpler
- Cantilever walls - no props, simpler
- No tanking - simpler, & anyway it always leaks somewhere
- No constraint on construction sequence - leaves more options open
- when things get out of sequence. He will assert that HIS sequence CANNOT have any affect on the design forces
- Get him on-side ASAP - he can be an ally

Concrete Basements
Outline of the design process
1. Establish Clients requirements
2. Site surveys, etc
3. Outline designs, methodology and proposals
4. On approval do detailed design
5. Construction

And Engineers? . . . . . . . . . . a simple life!
Concrete Basements

Planning a basement

Grades

**BS 8102:2009** Table 2 provides guidance:

<table>
<thead>
<tr>
<th>Grade of use</th>
<th>Grade 1</th>
<th>Some leakage, some damp. Parking, Plant rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 2</td>
<td>No water penetration or damp patches. Plant rooms, workshops</td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>Dry environment. Ventilation required. Residential, Commercial</td>
<td></td>
</tr>
<tr>
<td>Grade 4</td>
<td>(totally dry and vapour proof) Archives, stores ... go to BS 5454</td>
<td></td>
</tr>
</tbody>
</table>

As an aid . .

Planning a basement

Types

**BS 8102:2009**

**Type A**
Barrier protection

**Type B**
Structurally integral protection

**Type C**
Drained protection

Planning a basement

Forms of rc basement construction related to site conditions and use of basement space:

<table>
<thead>
<tr>
<th>Water Level</th>
<th>Form of construction</th>
<th>Method of construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low: generally below floor level</td>
<td>RC box</td>
<td>In open excavation or within temporary works</td>
</tr>
<tr>
<td>Medium to high: permanently above lowest floor level</td>
<td>Contiguous piling</td>
<td>Basement excavated after piling with the floors acting as props in the final condition with/without subsequent concrete facing</td>
</tr>
<tr>
<td>Medium to high: permanently above lowest floor level</td>
<td>Secant piling or sheet piling, etc.</td>
<td></td>
</tr>
<tr>
<td>Medium to high: permanently above lowest floor level</td>
<td>Diaphragm walling</td>
<td>Basement excavated after diaphragm with the floors acting as props in the final condition</td>
</tr>
</tbody>
</table>

Planning a basement

Types of water-resisting construction vs risk

<table>
<thead>
<tr>
<th>Risk area</th>
<th>Water level</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Medium</td>
<td>Variable</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Planning a basement

Other subjects

- Surveys and ground investigations
- Precautions near underground tunnels, sewers & service mains
- Working adjacent to existing structures: Party walls
- Tolerance of buildings to damage
- Space planning
- Integrating basement with the superstructure
- Fire safety considerations
- Client approval
Concrete Basements

Planning a basement

Exploratory works
NEEDED EARLY - commission early!
desk study
• geological maps, borehole records,
  • ordnance survey, water courses, utilities.
site surveys
• boundaries, adjoining buildings and roads, liaison with adjacent owners, party walls,
  • incoming services, tunnels
subsoil investigation
• bearing capacity, water level, pile design,
  • earth pressures, settlements, (modulus of subgrade reaction) contaminants. See BS EN 1997-2
money well spent!
assess
• risk of risk of flooding (EA), likely obstructions, foundation details of adjoining buildings, disposal of groundwater

Planning a basement

Space planning:

Check for:
• room for temporary works - clearances for piling rigs, diaphragm wall equipment takes up considerable space,
• restrictions imposed by owners of underground tunnels and utility companies
• dimensions of guide walls for contiguous piles (may be around pile diameter + 800 mm);
• wall thicknesses - zone for cavity drains if relevant;
• tolerances for piling and temporary works;
• capping beams
• projecting features of adjoining structures.
• superstructure - follow through into basement,
• Fire - means of escape, compartmentation, access

