The role of concrete in water-retaining structural design.

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ZUTARI
IMPACT. ENGINEERED.

CEMENT & CONCRETE SA

Agenda

1 Design principles

2 Construction considerations

3 Projects

4 Acknowledgements

Design principles

Structure fulfils its function while subjected to **loads** all while remaining **durable** under constant/varying **exposure conditions**

LOADS:

- PERMANENT (self-weight, hydrostatic, earth pressures, vibrations)
- TRANSIENT (live loads, wind, lifting equipment, vibrations).
- SEISMIC (elevated water tanks and containment structures).
- TEMPERATURE (induced stresses from expansion and contraction in concrete and structural steel due to internal and external factors, seasonal variation, hydration reaction in concrete etc.).

DURABILITY:

- CONSTANTLY SUBMERGED vs CYCLIC WETTING/DRYING
- ABRASIVE ACTION (mechanical weathering due to sustained splashing/water impact over time)

Design principles

Design a structure that can fulfil its function while resisting specific **loads** and remaining **durable** under constant/varying **exposure conditions**

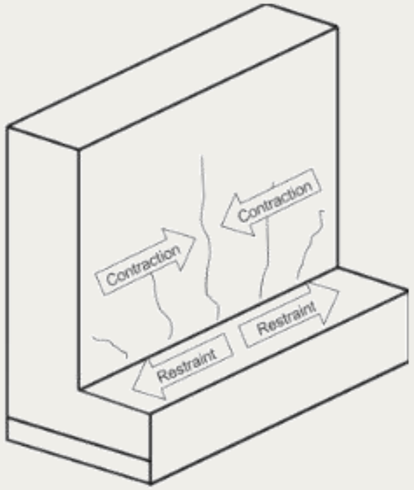
DURABILITY:

- CONTAINMENT LIQUID (some streams more aggressive than others depending on stages of treatment process, structure open or enclosed, concrete protection).

Design principles

Cracking results from tensile strains of various origins:

- Flexure (one face only)
- Tension (right through section)
- Temperature and shrinkage-induced strains in the presence of restraint (construction joints/construction sequencing, changes in geometry/section thickness, temperature differentials)



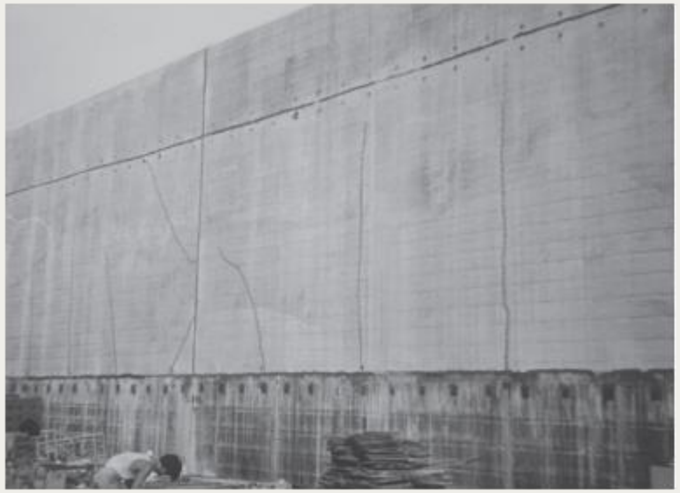


Figure 4.16 Early-age cracking in the walls of a box-section tunnel wall

Design principles

Typical design procedure: control the cracking

Limiting crack-width design

Table 2.3 Provisions for achieving BS EN 1992-3:2006 tightness class

Tightness class	Requirements for leakage	Provisions for achieving leakage requirements in BS EN 1992-3
0	Some degree of leakage acceptable, or leakage of liquids irrelevant.	General provisions for crack control (BS EN 1992-1-1, clause 7.3.1) with limiting crack widths in accordance with Table 2.2.
1	Leakage to be limited to a small amount. Some surface staining and damp patches acceptable.	For full thickness cracks the width, w_{k1}, is related to the pressure head, h_p. For $h_p/h < 5$, $w_{k1} = 0.2$ mm while for $h_p/h > 35$, $w_{k1} = 0.05$ mm, with linear interpolation for intermediate values (unless given in the National Annex).
2	Leakage to be minimal. Appearance not to be impaired by staining.	Cracks that may be expected to pass through the full thickness should be avoided unless appropriate measures (eg liners or prestress) have been incorporated.
3	No leakage permitted.	Special measures (eg liners or prestress) may be required to ensure water tightness.

Tightness class 1 – accounts for self-healing in concrete

Aim for 0.2mm – 0.3mm limiting Cw for durability purposes

Design principles

Typical design procedure: control the cracking

Allowable stress design

Table 3.5 Allowable steel stresses in direct or flexural tension for serviceability limit states
BS8007[10]

Design crack width (mm)	Allowable stress (N/mm^2)	
	Plain bars	Deformed bars
0.1	85	100
0.2	115	130

Design principles

Typical design procedure: control the cracking

Influence of Reinforcement Configuration on Crack-Width

- 600 THK member
- **Y20@200 (As = 1570mm²/m)**
- Crack-width of 0.20mm

- 600 THK member,
- **Y16@150 (As = 1340mm²/m)**
- Crack-width of 0.19mm

Good design – understand **requirements of structural element** and **deterioration mechanisms** (cover, concrete strength, combination of rebar spacing and diameter).

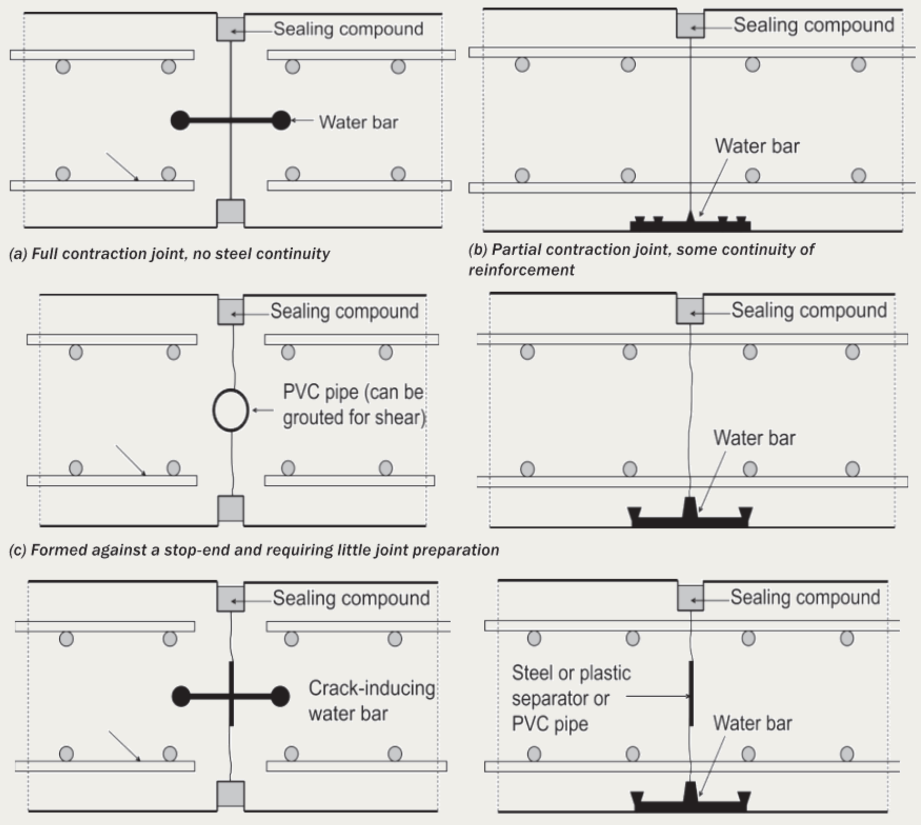
Good practice – smaller bars, closer spacing (better crack control, but can become congested, complicating QC on site!!).

Additional protection – relaxation of Cw design (less reinforcement)!!

