Petrographic Analysis of Precipitation-Damaged Freshly Placed Concrete

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Overview

• Introduction to concrete petrography.
  • Our methods to petrographically analyze concrete.

• Case studies – evaluation/repair of slabs subjected to snow melt falling from above during placement:
  • Case study 1 – slab was hard-troweled while wet.
  • Case study 2 – slab was hard-troweled after excess water was removed
Concrete Petrography

Polished “thick” section

“Ultrathin” section
Polished “Thick” Sections

- “Big picture” condition assessment
- Provides valuable information about aggregate composition and distribution, macroscopic cracking, air void system, etc.
Blue-dye epoxy-injected ultrathin sections

- Detailed assessment; high magnification
- Composition of the cementitious paste, estimate w/cm (see photos above), detailed examination of microcracks, determine potential causes of distress.
Blue-dye epoxy-injected ultrathin sections

- Detailed assessment; high magnification
- Composition of the cementitious paste, estimate w/cm (see photos above), detailed examination of microcracks, determine potential causes of distress.
Case Study 1 – Background

• First level cast-in-place concrete slab on metal deck
  • Placed in February 2021.
  • Mix design – 5,000 psi, 0.40 w/cm, 6.5% air content, normal weight.
  • Concrete cylinder QC testing indicated 28-day strength >5,000.
Case Study 1

• Exposed to water dripping from melting snow on metal decks above during placing and finishing

• Pitting, scaling, etc. observed mid-February during site inspection.
Case Study 1 – 3rd Party Onsite Testing and Sample Extraction

• Observations prompted rebound hammer testing; indicated overall decrease in concrete strength.
  • Weak upper surface layer?
• Someone decided cores were in order
• 2-3/4 in. cores extracted; well below nominal (5000 psi) strength

<table>
<thead>
<tr>
<th>Compressive Strength (Sixty-three days; psi)</th>
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<tr>
<td>Core 1</td>
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<tr>
<td>3,480</td>
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<td>2,760</td>
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Case Study 1 – Questions to answer

• We were engaged to petrographically analyze two concrete cores to address the following:
  • Extent of incorporation of snowmelt.
  • Cause of low concrete core compressive strength. Possibly related to snowmelt?
Case Study 1 – Finished Surface

- Hard-troweled surface
- Microcracks (red arrows) observed on the finished surface.
Case Study 1 – Polished Sections

- Mottled light-medium gray beige and green coloration
  - Typical of slag-cement concrete.
- Upper ~1/8 in. darker gray color
  - Typical of a hard-troweled finish.
Case Study 1 – Perpendicular Microcracks

- Microcracks perpendicular to finished (top) surface extend ~1/4 in. into concrete from finished surface.
- Break through aggregate (yellow arrows) and paste (red arrows) and taper with depth.
- Typical of early-age drying shrinkage cracks (common in most concrete).
Case Study 1 – Incorporation of Snowmelt

• Higher w/cm in uppermost (<20 mils) concrete (above yellow dashed line; lighter colored paste)
  • Likely a result of incorporated snowmelt.
• Horizontal microcracks (red arrows) in this higher w/cm zone.
Case Study 1 – Incorporation of Snowmelt

• Higher w/cm in uppermost (<20 mils) concrete (above yellow dashed line; lighter colored paste)
  • Likely related to incorporated snowmelt.

Higher w/cm

Lower w/cm
Case Study 1 – Incorporation of Snowmelt

- Zone of high w/cm (yellow arrows) within densified zone (darker gray paste).
- Likely caused by incorporation of snowmelt during finishing.
Case Study 1 – Uneven Air Void Distribution

- Clustered air voids adjacent to aggregate particles (yellow ovals) – typical of retempered concrete

- Air void analyses results measured 8% to 8.6% for air content
  - 6.5% mix design
Case Study 1 – Variable W/CM

• Pockets of high w-cm (yellow ovals; stronger saturation of blue epoxy) in paste structure at depth

• “Typical” w/cm was estimated between 0.40 to 0.45
  • 0.40 mix design
Case Study 1 – Petrography Summary

• Overall weaker upper ~1/8 in. of concrete – upper 10-20 mils higher w/cm, microcracking, and zones of high w/cm within the densified zone.
  • Explains surface deterioration (pitting, scaling, etc.) and low rebound hammer results.
  • Evidence for incorporation of snowmelt in the uppermost portion of concrete.

• Evidence of retempering and subsequent incomplete mixing of retempering water and overall higher than specified air content.
  • Retempering can result in higher air content, clustering of air voids, and variable w/cm.
  • Slight increase in air content (+2%), minor clustering of air voids at aggregate interfaces, and variable w/cm partially explains lower strength results.
Case Study 1 – Sample Extraction

- Recommended additional cores to address the apparent low strength of the concrete.
  - Small (2-3/4 in. diameter) original cores
  - Limited number of original cores
  - Unknown original core treatment
- Prior to testing, we cut out the uppermost ¼ in. of each core to remove the weak layer of concrete.
Case Study 1 – Compressive Strength Results

- Extracted 11 sets of 3 cores (33 total) throughout the slab
  - 3-1/4 in. diameter cores
  - Resampled areas previously tested for comparison.