Planning a basement

Capping beams

Agree excavation criteria and monitoring required with Local Authority
Temporary line locations and corrections
Living wall
150 x pile tolerances

Planning a basement

Party Walls/Adjacent buildings - notices

• 3m and 6m notices
• Distortions cause damage – not absolute movement
• 10 mm often used as a trigger

Planning a basement

Space requirements

Bored pile wall installation:
Site boundary clearances:

Typical clearances required at site boundaries:
A = 3.2 to 3.7 m
B = 3.5 to 3.9 m
C = 1.6 to 2.3 m

(1) Min need to consider
  clearances at height, dimension D & C for MV head, rather than at ground level
  spill removal

Planning a basement

Pile tolerances

Plan of basement wall before engineer advice

Standoff pile tolerance is 75mm on plan (25mm with guide wall) plus
1 to 75 vertically.
For a 4m deep basement, this equals 780mm

ASELB 29 April 2016
Concrete Basements

**Introduction/background**

Planning a basement
- Types & Waterproofing strategy
- Site Constraints

**Ground movements & Methods of construction**

**Materials**

Structural design
- Loads
- ULS
- SLS
- Example

Specification and construction

**Case studies**

**Ground movements**

**Vertical load & relief**

**Horizontal load relief**

**Construction Sequence**

- The temporary loads from the construction sequence will probably have an impact on the permanent design.
- For anything other than a very simple basement, the engineer should assume a construction sequence and include it in the tender documents.
- The contractor should be allowed to deviate from the assumed construction sequence; but at least everyone knows what the original assumptions were, and can see if any change will affect the design of the permanent works.

**Construction methods**

Open excavation
- Bottom - up
- Top - down
- Semi-top down

Groundwater

Options for basement walls:
- In open excavations: R C walls
- Incorporating temporary embedded retaining walls:
  - King post walls
  - Steel sheet piling
  - Contiguous piled wall
  - Secant piled wall
  - Diaphragm walls
  - Facing walls

Temporary works

**Retaining Wall Types**

- Reinforced Concrete
- Contiguous Walls
- Secant Walls
- Diaphragm Walls

- Grab
- Hydrotill
- Movement joint

Pre-cost guide to wall & capping beam system
Concrete Basements

Construction methods
Contiguous Piled Wall

Construction methods
Contiguous Piled Wall

Construction methods
Contiguous Piled Wall

Construction methods
Contiguous Piled Wall

Construction methods
Secant Piles

Construction methods
Secant Piles

Construction methods
Facing wall

Construction methods
Diaphragm Wall

Facing wall

Diaphragm Wall

ASELB 29 April 2016
Concrete Basements

Sheet Piles

Propped Excavation

Propped Excavation

Reality

Top Down Construction

Grouting

The controlled injection of special grouts into the ground to produce a solidified mass.

This allows the basement to be easily excavated.

All three types of waterproofing can be used with this method.
Concrete Basements

Introduction/background
Planning a basement
• Types & Waterproofing strategy
• Site Constraints
Ground movements & Methods of construction

Materials
Structural design
• Loads
• ULS
• SLS
• Example
Specification and construction
Case studies

Selection of materials
Type A construction:
Waterproofing membranes and systems:
• Category 1 - Bonded sheet membranes
• Category 2 - Cavity drain membranes
• Category 3 - Bentonite clay active membranes
• Category 4 - Liquid applied membranes
• Category 5 - Mastic asphalt membranes
• Category 6 - Cementitious crystallisation active systems
• Category 7 - Proprietary cementitious multi-coat renders, toppings and coatings

Bonded sheet membranes...modified bitumen on a range of carrier films

Liquid applied membranes...generally applied as a bitumen solution, elastomeric urethane or modified epoxy

Mastic asphalt...applied in 3 coats as a hot mastic liquid

Proprietary cementitious multi-coat renders, toppings and coatings
Proprietary cementitious multi-coat renders, toppings and coatings

