Concrete Mix Design Criteria for Tilt-Up Construction in The Arabian Peninsula

Fadi Elayache, Abu Dhabi May 19th, 2010

Outline
1. Strength
   - Construction of Tilt-up
   - Applied Loadings
   - Flexural Strength
2. Durability
   - Climatic Conditions
   - Durability Challenges
   - Mortar Fraction
3. Recommendations for a Concrete Mix Design of Tilt-up Construction

History of Tilt-Up Construction
“Tilt-up construction eliminates the costly, cumbersome practice of erecting two wooden walls to get one concrete wall.”
~ Thomas Edison, 1903 ~

Tilt-Up is a cost effective building method that achieves the benefits of solid steel-reinforced concrete walls, quickly, and without the need for wall forms or scaffolding.

Current trends of Tilt-Up Construction
- About 100 million Sqm of Built-up area are constructed with tilt-up every year worldwide. Mainly in the US, Canada, Australia, Mexico and New Zealand.
- Tilt-up is growing at about 20% yearly in the US.
- In the ME, First Tilt-up is under construction in Jordan.
- The next ones will be in Saudi Arabia and Afghanistan shortly.
The Tilt-Up Method

The Tilt-Up Process

Forming the Panels on a clean leveled Slab on Grade

The Tilt-Up Process

Add Architectural Rustication if Required

The Tilt-Up Process

Apply The Bond-Breaker Agent

The Tilt-Up Process

Reinforcement & inserts placement

The Tilt-Up Process

Concrete Casting & Consolidation
The Tilt-Up Process

Curing 5 to 7 Days & Preparation for Tilting

Imperative Testing
Compressive & Bending Strength

Lifting, It is a Day You Don’t Want to Miss

Multi-Stories With Tilt-up

Temporary Bracing

Grouting
Structural Roof/Slab Diaphragm made of Steel Joist, beams and decking

Braces Remain in-place until the Engineer of Record confirms they can be removed

Cleaning and Painting

Creativity With Tilt-up

Insulated Sandwich Panels
Is Tilt-up the Same as Precast?

<table>
<thead>
<tr>
<th>Precast</th>
<th>Tilt-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Walls</td>
<td>RC Walls</td>
</tr>
<tr>
<td>Cast in plant</td>
<td>Cast on Site</td>
</tr>
<tr>
<td>Transported to Site</td>
<td>No Transportation</td>
</tr>
<tr>
<td>Multiple Handling</td>
<td>Single Handling</td>
</tr>
<tr>
<td>Width 3.5 - 4.0 m</td>
<td>Width up to 12 m</td>
</tr>
<tr>
<td>Height: Up to 12 m</td>
<td>Height: 22 to 27 m</td>
</tr>
<tr>
<td>Weight 5 to 15 ton</td>
<td>Weight: 45 to 55 ton</td>
</tr>
</tbody>
</table>

Tilt-up Records:
Width = 30 m
Height = 33 m
Weight = 150 Ton

In Service Loadings and Transverse Load Resistance

Sample of (1.4) Factored
Tilt-up Maximum Flexural Tensile Stress (MPa)
of 1 m wide Solid Panel

<table>
<thead>
<tr>
<th>EDGE LIFT</th>
<th>Panel Height (m) = H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>100 mm</td>
<td>1.58</td>
</tr>
<tr>
<td>120 mm</td>
<td>1.31</td>
</tr>
<tr>
<td>150 mm</td>
<td>1.05</td>
</tr>
<tr>
<td>175 mm</td>
<td>0.90</td>
</tr>
<tr>
<td>200 mm</td>
<td>0.79</td>
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</table>

Sample of (1.4) Factored
Tilt-up Maximum Flexural Tensile Stress (MPa)
of 1 m wide Solid Panel

<table>
<thead>
<tr>
<th>SINGLE ROW FACE LIFT (3 pt)</th>
<th>Panel Height (m) = H</th>
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</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>4.0</td>
</tr>
<tr>
<td>100 mm 1.36</td>
<td>1.72</td>
</tr>
<tr>
<td>120 mm 1.13</td>
<td>1.43</td>
</tr>
<tr>
<td>150 mm 0.90</td>
<td>1.14</td>
</tr>
<tr>
<td>175 mm 0.78</td>
<td>0.98</td>
</tr>
<tr>
<td>200 mm 0.68</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Sample of (1.4) Factored
Tilt-up Maximum Flexural Tensile Stress (MPa)
of 1 m wide Solid Panel

<table>
<thead>
<tr>
<th>SINGLE Row FACE LIFT (4 pt)</th>
<th>Panel Height (m) = H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>4.0</td>
</tr>
<tr>
<td>100 mm 1.36</td>
<td>1.72</td>
</tr>
<tr>
<td>120 mm 1.13</td>
<td>1.43</td>
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<tr>
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</tr>
<tr>
<td>200 mm 0.68</td>
<td>0.86</td>
</tr>
</tbody>
</table>
Sample of (1.4) Factored Tilt-up Maximum Flexural Tensile Stress (MPa) of 1 m wide Solid Panel

