Concrete Construction: What Designers Should Know

By

David Darwin

University of Kansas

CEAE
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As designers, most of us think about:
We don’t design our structures to look like:
Or our pavements to look like:
“I’ve never seen a collapse due to poor concrete, but I’ve never seen one that did not involve poor quality concrete or low quality construction practices.”
Quality control

Not easy – trouble at every turn

*Supervising professional – in charge of all concrete construction

Variables – 60+

We’ll be discussing the prime ones!
“How to avoid gross errors”
Outline

No. 1 fallacy in concrete construction
Cement and aggregates
Job mix
Batching plant
Mixers
Mixing time
Conveying and placing
Consolidation
Finishing
Joints
Curing
Underwater placement
Hot weather concreting
Cold weather concreting
Sampling and testing
No. 1 fallacy in concrete construction:

Cement content controls the quality of concrete.

Let’s see how this is wrong.
## Uniform cement content and slump

<table>
<thead>
<tr>
<th></th>
<th>Temp</th>
<th></th>
<th>Slump</th>
<th></th>
<th>Cement</th>
<th></th>
<th>Water</th>
<th></th>
<th>Strength</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60°</td>
<td>→</td>
<td>90°</td>
<td></td>
<td>658 lb/yd³</td>
<td>658 lb/yd³</td>
<td>318 lb/yd³</td>
<td>338 lb/yd³</td>
<td>5200 psi</td>
<td>4600 psi</td>
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</tbody>
</table>
Uniform cement content, water, and $f'_c$

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<thead>
<tr>
<th>Temp</th>
<th>60° → 90°</th>
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<tbody>
<tr>
<td>Slump</td>
<td>4 in.</td>
</tr>
<tr>
<td></td>
<td>2 ½ in.</td>
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Cement, water, strength: No change
Uniform slump and $f'_c$

<p>| | | | |</p>
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Not problem free.....

We’ll come back to this example
Cement and Aggregate

Mixes may be designed with higher strength cement that used on the job.

Fluctuating chemistry and grinding

Mexico City
Washington State
LA
Simple test
Aggregates

Range on fineness modulus of sand ± 0.2

Check gradation of aggregates daily
Job mix

Should be designed by a lab using standard procedures

Run trial batches in the lab and in the field

Don’t experiment on the job!
Concrete is not just $f'_c$
Batching plant

Prevent segregation of aggregate
Fine aggregate
Fine aggregate

Keep it wet
Prevent segregation of aggregate

Coarse aggregate
Don’t

Separation

Wind
Don’t
Don’t
Prevent segregation of aggregate

Coarse aggregate

Store by size fractions

Handle in truck-size loads
Batch plants

Automatic batching preferred
Mixers
Mobile mixers

Volume batching
Horizontal drum and pan mixers

Central mixed concrete

Precast concrete
Tilted mixers – ready mix truck and dry batch plants
Tilted mixers

Ribbon feed materials
Mixing time

It’s not always 45 minutes
Setting time @ 70 to 75° ~ 2 to 3 hours

Varies with temperature of concrete
Safe mixing time

Mixing time = 1 hour @ concrete temp of 75° F

± 15 min/5° drop/rise in concrete temperature
$40^\circ \text{ F} \rightarrow 2 \text{ hr 45 min}$

$90^\circ \text{ F} \rightarrow 15 \text{ min}$
Effect of temperature on water demand

For constant slump

add 6 lb/yd$^3$ per 10° increase in concrete temperature

50° → 90° requires 24 lb of water
Rule of thumb

Add 12 lb of cement to lab mix per 10° F increase in concrete temperature

Problems with this approach

Alternatives – cool the concrete; add retarders or water reducers
Retempering
Adding water

Strictly forbidden – but…
Order what you need:

Quantity and consistency

Limit mixing time (starts when water is added)
Conveying and Placing

Key: Pick procedures that maintain the quality of the concrete
Chutes
Buggies
Conveyor belts
Crane buckets
Pumps
Mix design for pumping

Mix needs to be plastic and cohesive

For typical mixes, coarse aggregate content reduced by about 10%

Max. aggregate sizes ~ 0.33 – 0.40 of pipe inside diameter
Use finer sands

Lightweight aggregates

“Can’t rob the pump of cement”

Use optimized aggregate gradations
With well-proportioned mixes, high slump is not needed.
Limit free drop

3 – 5 ft

Higher drops
PLACING IN TOP OF NARROW FORM

CORRECT
Segregation is avoided by discharging concrete into hopper feeding into drop chute. This arrangement also keeps forms and steel clean until concrete covers them.