Selection of materials

Type A construction:
Waterproofing membranes and systems:
- Category 1 – Bonded sheet membranes
- Category 2 – Cavity drain membranes
- Category 3 – Bentonite clay active membranes
- Category 4 – Liquid applied membranes
- Category 5 – Mastic asphalt membranes
- Category 6 – Cementitious crystallisation active systems
- Category 7 – Proprietary cementitious multi-coat renders, toppings and coatings

Types B & C construction:
Concrete
Admixtures for watertightness

Selection of materials

Concrete:
- Benign soils: RC30/37: Cement IIB-V (CEM I + 21%-35% fly ash)
  or IIIA (CEM I + 36% - 65% ggbs).
- Aggressive soils: Advise producer of DC Class.
  For DC-2: FND-2? (C25/30)?
  More aggressive soils: Cement IIIB (CEM I + 66% - 80% ggbs) or
  IVV-B (CEM I + 36%-55% fly ash)
- Car Parks: C32/40? + provisos (PAV2?)
  • Fibres? Possibly. Fibres only help once the concrete has cracked.

Admixtures

Selection of materials

Concrete Society Working Group on Water Proofing admixtures:
- no conclusive evidence to support their use (- from a material scientist’s point of view),
- from data there is some evidence to suggest that they may reduce drying shrinkage (less permeability) and therefore reduce onset of cracking and reduce crack widths

Cost and risk:
- Traditional: Engineering, workmanship, supervision issues, risk & possible remedials and upheavals and contractual issues
  vs
- Admixtures: warranties, supervision & possible remedials and upheavals but few contractual issues

Whatever the basement should still be designed properly!

Selection of materials

Water stops
- Preformed strips - rubber, PVC, black steel
- Water-swellable water stops
- Cementitious crystalline water stops
- Miscellaneous post-construction techniques
  • (Re) injectable water bars
  • Rebate and sealant

Selection of materials

Type A construction:
Waterproofing membranes and systems:
- Category 1 – Bonded sheet membranes
- Category 2 – Cavity drain membranes
- Category 3 – Bentonite clay active membranes
- Category 4 – Liquid applied membranes
- Category 5 – Mastic asphalt membranes
- Category 6 – Cementitious crystallisation active systems
- Category 7 – Proprietary cementitious multi-coat renders, toppings and coatings

Types B & C construction:
Concrete
Admixtures for watertightness

Water stops
- Preformed strips - rubber, PVC, black steel
- Water-swellable water stops
- Cementitious crystalline water stops
- Miscellaneous post-construction techniques
  • (Re) injectable water bars
  • Rebate and sealant

Selection of materials

Type A construction:
Waterproofing membranes and systems:
- Category 1 – Bonded sheet membranes
- Category 2 – Cavity drain membranes
- Category 3 – Bentonite clay active membranes
- Category 4 – Liquid applied membranes
- Category 5 – Mastic asphalt membranes
- Category 6 – Cementitious crystallisation active systems
- Category 7 – Proprietary cementitious multi-coat renders, toppings and coatings

Selection of materials

Admixtures

Selection of materials

Concrete:
- Benign soils: RC30/37: Cement IIB-V (CEM I + 21%-35% fly ash)
  or IIIA (CEM I + 36% - 65% ggbs).
- Aggressive soils: Advise producer of DC Class.
  For DC-2: FND-2? (C25/30)?
  More aggressive soils: Cement IIIB (CEM I + 66% - 80% ggbs) or
  IVV-B (CEM I + 36%-55% fly ash)
- Car Parks: C32/40? + provisos (PAV2?)
  • Fibres? Possibly. Fibres only help once the concrete has cracked.

