Super Thin Ultra-Light Posttensioned Flat Plate Floor Systems for Affordable Urban Housing

Zuzanna Sobczak

College of Engineering

Fatmir Menkulasi, PhD, P.E.
Civil and Environmental Engineering

Introduction and Research Motivation

Median housing prices in many big cities are well above the national average. In Boston, New York City, Washington DC, Denver, and Seattle median housing prices are between $300k and $400k. Cities in the west coast such as San Francisco, Los Angeles and San Diego feature median housing prices that are well above $400k (Clear Capital 2015). Accordingly, urban housing is still not affordable for many people. The combinations of high construction cost due to the inability of traditional materials to provide efficient and sustainable structures and land use regulations create challenges for investors who are trying to provide affordable housing and maximize profit. To address these issues, this research will present several super thin lightweight posttensioned floor systems that can be used in midrise and high-rise construction to accommodate the growing demands for affordable urban housing while complying with existing regulatory limits on building height (Fig. 1).

Technical Objectives

The objective of this research is the development of super thin ultra-light posttensioned flat plate floor systems by using high performing ultra-light cementitious composites that lead to slender, sustainable structures to remove the limitations imposed by commodity materials on midrise and high rise construction. This objective will be achieved by investigating the full-scale behavior of these super thin floor systems using high fidelity finite element analyses in terms of flexure, punching shear, long term deflections, and vibrations.

Research Approach

To demonstrate the benefits of super thin ultra light posttensioned floor systems, a typical floor plan featuring 3 bays with 20 ft by 25 ft maximum bay sizes was designed using traditional and high performance concrete mixes. The design for stresses at service, flexure and punching shear was conducted using hand calculations according to ACI 318-14. Load demands were determined using a column strip approach and were later verified with those obtained from linear elastic finite element analyses software (Ram Concept). Vibration performance was quantified using linear elastic dynamic analyses. Long term deflections were determined using linear elastic analysis using cracked sections properties. Creep was considered using the age adjusted effective modulus approach.

Material Properties

The material properties for the traditional concrete mix as well as high performance concrete mixes are presented in Table 1. The HPC mixes feature unit weight as low as 116pcf and compressive strength as high as 21 ksi, additionally, tensile strengths are as high as 2.9 ksi.

Table 1. Material properties at 28 days.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Unit Weight (pcf)</th>
<th>f'c (ksi)</th>
<th>f'k (ksi)</th>
<th>E (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>145</td>
<td>4</td>
<td>0.38</td>
<td>0.47</td>
</tr>
<tr>
<td>Distal</td>
<td>156</td>
<td>21</td>
<td>1.62</td>
<td>2.61</td>
</tr>
<tr>
<td>WHPBC140</td>
<td>148</td>
<td>17.3</td>
<td>3.12</td>
<td>5.92</td>
</tr>
<tr>
<td>LWHPBC140</td>
<td>129</td>
<td>13.1</td>
<td>1.16</td>
<td>2.64</td>
</tr>
<tr>
<td>LWHPBC120</td>
<td>122</td>
<td>10.9</td>
<td>0.90</td>
<td>2.08</td>
</tr>
<tr>
<td>LWHPBC116</td>
<td>116</td>
<td>9.2</td>
<td>0.85</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Flexure and Punching Shear

Flexural strength of the floor featuring the traditional mix was quantified using Whitney’s stress block. Whereas the flexural strength of the floors with the HPC mixes was calculated using experimentally obtained stress strain curves. Punching shear strength was based on ACI 318-14 equations.

Conclusions and Recommendations for Future Work

The utilization of HPC mixes results in floor weight and floor thickness reductions as high as 50% and 38%, respectively. Additionally, gravity loads demands on columns and walls, and seismic load demands on lateral load resisting systems are significantly reduced. The behavior of the super thin floors was investigated using linear elastic finite element analyses and hand calculations using strength prediction equations based on ACI 318-14. Full scale nonlinear finite element analyses will be employed in the future to capture the true behavior of the slabs. These investigations will consider the contribution of concrete in tension after cracking occurs, which is expected to reduce long term deflections and improve dynamic behavior in terms of vibrations.

Acknowledgements

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References

1. ACI 318-04 (2014) “Building Code Requirements for Structural Concrete and Commentary”, American Concrete Institute, Farmington Hills, MI.