Design principles

Typical design procedure: control the cracking

- Partial vs Full movement joints
- Expansion vs Contraction joints
- Movement joints reduce restraint, but introduce plane of weakness in terms of water-tightness
- Joint spacing (BS, ACI, EN, AS):
  - Partial < 7.5m
  - Full < 15m
  - Aspect Ratio maximum 1:1.5 (preferably as close as possible to 1:1)
  - Avoid panels with acute angles at corners
  - Avoid concentrated loads at joints (differential = leaking!)
- **Joint Materials, Joint Location guiding selection of joint type (Wall centrebulbs vs floor rearguards,**



(a) Full contraction joint, no steel continuity

(b) Partial contraction joint, some continuity of reinforcement

(c) Formed against a stop-end and requiring little joint preparation

(d) Cracks induced using water bars, separator plates or PVC pipes. The latter may be grouted to provide a shear key

Construction considerations

Project specifications: concrete mix design for durability

Denser, less permeable microstructure and cover zone = durable concrete:

- Limiting w/b ratio
- Cement replacement by extenders e.g. Fly Ash, GGCS, GGBS, CSF (or Metakaolin…?).
- Type of coarse aggregate (major variable in ASR – Granites in the Western Cape).
- Minimum coarse aggregate fraction > 0.55 (aggregate does not shrink and is stable).

Construction considerations

Project specifications: concrete mix design for durability

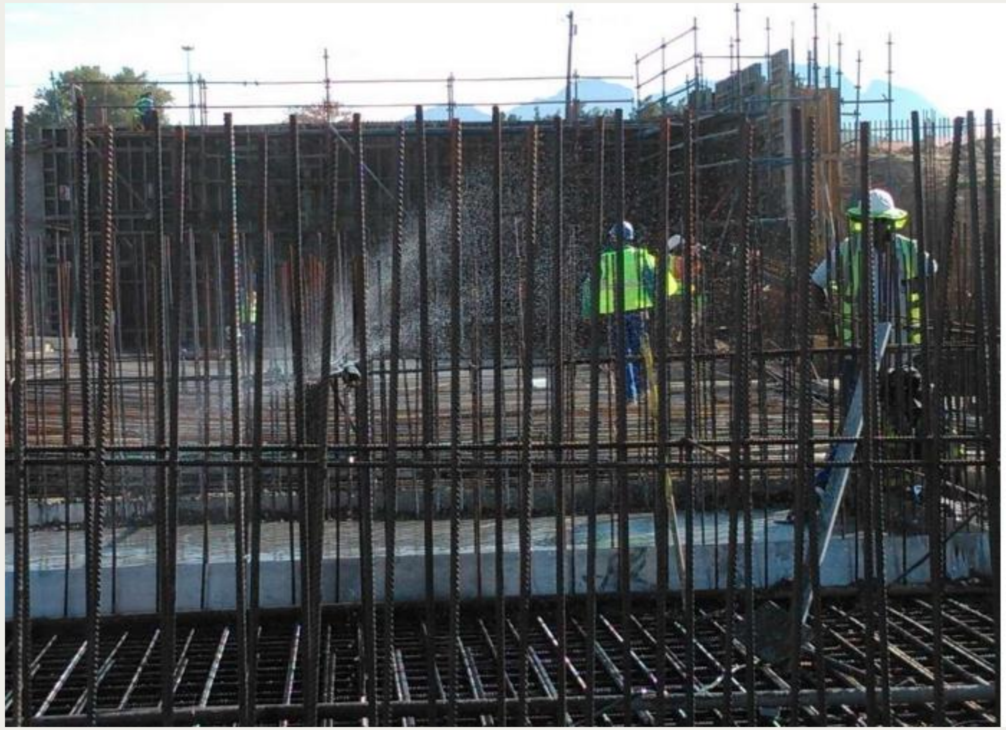
Engineer vs contractor

Criteria	Engineer	Contractor
Water	Low	High water (placement) Low water (water: binder ratio - cost)
Coarse aggregate fraction	High (low paste / shrinkage / water-demand)	Low (placement)
Binder	Low (heat of hydration)	Low (Cost)
Formwork	Steel (generally)	Plywood (Cost)
Extender	Want extenders	Depends on local availability/cost

Construction considerations

Project specifications: concrete mix design for durability

Covering with plastic, water-ponding, covering with wet sand, fine mist sprays around pour area



Construction considerations

Project specifications: concrete mix design for durability

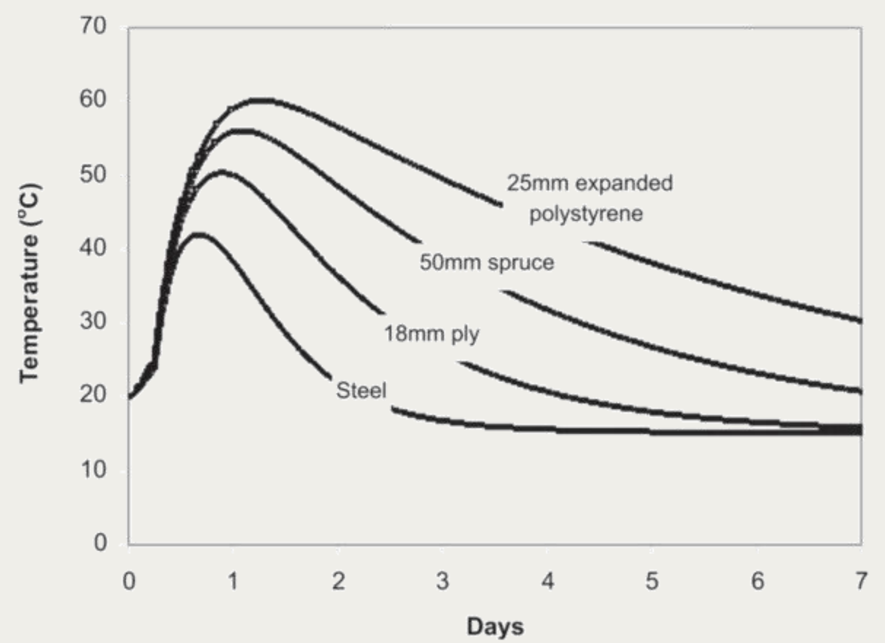


Figure 4.2 The effect of formwork type on the temperature rise in 500 mm thick walls (for 350 kg/m³ CEM I)