Admixtures

Selection of materials

Concrete Society Working Group on Water Proofing admixtures:
- no conclusive evidence to support their use (- from a material scientist’s point of view),
- from data there is some evidence to suggest that they may reduce drying shrinkage (less permeability) and therefore reduce onset of cracking and reduce crack widths

Cost and risk:
- Traditional: Engineering, workmanship, supervision issues, risk & possible remedials and upheavals and contractual issues
  vs
- Admixtures: warranties, supervision & possible remedials and upheavals but few contractual issues

Whatever the basement should still be designed properly!
Concrete Basements

**Construction, inspection and testing**

- **Waterbar**
- **Hydrophilics**
- **Resin injection**
- **Cavity drain membranes...high density dimpled polyethylene sheets**
- **Cavity drain**
- **Sump pump**
Concrete Basements

Introduction/background
Planning a basement
- Types & Waterproofing strategy
- Site Constraints
Ground movements & Methods of construction
Materials
Structural design
- Loads
- ULS
- SLS
- Example
Specification and construction
Case studies

Structural design outline:

Ultimate Limit State  ≡ ‘normal’ design
Serviceability Limit State  ≡ control of cracking

Structural design - Loads

Loads to be considered:
- Slabs: column & wall loads, basement slab load, upward water pressure, heave.
- Walls, lateral earth pressure, water pressure, compaction, loads from superstructure, imbalances.

Design ground water pressure
- ‘Normal’ and ‘maximum’ levels

Options for basement slabs
- Soil-structure interaction
- Beams on elastic foundations
- FEA

Options for basement walls
- Temporary conditions: construction method and sequence
- Permanent condition

Unplanned excavations
- Allowances for cantilever retaining systems

Structural design - Loads

Calculation of lateral earth pressures
Angle of shearing resistance:
- Granular soils:
  Estimated peak effective angle of shearing resistance
  \( \phi'_{\text{max}} = 30 + A + B + C \)
  (A - Angularity, B - Grading, C - N blows)
- Clay soils
  In the long term, clays behave as granular soils exhibiting friction and dilation.

Design angle of shearing resistance: \( \tan \phi' = \tan \phi'/\gamma \) (\( \gamma \) according to Combinations 1 and 2)

Pressure coefficients
- Active pressure at depth z below ground surface \( \delta_{a} = K_{ad} \delta_{v} + u \)
- Passive pressure at depth z below ground surface \( \delta_{p} = K_{pd} \delta_{v} + u \)
- At rest pressure at depth z below ground surface \( \delta_{r} = K_{0d} \delta_{v} + u \)

Surcharge loadings:
- Imposed loads: general, highways
- UDLs, point loads, strip loads, rectangular loads: Boussinesq
- Compaction pressures

Structural design - Loads

Calculation of lateral earth pressures

Structural design - Loads

Decoding Eurocode 7
- Fig 10.8

Table 7.4

<table>
<thead>
<tr>
<th>Material type (%)</th>
<th>Fracture type (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>75</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
</tr>
<tr>
<td>S</td>
<td>35</td>
</tr>
<tr>
<td>N</td>
<td>25</td>
</tr>
<tr>
<td>W</td>
<td>20</td>
</tr>
<tr>
<td>M</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Page 29 of 36
Concrete Basements

**Structural design - Loads**

Calculation of lateral earth pressures

Pressure coefficients: $K_{ad}$, $K_0$, or $K_{pd}$

- If the soil has a chance to ‘relax’ it will and $K_{ad}$ is appropriate.
- In some situations, e.g., top down, it can’t and that is where $K_0$ comes to the fore. Sometimes it can move ‘partially’ and some designers will go between $K_{ad}$ and $K_0$. Some always use $K_{pd}$.
- Where you have compaction both the ‘soil’ and the uncompacted backfill have a chance to move so $K_0$ is appropriate. With compaction, you start initially the uncompacted backfill have a change to move so $K_{ad}$ is appropriate. $K_{ad}$ and move towards $K_0d$ - hence the pressure additional to $K_{ad}$. The amount of the addition depends on the size of the design force of the compaction plant.