INCORRECT
Permitting concrete to strike against form and ricochet on bars and forms causes segregation and honeycomb at the bottom.
DROPCHUTE LOCATIONS IN WALL FORM
Placing on slopes

**CORRECT**

Start placing at bottom of slope so that compaction is increased by weight of newly added concrete. Vibration consolidates the concrete.

**INCORRECT**

When placing is begun at top of slope the upper concrete tends to pull apart especially when vibrated below as this starts flow and removes support from concrete above.
Consistency and Slump

± 1 in.
Consolidation
RADIUS OF ACTION

\[ R = (3 \text{ to } 5) \times d \]

\[ 1-1/2 \times R \]
Systematic vibration of each new lift

**CORRECT**
Vertical penetration of vibrator a few inches into previous lift (which should not yet be rigid) at systematic regular intervals will give adequate consolidation.

**INCORRECT**
Haphazard random penetration of the vibrator at all angles and spacings without sufficient depth will not assure intimate combination of the two layers.
Finishing
Finishing

- Screeding
- Bullfloating or darbying
- Floating
- Toweling
- Texturing
Bullfloating
Floating
Texturing
Joints
SAWED CONTRACTION JOINT

TONGUE AND GROOVE CONTRACTION JOINT

CONTRACTION JOINT IN THICK FLOOR SLABS

PREMOLDED INSERT CONTRACTION JOINT

CONTRACTION JOINT WITH DOWELS
BRASS GROOVER

X
Spacing = 24 to 36 x $t_{\text{slab}} \leq 18$ ft
Elastomeric joint sealant (where required)

Preformed joint filler

Concrete around steel

Column

Floor

Base

Foundation

Section
Loading dock

Provide 1/4" (6 mm) gap where angles intersects contraction joint.

Angles on three sides.

Perimeter angle

Dock pit floor

Bond breaker on smooth surface

Contraction joint

1/4" (6 mm) Gap
HALF SLAB THICKNESS

12 in.

SHADING ON DOWELS INDICATES BOND BREAKER
Curing
## General curing requirements

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Saturated at all times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>50 - 100°F</td>
</tr>
<tr>
<td>Time</td>
<td>3 – 7 days (minimum)</td>
</tr>
</tbody>
</table>
Compressive Strength, percent of 28-day moist-cured concrete

- Moist-cured entire time
- In air after 7 days
- In air after 3 days
- In air entire time

Age, days

0  25  50  75  100  125  150

3  7  28  90  180
Curing also cuts down on shrinkage at early ages and ties up more water (that can’t evaporate)
How am I going to make sure that they cure properly?

Pay for it!
Underwater placement
Tremie
Hot-Weather Concreting
Hot weather

Cool the concrete
Strength vs. Temperature

![Graph showing the relationship between compressive strength and curing temperature. The graph includes two curves: one for strength at 28 days and another for strength at 1 day. The y-axis represents the compressive strength in psi, and the x-axis represents the curing temperature in °F.]
EVAPORATION OF SURFACE MOISTURE FROM CONCRETE

Air temperature, °F 40 60 80 100

Relative humidity, %

Concrete temp.

100°F

Wind velocity, mph

Rate of evaporation, lb/sq ft/hr

0 0.2 0.4 0.6 0.8
To control shrinkage cracking

Protect plastic concrete

Use: high aggregate content
    low water content
    low cement content

Cool the concrete

Use contraction joints
Cold-Weather Concreting
Low temperature effects

Curing:
Specimens cast and moist-cured at temperature indicated for first 28 days. All moist cured at 73°F thereafter.

Compressive Strength, percent of 28-day 73°F-cured concrete

<table>
<thead>
<tr>
<th>Age of Test, days</th>
<th>1</th>
<th>3</th>
<th>7</th>
<th>28</th>
<th>90</th>
<th>365</th>
</tr>
</thead>
<tbody>
<tr>
<td>73°F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
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Mix data:
W/C ratio = 0.43
Air content = 4 to 5 percent
Cement = Type I, 517 lb/cu yd
Methods to accelerate strength gain and reduce curing time

Type III cement
Increase cement content (usually 1/3)
Keep concrete warm
Saturated warm air or steam curing  
(cool slowly)
Type I cement and an accelerator  
(least desirable)
Sampling and testing

Must be truly random
Summary

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Questions?
The University of Kansas

David Darwin, Ph. D., P.E.
Deane E. Ackers Distinguished Professor
Director, Structural Engineering & Materials Laboratory

Civil, Environmental & Architectural Engineering
1530 W. 15th Street, 2142 Learned Hall
Lawrence, Kansas, 66045-7609
(785) 864-3827    Fax: (785) 864-5631

daved@ku.edu