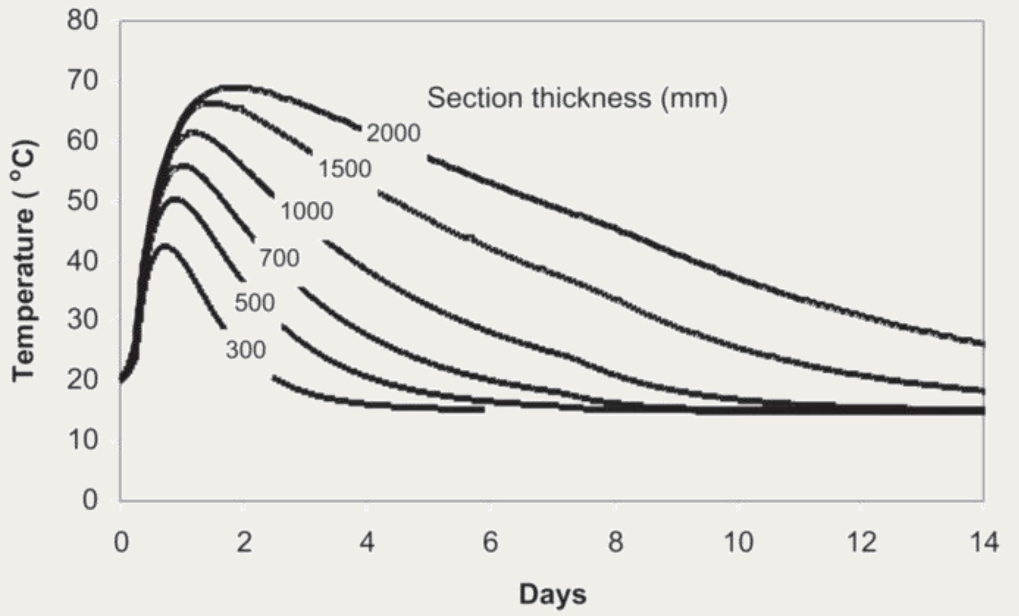
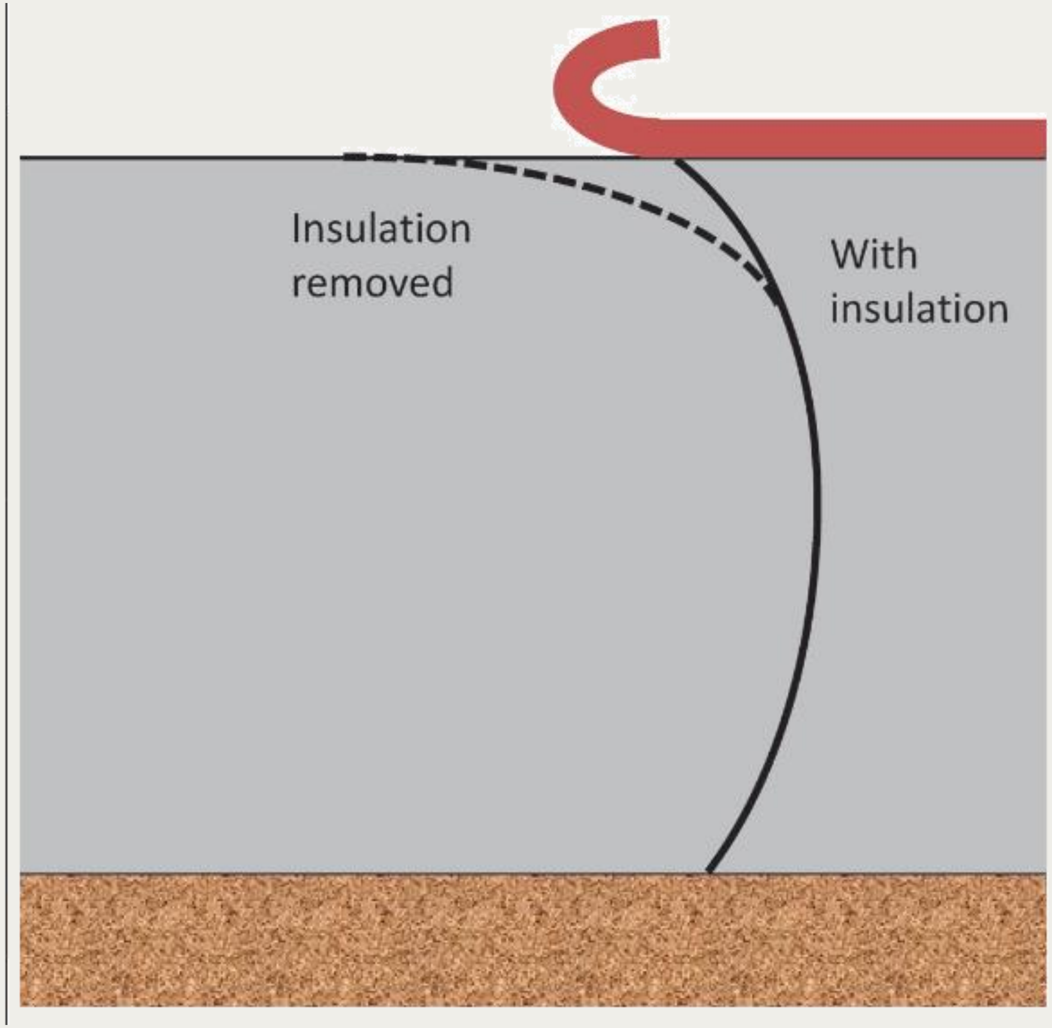


Figure 4.1 The effect of wall thickness on the temperature rise (for 350 kg/m³ CEM I, 18 mm plywood formwork removed after seven days)


Insulation
removed
With
insulation

Construction Considerations

Prescr. vs performance-based

Parameter	Limit
Maximum w/b ratio	0.50
Min/Max cementitious binder content	300/360 kg/m^3
Linear Expansion Potential (accelerated mortar bar prism test – SANS 6245)	< 0.10% - Innocuous 0.10% - 0.20% - Potentially Reactive > 0.20% - Highly Reactive
Max coefficient of thermal exp α	Between $10x10^{-6}/°C$ and $12x10^{-6}/°C$
Coarse Aggregate Type	Granites where commercially viable e.g. Western Cape
Min coarse aggregate fraction (coarse agg / coarse + fine agg)	0.55
Supplementary cementitious material required (recommended % replacement levels)	GGCS/GGBS (40% – 50%) FA (20% – 30%) CSF (10% – 15%)
Max shrinkage strain (accelerated shrinkage test – SANS 6085)	350 µm / m

Materials specifications

Prescr. vs performance-based

Parameter	Limit
Maximum acceptable cover	Depending on nature of exposure environment and element (economy of design – can save on reinforcement!!)
Durability Indices (Oxygen Permeability Index, Water Sorptivity)	See table below

	Durability Index Test Results (x)	
Category	**OPI (log scale)**	**Water Sorptivity (mm/√h)**
(i) Laboratory (trial mixes)	x ≥ 10.0	X ≤ 6
(ii) Acceptance	x ≥ 9.7	x ≤ 8.5

Zandvliet WWTW

Project background

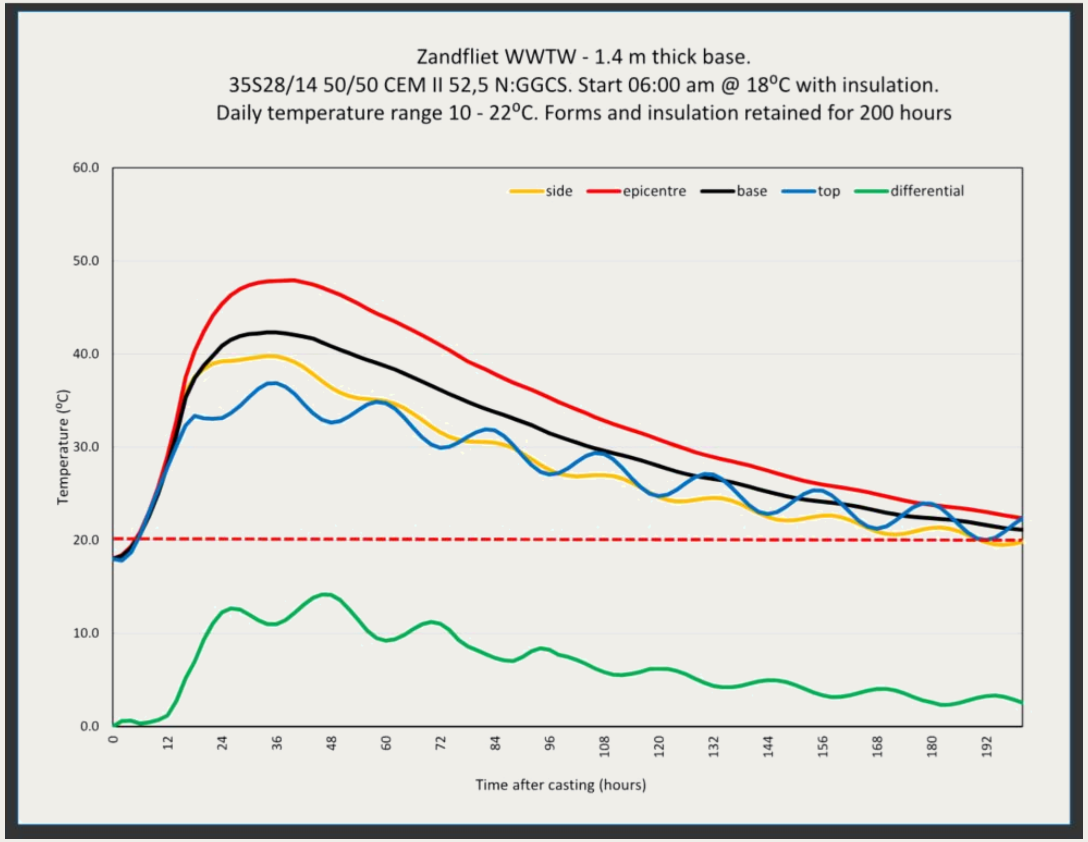
Zandvliet WWTW project details	
Design capacity	90 ML/d (M&E); 90 ML/d (CIV) Most structures sized for 150 ML/d
Contract value	R2,1bn (2 CIV; 2 M&E)
Start date	26 November 2018 (CIV)
Practical completion	18 October 2023 (M&E)
Completion date	18 October 2024 (M&E)