**Structural design - SLS**

Design for Serviceability Limit State

≡ Control of cracking

**Structural design - SLS**

Design for Ultimate Limit State

EQU - Equilibrium Limit State

STR & GEO - Structural and geotechnical Limit States

- EC7: Combinations 1 and 2

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Combinations</th>
<th>Combination factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.35</td>
</tr>
</tbody>
</table>

- $\gamma_f$ for ground water
  - Normal $\gamma_f = 1.35$
  - Most unfavourable $\gamma_f = 1.20$ (Accidental)

- Structural design
  - As ‘normal’ elements
  - 3D nature of design

**Structural design - ULS**

Test for restraint cracking

A section will crack if:

$$\varepsilon_r = K(T_1 + \varepsilon_{ctu}) R_1 + (K(T_2) \varepsilon_{cd} R_3) > \varepsilon_{ca}$$

where $K$ = allowance for creep

- $T_1$ is calculated using CIRIA C660
- $T_2$ is calculated using BS EN 1992-3
- $\varepsilon_{ctu}$ is the autogenous shrinkage strain – value for early age (3 days: see Table A9)
- $\varepsilon_{cd}$ is the drying shrinkage strain, dependent on ambient RH, cement content and member size (see BS EN 1992-1-1 Exp. (3.9) or CIRIA C660 or Table A10). CIRIA C660 alludes to 45% RH for internal and long-term drop in temperature after concreting, $\varepsilon_{ca}$ = 0.65 when $R$ is calculated using CIRIA C660

For edge restraint, where the restraint is truly rigid 1.0 is most often used, for instance in piled slabs. This figure might be overly pessimistic for piled slabs.

- $\varepsilon_{ca}$ is the most unfavourable restraint factors. See Section A.6.4

- For edge restraint from Figure L1 of BS EN 1992-3 for short- and long-term thermal and long-term drying situations. For base-wall restraint they may be calculated in accordance with CIRIA C660. Figure L3 may be used with CIRIA C660 methods giving an adjustment for creep in stone (see Figure A2 and note).

- $T_2$ is calculated in accordance with CIRIA C660. Figure L1 may be used with CIRIA C660 methods giving an adjustment for creep in stone (see Figure A2 and note).

- $T_1$ is the difference between the peak temperature of concrete during hydration and ambient temperature °C.

**Test for restraint cracking**

A section will crack if:

$$\varepsilon_r = K(T_1 + \varepsilon_{ctu}) R_1 + (K(T_2) \varepsilon_{cd} R_3) > \varepsilon_{ca}$$

where $K$ = allowance for creep

- $T_1$ is calculated using CIRIA C660
- $T_2$ is calculated using BS EN 1992-3
- $\varepsilon_{ctu}$ is the autogenous shrinkage strain – value for early age (3 days: see Table A9)
- $\varepsilon_{cd}$ is the drying shrinkage strain, dependent on ambient RH, cement content and member size (see BS EN 1992-1-1 Exp. (3.9) or CIRIA C660 or Table A10). CIRIA C660 alludes to 45% RH for internal and long-term drop in temperature after concreting, $\varepsilon_{ca}$ = 0.65 when $R$ is calculated using CIRIA C660

For edge restraint, where the restraint is truly rigid 1.0 is most often used, for instance in piled slabs. This figure might be overly pessimistic for piled slabs.

- $\varepsilon_{ca}$ is the most unfavourable restraint factors. See Section A.6.4

- For edge restraint from Figure L1 of BS EN 1992-3 for short- and long-term thermal and long-term drying situations. For base-wall restraint they may be calculated in accordance with CIRIA C660. Figure L3 may be used with CIRIA C660 methods giving an adjustment for creep in stone (see Figure A2 and note).

- $T_2$ is the difference between the peak temperature of concrete during hydration and ambient temperature °C.