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>600</th>
<th>700</th>
<th>750</th>
<th>800</th>
<th>850</th>
<th>900</th>
<th>950</th>
<th>1000</th>
<th>1050</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mm</td>
<td>1.60</td>
<td>1.86</td>
<td>2.13</td>
<td>2.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 mm</td>
<td>1.33</td>
<td>1.55</td>
<td>1.78</td>
<td>2.02</td>
<td>2.28</td>
<td>2.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 mm</td>
<td>1.07</td>
<td>1.24</td>
<td>1.42</td>
<td>1.62</td>
<td>1.83</td>
<td>2.05</td>
<td>2.28</td>
<td>2.53</td>
<td></td>
</tr>
<tr>
<td>175 mm</td>
<td>0.91</td>
<td>1.06</td>
<td>1.22</td>
<td>1.39</td>
<td>1.56</td>
<td>1.75</td>
<td>1.95</td>
<td>2.16</td>
<td>2.39</td>
</tr>
<tr>
<td>200 mm</td>
<td>0.80</td>
<td>0.93</td>
<td>1.07</td>
<td>1.21</td>
<td>1.37</td>
<td>1.53</td>
<td>1.71</td>
<td>1.90</td>
<td>2.09</td>
</tr>
</tbody>
</table>

**Design Loadings During Lifting**

- Consists of:
  1. Self Weight of Panel
  2. Suction Load between Panel and Casting Surface
  3. Dynamic Load at the time of lifting between the panel and the casting surface

All of the above shall not exceed the flexural strength of concrete as obtained by ASTM C78 third point Loading at the time of lifting.

Suction and Dynamic loadings are usually estimated at 40% of panel self weight.

**Correlation between Flexural & Compressive Strength**

For Normal Concrete Construction

\[ Mr = Modulus \ of \ Rupture \ (ROM) = 7.5 \sqrt{f'c} \] in PSI
\[ 0.71 \sqrt{f'c} \] in MPa

For Tilt-up Construction,

\[ Mr = Modulus \ of \ Rupture \ (ROM) = 4.0 \sqrt{f'c} \] in PSI
\[ 0.4 \sqrt{f'c} \] in MPa

At Early Age 5 to 7 day, Mr shall be obtained by testing via ASTM C78

**Climatic Conditions**

- Max & Min Temperature
- Daily Sunshine

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- Max & Min Temperature
- Daily Sunshine

(Max – Min) Temp ~ 20 Deg C

Daily Sunshine in July = 11 hrs
Climatic Conditions
Min & Max Relative Humidity

RH variation in a Typical Day is about 60%

Climatic Conditions
Rainfall & Evaporation

On average Less 0.5 mm daily rainfall with 5 mm of evaporation

Climatic Conditions
Gulf Salinity

- High Temperature
- High Daily Sunshine
- High Evaporation
- Low Rainfall
- Shallow water of the Gulf

High Salinity

Micro Climatic Conditions
Temperature & Relative Humidity

Variation of RH and Temperature During a Typical Day in April, (Sharjah, UAE)

Durability Challenge – Chloride ingress into Concrete 1st stage

During Wetting Cycle (high RH), the near-surface concrete absorbs the chloride solution from exposed surface

Durability Challenge – Chloride ingress into Concrete 2nd stage

During dry period (low RH), water evaporates from surface and high chloride concentration forms. Moist gas in the inner concrete carries the Cl ions deeper into concrete due to vapor pressure and temperature gradients.
**Durability Challenges and Remedy**

To Minimize the chloride ingress into Concrete,

1. Concrete cover shall be crack free
2. Reduce the porosity of Mortar Fraction
3. Reduce the Mortar Fraction Volume in the mix

(Ref: G. R. Summers, Gulf Construction, Sep 2001)

**Concrete Mix Design Criteria for Tilt-up Construction in the Arabian Peninsula**

- $f'_c$ (cube) = 40 to 45 Mpa
- Slump = 150 ± 25 mm
- Sand Type: Well Graded
- Aggregate Type: Crushed
- Max Aggregate Size = 20 mm
- Water Cement Ratio = 0.42 to 0.45 depending on exposure condition
- Cement Type: I or II
- Max cement Content = 400 kg
- Max Water Content = 150 liter per m$^3$ of mix
- MF = 50 to 55 %
- Cement Supplement: None Heat inducing Air Content: 2 to 3 %

**References**

1. CON/STEEL LJB Library
2. “Guide to the Construction of Reinforced Concrete in the Arabian Peninsula” CIRIA CS77
3. R. G. Summers, Gulf construction, Sep 2001
4. Fadi Elayache, Samir Chidiac, Nabil Kallas, “Concrete Durability Issues for the Gulf Region” IPCPM, Feb 18, 2003

**Q & A**