Concrete mix design spec vs actual

<table>
<tr><th>Cons</th><th>Pros</th></tr>
<tr><td>Material availability (FA vs GGCS)</td><td></td></tr>
<tr><td>Possible supply interruption (more plants with GGCS than FA)</td><td></td></tr>
<tr><td rowspan="3">Pump mix (more prone to cracking)</td><td>Pump mix (speed of construction)</td></tr>
<tr><td>Pump mix (reduced safety risk of fatigue to workers – long pour with traditional placement methods)</td></tr>
<tr><td>Pump mix (better placement rate)</td></tr>
<tr><td rowspan="2">Hoh higher with GGCS than FA (material knowingly associated with higher Hoh)</td><td>Hoh development can be mitigated with insulation.</td></tr>
<tr><td>Hoh development can be mitigated during pour/construction via monitoring and removing/adding insulation at key times.</td></tr>
</table>

Concrete mix design spec vs actual

- Modelling of thermal behaviour (heat development profile) – positive results.
- Proper insulation in place (Project Spec supplemented by Method Statements).
- Low potential shrinkage (verified with testing of mix and controlled with curing/immediate protection method statements / practices on site).
- Above parameters can offset disadvantages associated with pump mix.



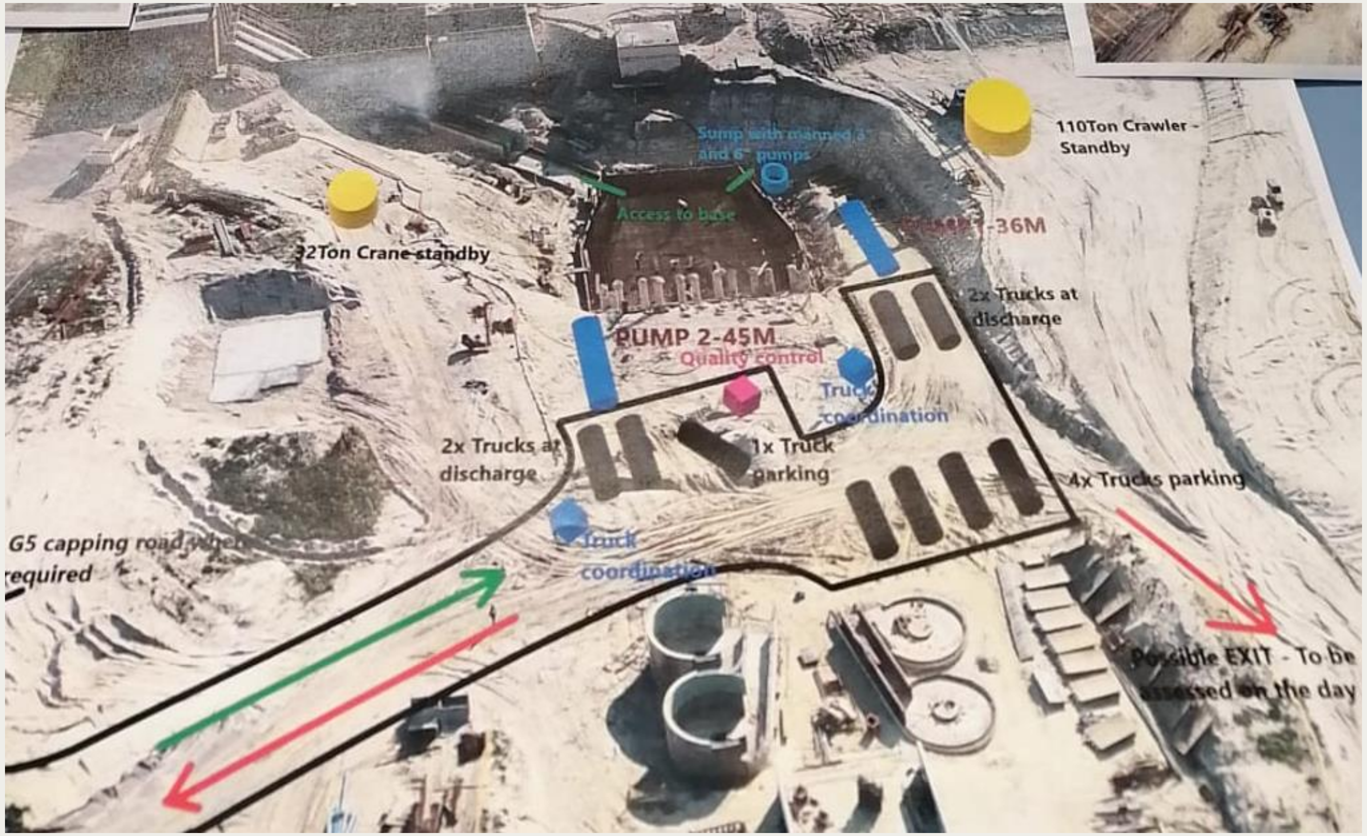
Adopted mix design

Parameter	Limit
Maximum w/b ratio	0.50
Min/Max cementitious binder content	300/360 kg/m³
Max water content	180 L/m³
Max coefficient of thermal exp α	10×10^{-6}/°C
Min coarse aggregate fraction (coarse agg / coarse + fine agg)	0.49 Reduced max coarse aggregate fraction
Supplementary cementitious material required (recommended % replacement levels)	GGCS (50%) Different supplementary cementitious material
Max shrinkage strain (accelerated shrinkage test – SANS 6085)	300 µm / m Reduced max shrinkage strain

Construction

SOME FIGURES:

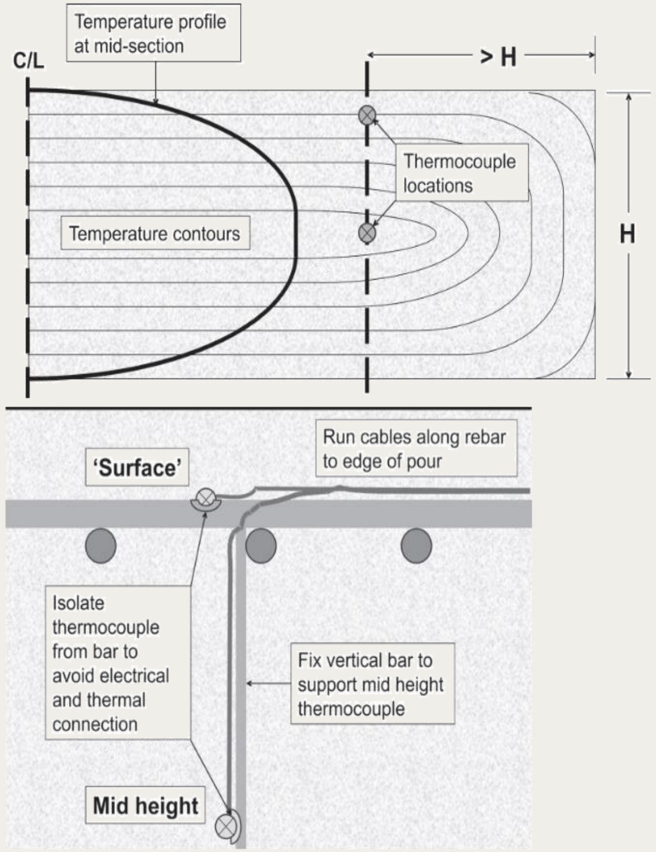
- 1400mm thk RC Raft.
- 58 tons for reinforcement (fixed over 6 days with 17 fixers FT).
- 635m³ of concrete in on continuous pour:
    - 9 hrs from beginning to end (Saturday)
    - Fleet of 20 trucks
    - 2 boom pumps
    - 72 No. of Test cubes
    - 105 slump checks
- Blinding completed 13 June 2019.
- Pour completed 22 June 2019.