**Test for restraint cracking**

A section will crack if:

$$\varepsilon_r = K(T_1 + \varepsilon_{ctu}) R_1 + (K(T_2) \varepsilon_{cd} R_3) > \varepsilon_{ca}$$

where $K$ = allowance for creep

- $T_1$ is calculated using CIRIA C660
- $T_2$ is calculated using BS EN 1992-3
- $\varepsilon_{ctu}$ is the autogenous shrinkage strain – value for early age (3 days: see Table A9)
- $\varepsilon_{cd}$ is the drying shrinkage strain, dependent on ambient RH, cement content and member size (see BS EN 1992-1-1 Exp. (3.9) or CIRIA C660 or Table A10). CIRIA C660 alludes to 45% RH for internal and long-term drop in temperature after concreting, $\varepsilon_{ca}$ = 0.65 when $R$ is calculated using CIRIA C660

For edge restraint, where the restraint is truly rigid 1.0 is most often used, for instance in piled slabs. This figure might be overly pessimistic for piled slabs.

- $\varepsilon_{ca}$ is the most unfavourable restraint factors. See Section A.6.4

- For edge restraint from Figure L1 of BS EN 1992-3 for short- and long-term thermal and long-term drying situations. For base-wall restraint they may be calculated in accordance with CIRIA C660. Figure L3 may be used with CIRIA C660 methods giving an adjustment for creep in stone (see Figure A2 and note).

- $T_2$ is the difference between the peak temperature of concrete during hydration and ambient temperature °C.
Concrete Basements

**Structural design - SLS**

**SLS Design vs time**

- Short term load strength
- Long term load strength
- Stress due to early-age water curing for creep

**Structural design - SLS**

**9.5 Minimum reinforcement**

\[ A_{min} = f_y k A_{min} / f_y k \]

where

- \( A_{min} \) is the area of concrete in the tension zone just prior to onset of cracking.
- \( f_y \) is the characteristic yield strength of the reinforcement.
- \( k \) is the factor accounting for creep in concrete due to sustained tensile stress.
- \( A_{min} \) is determined from section properties but generally for basement slabs and walls is most often based on full thickness of the section.

**Assume it cracks!!**

- There are two possibilities:
  - Use the exact cracked section for calculation.
  - Use the effective cracked section for calculation.

**Structural design - SLS**

**Crack widths and watertightness**

<table>
<thead>
<tr>
<th>Tightness Class</th>
<th>Leak age ( t )</th>
<th>Suggested measures to meet the requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Irrelevant or some acceptable</td>
<td>Design to clause 7.3.1 of BS EN1992-3. See note A</td>
</tr>
<tr>
<td>1</td>
<td>Small amount, some sealing patching acceptable</td>
<td>Through cracks limited to ( w_{cr} ). See note B (phenomenon)</td>
</tr>
<tr>
<td>2</td>
<td>No sealing permitted</td>
<td>Special measures will be required (e.g. lining or process)</td>
</tr>
</tbody>
</table>

**Key**

- 0, 1, 2 = design to Tightness Class 0, 1, 2 of BS EN 1992-3. See Table 9.2. Generally 0.3 mm for cracks that pass through the section.
- 0.30 = for RC structures.
- 0.05 to 0.20 = for base and wall restrants.
- 0 = for RC structures.

**Structural design - SLS**

**Crack widths and watertightness - recommendations for basements (TCC)**

<table>
<thead>
<tr>
<th>Construction type</th>
<th>Expected performance of structure</th>
<th>Crack width requirement</th>
<th>Tightness Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Sometimes considered water tight</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>E</td>
<td>High permanently high water table</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>F</td>
<td>Variable permanently high water table</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>G</td>
<td>Lower permanently low water table</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>H</td>
<td>Structure itself is not necessarily considered water tight</td>
<td>-</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Key**

- 0.30 = for RC structures.
- 0.05 to 0.20 = for base and wall restrants.
- 0 = for RC structures.
Concrete Basements