Construction

Construction

Construction



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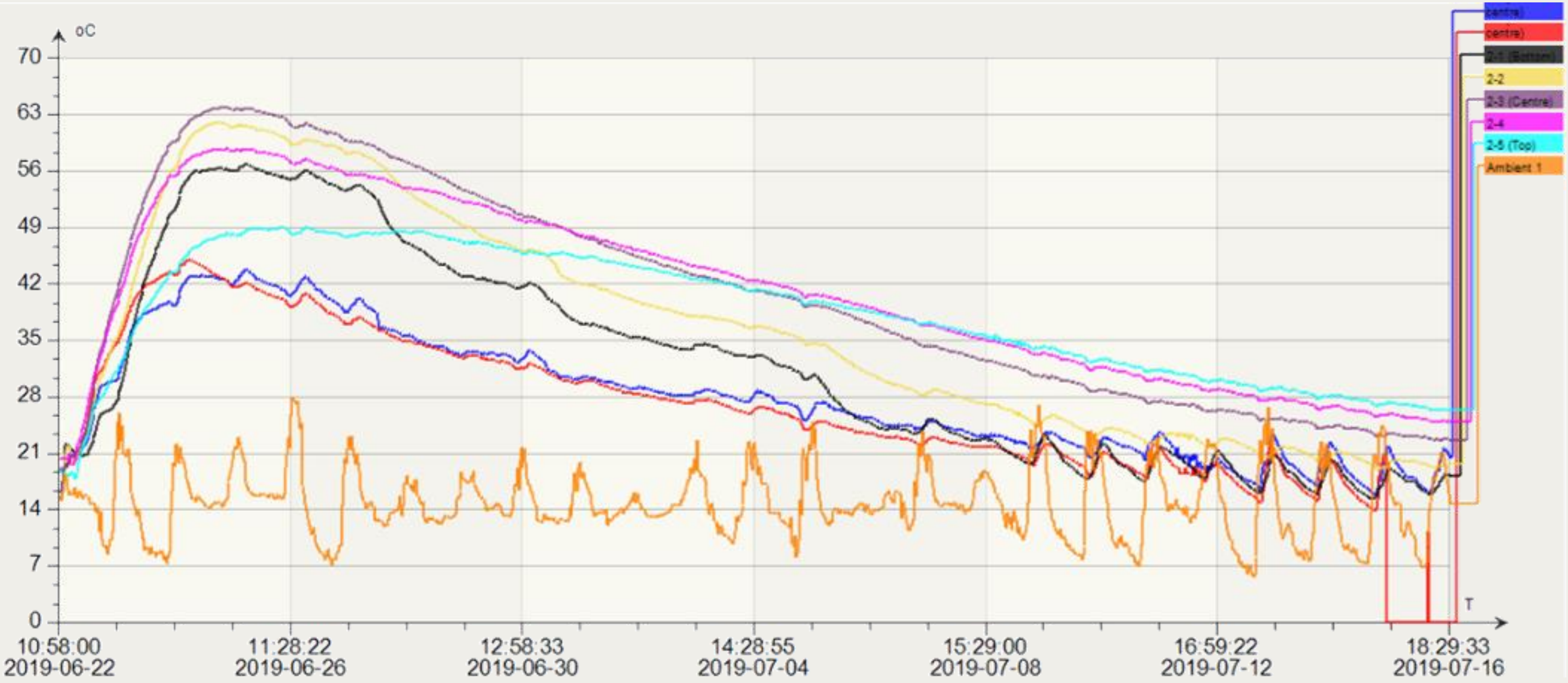

Paarl WWTW

Project background

Paarl WWTW project details	
Design capacity	35 ML/d (M&E and CIV)
Contract value	R412m (CIV & M&E)
Start date	13 September 2023 (CIV)
Practical completion	14 January 2025 (CIV)
Completion date	14 January 2026 (CIV)

Paarl WWTW

Client:		Date: 2021
Project/Job:	Job No:	
Subject: **METHOD STATEMENT GUIDELINE - IMMEDIATE PROTECTION AND CURING**	Sheet No: 1	By M. ANGELUCCI

Formwork stripping times to be abided by as per Table in PSG 5.2.5 (Removal of Formwork to Structural Member). Note the difference in removal times between CEM-II-A (less than 20% extender) and CEM-II-B / CEM III (more than 20% extender).

Practices of formwork being "loosened", but still staying upright (in the case of wall shutters and side shutters on slabs, but is also applicable for soffit formwork on suspended slabs) is classified as removal for immediate protection and curing purposes and will not be permitted. Hence the formwork needs to stay on, tight/unloosened, for the required duration of time as set out in PSG 5.2.5.

If Contractor wants to deviate from the removal times as set out in PSG, they cannot do so without prior written approval form the Engineer following a detailed request justifying why they want to deviate from these (NOTE – this is especially crucial when using Fly-Ash).

Methods of immediate protection (i.e. methods of preventing moisture loss of "wet" cover-crete prior to when it is possible to cure by 7-day physical covering):

a. Mist sprays around perimeter in installed pipe network (costly and can fail and sensitive to wind direction)

b. Erect perimeter wind barriers (awkward)

c. Physical covering (plastic) between first float and final float (but will often impact on finish as this affects finish/tolerances – but very easy/effective if it is to be screeded later – i.e. finish not NB)

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Client:		Date: 2021
Project/Job:	Job No:	
Subject: **METHOD STATEMENT GUIDELINE - CONCRETE REPAIR**	Sheet No: 1	By M. ANGELUCCI

Generally, we tend to give the following guidelines to Contractors for repair work to be carried out and ask them to submit a Method Statement outlining their repair strategy in terms of the following (broad) categories:

1) Insignificant surface repairs (say less than 10mm deep). What product(s) and how they will apply.

NOTES

Shallow repair products have a minimum application depth – so ensure that they saw-cut to this minimum depth to avoid "feathering" of shallow repair product.

Roughen the saw-cut edge as well - smooth is not good for bonding.

2) Repairs 10mm to around 50mm deep (or so). What product(s), how they will apply, how they will treat exposed reinforcing.

NOTES

Medium repairs can typically be done by trowel-applied products, but we could also be deep into cover region, so we need to pay attention to their quality and if they need bonding agents, and if so, the window periods of application of those bonding agents which are critical.

If reinforcement is exposed (which in this depth range is likely), they need to address how they will clean and treat the exposed reinforcement, as well as which main products/proprietary products they will use to do this. Similar to 1) above, products have minimum (and maximum) application depths so saw-cutting essential.

3) Repairs deeper than say 50mm. What product(s) and how they will apply, how they will treat exposed reinforcing.

Client:		Date: 2021	
Project/Job:	Job No:		
Subject: GENERAL INSPECTION CHECKLIST	Sheet No: 1	By M. ANGELUCCI	

GENERAL CHECKLIST (SLABS, BEAMS, WALLS, GROUND-SLABS, COLUMNS ETC.)

- General rebar check (spacing, lengths, key dimensions of relevant shape codes).

- Clashes of horizontal rebar with Joint F galvanised steel strip (very important, not always taken into account when detailing rebar in kicker and can cause hefty delays on site).

- Correct length and position of laps (both horizontal and vertical rebar), ABR arrangement occurring if and where detailed.

- Any special items (rebar needed around pipes/box-outs, rebar being cut or detailed short for walkway slots into walls etc., pull-out bars for horizontal elements tying into walls/rafts etc.).

- Continuity of fixed rebar is actually as detailed/needed (continuity over supports of slabs/beams/walls etc.), curtailment rules (lapping of bottom bars at supports, lapping of top bars at mid-span etc.).