**Structural design - SLS**

**Crack width calculations**

\[ w_c = \frac{k_{cr}}{\phi} \]

where

- \( k_{cr} = \text{Maximum crack spacing} = 3.4c + 0.425(k_{ow} \cdot r) \)
- \( c = \text{nominal cover} \)
- \( k_{ow} = 0.8 \)
- \( r = \text{radius of the bar in mm.} \)

\( \phi = \frac{1}{0.5 + 0.14(c + 0.5 \cdot \rho / \Phi)} \)

\( \frac{1}{0.5 + 0.14(c + 0.5 \cdot \rho / \Phi)} \)

**end restraint crack-inducing strain**

**flexural (and applied tension) crack-inducing strain**

**Test for restraint cracking**

A section will crack if:

\[ \varepsilon_{cr} = K[\alpha_1 \cdot \varepsilon_{cm}] R_1 + 0.5 \cdot \varepsilon_{ctu} \]

**Good practice:**

- Crack control without direct calculation: don’t do it!
- Crack widths - keep restraint and flexural cracking separate!
- Deflection control - as per ‘normal’ design

- Minimise the risk of cracking:
  - Prewet the concrete
  - Use a shrinkage control admixture

**Concrete Basements**

See Concrete Basements Section 9.7
Concrete Basements

(Thick sections > say 750 mm)

- Game changer!
- Internal restraint:
  T₁ becomes large and internal restraint (difference in temperature and stiffness between core and surface) dominates (external restraint still relevant).

(Thick sections > say 750 mm)

- Game changer!
- SLS Analysis:
  For rafts especially, all the analysis is a waste of time unless one knows:
  - Precise properties of the concrete being used.
  - Detailed pour layout.
  - The ambient temperature of the soil beneath the raft.
  - Residual strains after the concrete first cracks
  - Going by experience even large diameter piles offer little or no restraint to thick slab movement (See C660 Annex A5)
  - etc.
- Pass the problem to specialists!

Concrete Basements

Introduction/background
Planning a basement
- Types & Waterproofing strategy
- Site Constraints
Ground movements & Methods of construction
Materials
Structural design
- Loads
- ULS
- SLS
- Example
Specification and construction
Case studies

Structural design - Example
Basement example

Slab 300 mm
Walls 250 mm
GFS 250 mm
C30/37
Class R cement
wₑ max =0.2 mm
Concrete Basements

ASELB 29 April 2016

**Structural design - Example**

**Baseline reinforcement**

<table>
<thead>
<tr>
<th>A_{req} Slab</th>
<th>as an upside down flat slab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**UES:** Reinforcement for vertical and uplift cases (mm²/m)

<table>
<thead>
<tr>
<th>Support#</th>
<th>Span#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column strip</td>
<td>789 T2</td>
</tr>
<tr>
<td>Middle strip</td>
<td>362 T2</td>
</tr>
</tbody>
</table>

H20 @100 B2 & T2

<table>
<thead>
<tr>
<th>Asreqd slab (as an upside down flat slab)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**SLS:** Reinforcement for 0.20 mm crack width assuming end restraint

<table>
<thead>
<tr>
<th>Combination 1</th>
<th>Combination 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# NB Min = 870 mm²/m T and B

**Characteristic actions on basement wall and adjacent slabs: LC1 water at ground level**

**Combination 1**

**Combination 2**

**Characteristic actions on basement wall and adjacent slabs: LC2 no water**

**Combination 1**

**Combination 2**

**Compaction pressure**

**Basement wall moment envelope, ULS**

**Lessons:**

- **Slab**
  - SLS dictates - even with uplift
  - Ends restraint = lots of reinforcement

- **Wall - Vertical rebar**
  - Loads and load cases a nightmare but necessary
  - Minimum steel provides enough moment capacity in most places

- **Wall - Horizontal rebar**
  - SLS dictates - use CIRIA C660!