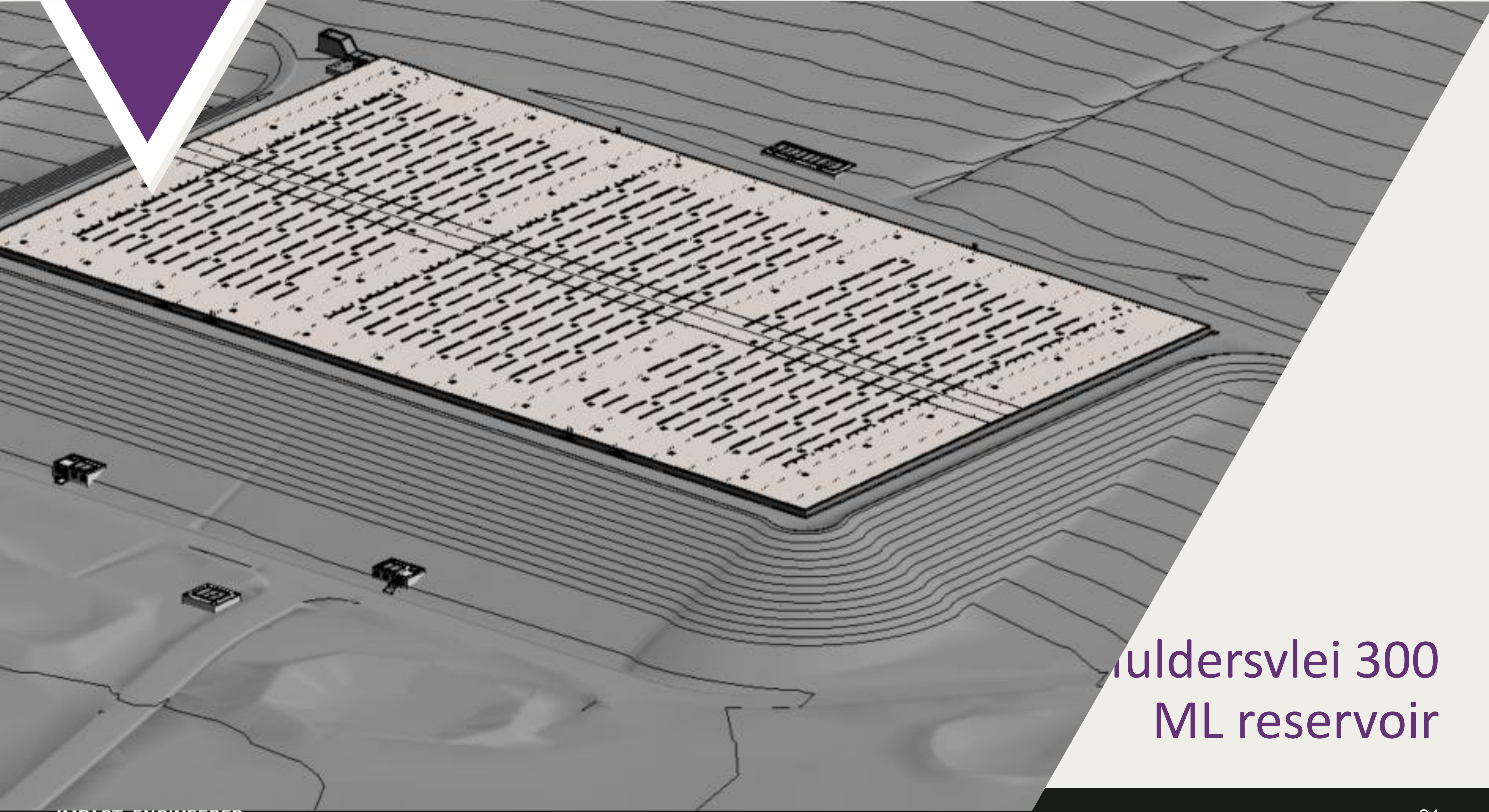
- Stability of cage (in raft footings, for example, where the cage can wobble laterally when concrete is placed).

- Cover blocks (in raft footings, bottom cover blocks can sometimes crush under weight of cage, increase number of blocks where needed – doubling/tripling up).

- Cover blocks in walls (start checking the cover blocks against the shutter face that is already up, raise any warnings before the box is closed up).

- Generally acceptable cover (always to be compared to project spec):
  50mm ground slabs/foundations
  40mm walls, beams, slabs, columns in wet areas/process areas
  30mm slabs, beams, stairs in internal climate-controlled areas (offices, admin areas etc.)
  Tolerance on abovE not more than 10 – 20mm either way, to be compared to proj spec and use engineering judgement for each individual case.

- Start inspecting cleanliness of cast area (binding wires, sand, dirt etc.).



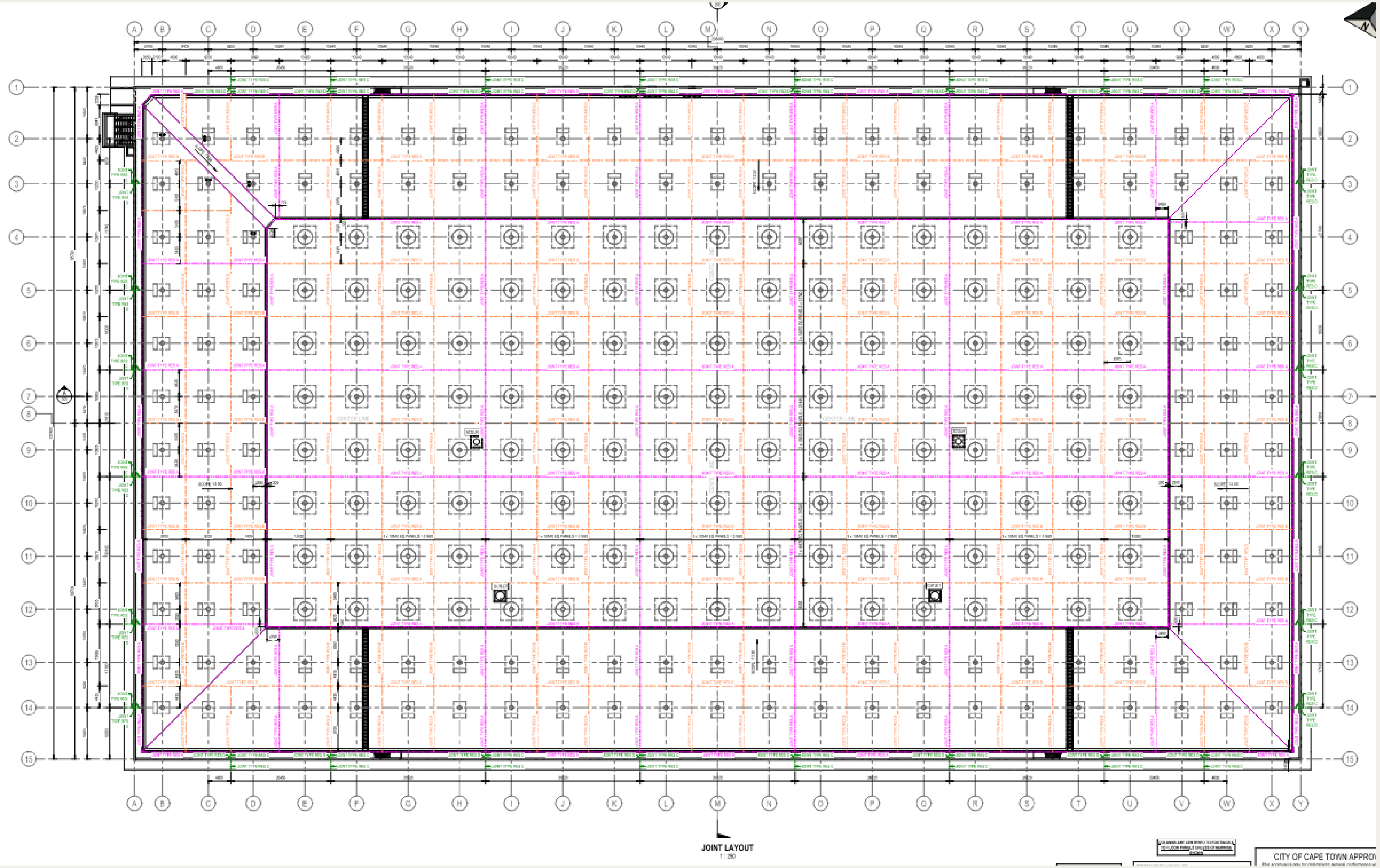
uldersvlei 300 ML reservoir

Project background

Muldersvlei 300 ML reservoir project details	
Design capacity	300 ML
Contract value	TBD
Start date	TBD (Sept 2024)
Practical completion	TBD
Completion date	TBD

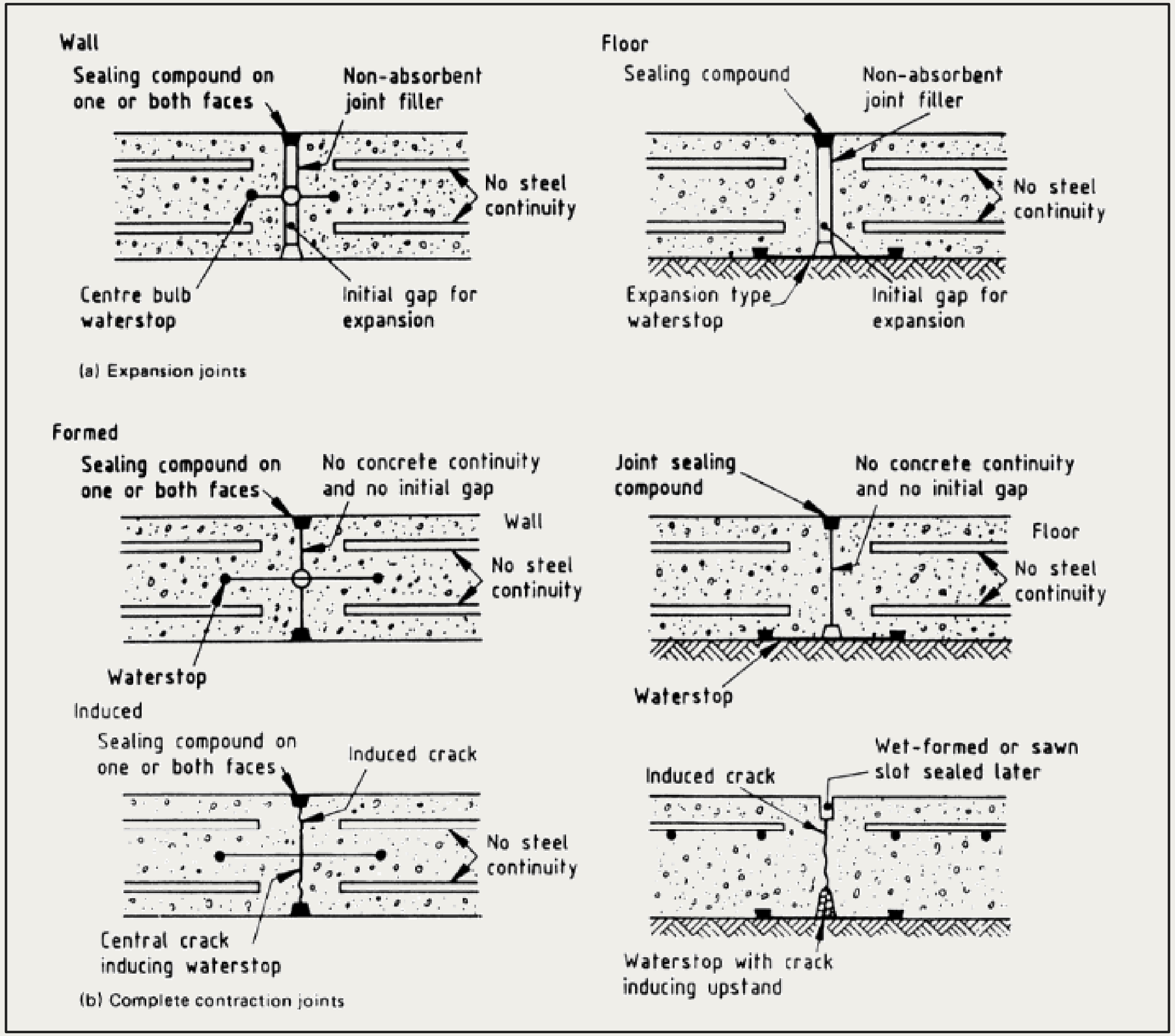
Floor panel sizes

- Full movement joints to reduce restraint – more manageable pours and less reinforcement to limit cracking.
- Panel sizes - Aspect Ratio maximum as close as possible to 1:1, mitigating restraint-induced cracking.
- Joints are possible planes of weakness (leaking), mitigated with proper selection of waterstops.



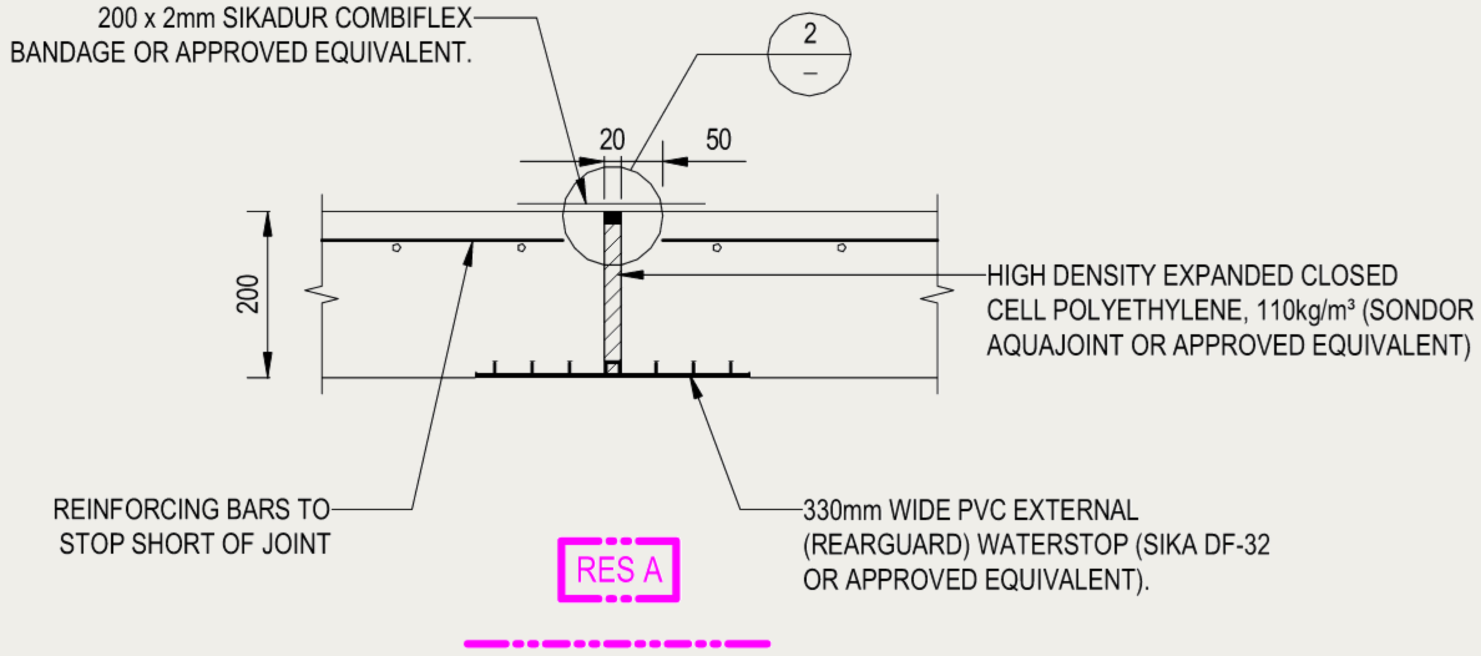
Watertight joints

Material suitable to application (rearguards in floors vs centrebulbs in walls, PVC vs rubber (vs hybrids) vs copper, function of hydrostatic head and expected movement at joint.



Watertight joints

Double Joint system - watertightness “belts and braces” – waterbar in concrete element supplemented by flexible waterproof bandage over the joint.