- Cover critical

**Mitigating measures?**
Concrete Basements

Introduction/background
Planning a basement
- Types & Waterproofing strategy
- Site Constraints

Ground movements & Methods of construction
Materials
 Structural design
- Loads
- ULS
- SLS
- Example

Specification and construction
Case studies

Mitigating measures:
Slab - lower strength and/or thinner
H20@90B2 >> H20@125B2 if C25/30, c_{min} = 40 and k_c = 0.8
H20@90B2 >> H20@110B2 if h = 250 mm

Structural design - Example
Mitigating measures - Concrete strength and Cement class (type)

Influence of $T_1$ on Horizontal rebar in wall

Design to: EC2-3
Original design
Concrete:
C30/37
Cement Class:
R
Outside reinf.:
H20@100
$A_{p,vap}$:
3.140
$A_{p,vap}/A_{p,vap,orig}$:
100%
Concrete Basements

Introduction/background
Planning a basement
• Types & Waterproofing strategy
• Site Constraints
Ground movements & Methods of construction
Materials
Structural design
• Loads
• ULS
• SLS
• Example
Specification and construction
Case studies

Construction, inspection and testing

NSCS Max pour sizes

Table 1: AREAS AND DIMENSIONS FOR DIFFERENT TYPES OF CONSTRUCTION.

<table>
<thead>
<tr>
<th>Construction</th>
<th>Maximum Area (m²)</th>
<th>Maximum Dimension (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water – resisting walls</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Water – resisting slabs</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Slabs with major restraint at both ends</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>Slabs with major restraint at one end only</td>
<td>250</td>
<td>20</td>
</tr>
<tr>
<td>Slabs with little restraint in any direction</td>
<td>500</td>
<td>30</td>
</tr>
<tr>
<td>Walls</td>
<td>40</td>
<td>10</td>
</tr>
</tbody>
</table>

“Unless otherwise agreed” . . . . . .and designed.
Salient features

- 4 m deep basement (depth of excavation about 5 m)
- Use – archives, exhibition and public spaces
- Soil – gravels
- Water table about 1 m below ground level
- Propped secant piling to facilitate excavations
- Concrete box designed to be inside the secant piles
- Vapour barrier membrane sandwiched between the piles (faced with polystyrene) and the concrete box
- Drained cavity inside walls and above floor

By courtesy Clark Smith Partnership

GA & details: Temp works

Construction methods
Concrete Basements

The Fusion Shoreditch

Case study - residential

Concrete Basements

Pictures!
Concrete Basements: Summary

Introduction/background
Planning a basement
• Types & Waterproofing strategy
• Site Constraints
Ground movements & Methods of construction
• Site Constraints
Materials
• Loads and again preferably in league with the constructor
Structural design
• Loads and again preferably in league with the constructor
Case studies

Concrete Basements

This guide covers the design and construction of reinforced concrete basements and is in accordance with the Eurocodes.

The aim of the guide is to assist designers of concrete basements of modest depth, i.e. not exceeding 10 metres. It will also prove relevant to designers of other underground structures. It brings together in one publication the salient features for the design and construction of such water-resisting structures.

The guide has been written for generalist structural engineers who have a basic understanding of soil mechanics.

CS meeting 8/3/16

Basement issues.
• Clients don’t understand Grades 1, 2 and 3.
• Many specifications and designs looking for two or even 3 types of water resisting construction (membrane + integral + drained cavity). Within BS8102 but £££?
• NHBC looking for combination of 2 types
• Members of the WG convinced that water resisting construction is a lot to do with workmanship. Admixtures are a load of ********, which are just insurance policies.
• Designers saying ‘we’ve designed it properly now any cracks will be down to workmanship’. Concentrates minds!

Concrete Basements

Guidance on the design and construction of in-situ concrete basement structures

Charles Goodchild
CEng., MICE, MInstP
Principal Structural Engineer
The Concrete Centre

Thank you