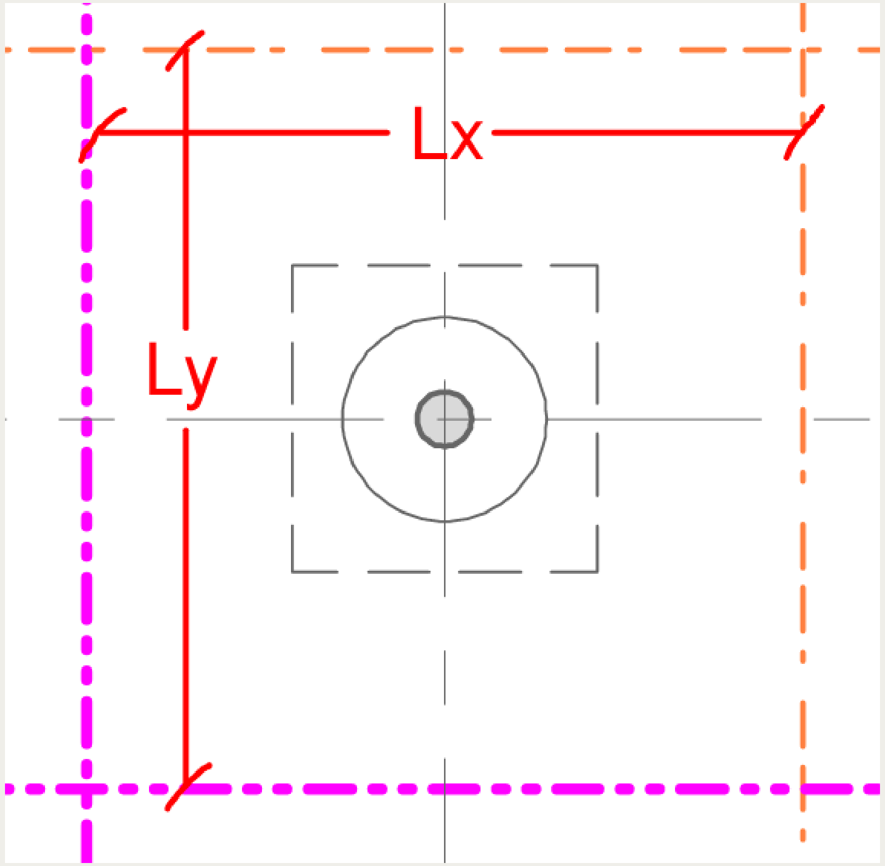


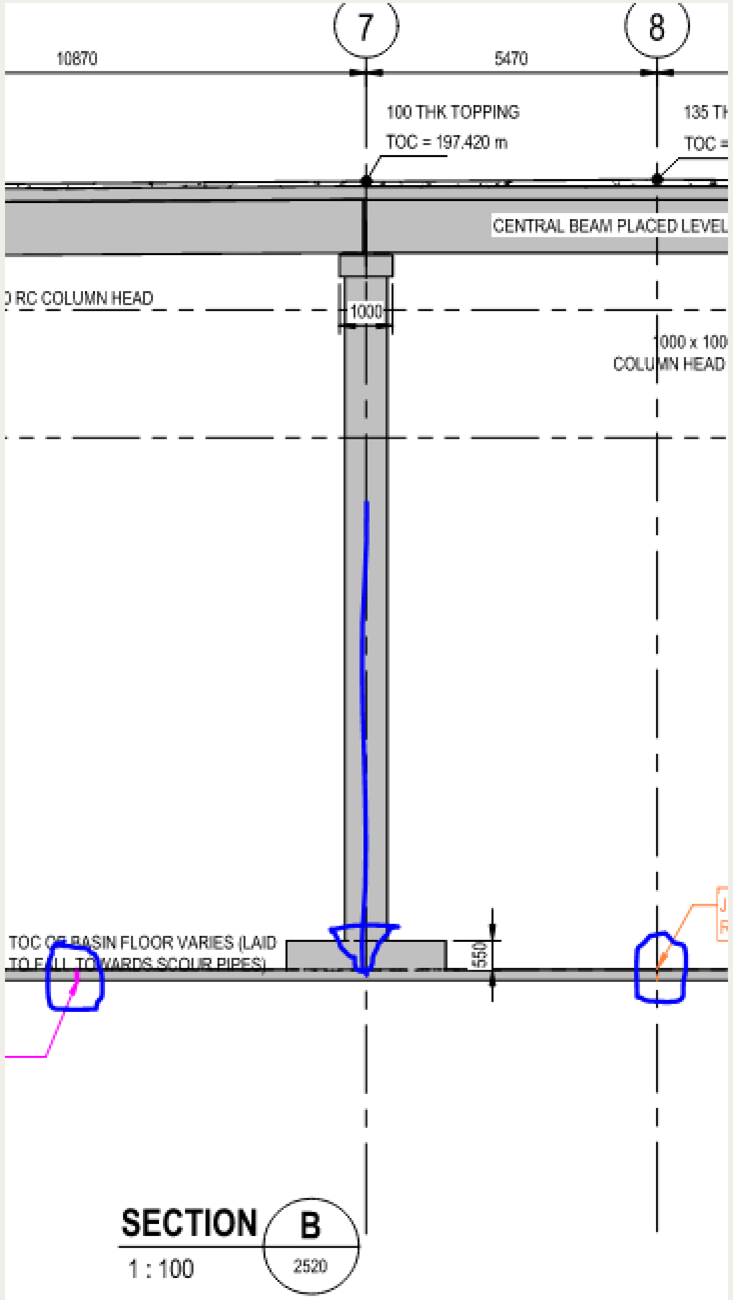
EXPANSION JOINT TYPE RES A IN FLOOR (REARGUARD)

1 : 10

Joint Positions

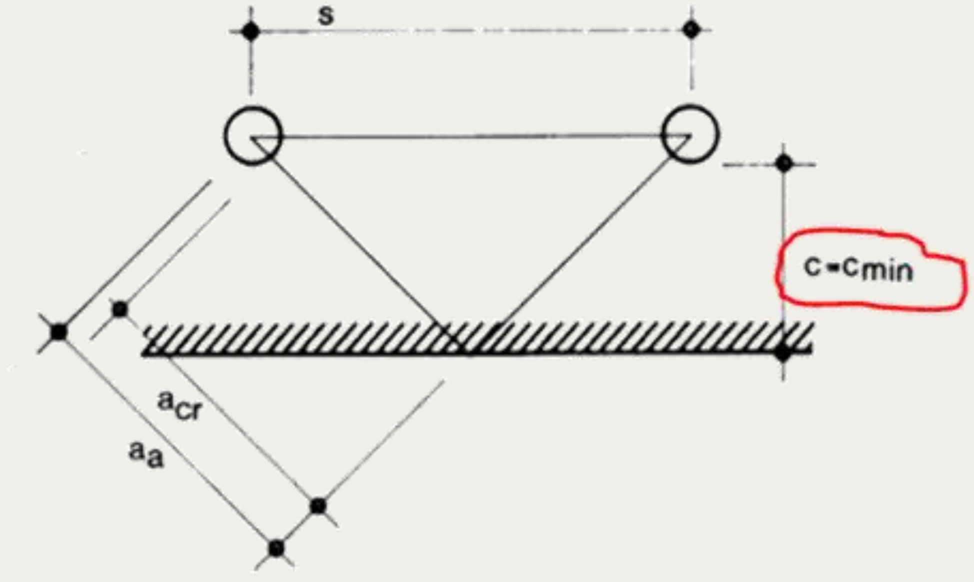
- Columns supporting post-tensioned beams and precast roof slabs – high concentrated loads.
- Place away from joints to avoid differential settlements (leaking).





Concrete mix design and site practice

- Limiting w/b ratio
- Cement replacement by extenders e.g. Fly Ash
- Type of coarse aggregate (major variable in ASR – Granites in the Western Cape).
- Minimum coarse aggregate fraction > 0.55 (aggregate does not shrink and is stable).
- Reduce concrete cover for elements that will be submerged for most of design life e.g. basin floors (less rebar and better control of cracking due to reduced cover).



Definition of a_{cr}

Quality assurance

Workshopping with Contractor beforehand on Method Statements for Site Procedures (good site practices = more durable concrete):

- Immediate Protection
- Curing
- Concrete Repairs

Testing and Quality Assurance (**large volumes of concrete** in excess of **16,000 m3** just for reservoir):

- Compressive Strength Testing (conventional)
- Durability Index Testing
- Cover Surveys

What does the Future hold?

- SANS 10100-3: Local code on water-retaining concrete design (Stellenbosch University).
- Protective Admixtures (overseas e.g. ME already using retarders, waterproofers, corrosion protection admixtures – cost-saving not an issue).
- Self-Healing effect in concrete – Quantifiable design?
- Cement replacement by new extenders e.g. (Metakaolin?).
- **Alternative Materials e.g. LC2 and LC3 for partial / full cement replacement**

Acknowledgements

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

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DRAKENSTEIN
MUNISIPALITEIT • MUNICIPALITY • UMASIPALA

Stefanutti Stocks

CEMENT & CONCRETE SA

We owe it to ourselves and to the next generation to conserve the environment so that we can bequeath our children a sustainable world that benefits all.

WANGARI MAATHAI

ZUTARI

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