- All eleven sets average above 85% nominal strength

- One core (5C) below 75% nominal
  - >3 three standard deviations below the 5,740 psi average; likely an outlier.

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Case Study 1 – Structural Adequacy Assessment

• 5,740 psi average core strength > 5,000 psi nominal
• Without outlier, all cores met requirements:
  • Average of three cores is at least 85% of nominal (4,250 psi)*
  • No single core is less than 75% of nominal strength (3,750 psi)*
  • (Section 26.12.6.1 (e) of ACI 318 – Building Code Requirements for Structural Concrete)

* Note this is really applicable only for sets of 3 cores, but that’s for another day – see Bartlett and Lawler, 2011
Case Study 1 – Structural Adequacy Summary

• The newly-extracted cores indicated that the concrete is structurally adequate and meets the stipulations of Section 26.12.6.1 (e) of ACI 318-19
  • Considering outlier of Core 5C
  • All parties involved satisfied with the results

• Difference between previous and compressive testing?
  • The newly-extracted cores (3-1/4 in.) are larger than previously extracted cores (2-3/4 in.). Smaller cores are known to produce lower strength results.
  • Previous testing may not have removed the uppermost weaker layer, which would provide a preexisting plane of weakness and would not be representative of the overall slab strength.
Case Study 1 – Conclusions

• Concrete exhibits adequate strength development
  • Petrography identified retempering, but it was not detrimental to the overall strength.

• Incorporation of (detrimental) snowmelt restricted to the uppermost portion of concrete (~1/4 in.).
  • Revealed by petrographic analysis.
  • Uppermost weaker portion of concrete could be removed by abrasion/shotblasting.
Case Study 1 – Lessons Learned

• Stop finishing activities until the precipitation/excess water is dealt with.

• Think before you core and test
  • QC cylinders indicated adequate strength.
  • Rebound hammer low, but weak upper surface...
  • Surface deterioration observed, but no indication of “deep” water incorporation.
  • Consider petrography for a detailed analysis prior to testing in compression.

• If coring for compressive testing, extract the largest diameter cores possible
  • Know what and why you’re testing and use this as a last resort.
Case Study 2 - Background

• Cast-in-place concrete slab on metal deck; 4000 psi, 0.45 w/cm, lightweight.

• Snow on roof deck melted and fell ~30 feet onto the slab, eroding parts of the surface.

• Contractor stopped finishing operations (hard troweling), waited for it to stop, removed excess water, and completed finishing operations.

• The Owner directed the Contractor to demolish and replace the worst areas and investigate the remaining portions.
Case Study 2 – Questions to answer

• We were engaged to investigate the concrete slab and petrographically analyze extracted concrete cores to determine:
  • Depth of the incorporation of excess water.
  • Geographic extent of water-affected areas – is it localized, or did excess water detrimentally affect the entire slab?
Case Study 2 – Heavily Water-Affected Zone

- Photo taken shortly after the snow melt event.
- Concrete in this area (right side of photo; covered in curing blankets) was later removed.

Close up photos next slide
Case Study 2 – Heavily Water-Affected Zone

• Surface roughness, cement slurry, and exposed welded wire reinforcement (WWR). Rebound hammer results were generally low in this area, compared to other areas.
Case Study 2 – Heavily Water-Affected Zone

- The most water-affected portion of the slab was removed.
- Three cores were extracted prior to demolition (next slide).
Case Study 2 – Heavily Water-Affected Zone

• Core 1 exhibits evidence of “soft” paste (outlined in yellow box) in uppermost ~1/4 in.
  • Likely related to minor intrusion and mixing of excess water in the near-surface region.

• Upper portion of Cores 2 and 3 exhibit a densified layer (red arrows).
  • Typical of a hard-troweled finish.
Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Area that was subject to minor amounts of snowmelt.
Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Minor surface imperfections (yellow circles). Rebound hammer results were generally consistent in these areas and greater than in the heavily water-affected zone.
Case Study 2 – Areas Away from Heavily Water-Affected Zone

• Upper portion of all cores exhibit a densified layer (red arrows).
  • Typical of a hard-troweled finish.
• No evidence for incorporation of snowmelt.
Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Upper portion of cores exhibit a densified layer.
  - Typical of a hard-troweled finish.
- No evidence for incorporation of snowmelt.
Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Minor early-age plastic tear microcracks (red arrows) in the uppermost portion of each core.
  - Likely a result of the hard-trowel finishing.
- Bleed water channel (yellow arrow) that connects to a thin uppermost porous zone (above yellow dashed line).
  - Indicates some bleed water was incorporated into the densified layer.
  - No evidence of snowmelt incorporation.
Case Study 2 –Summary

• In the area subjected to a high volume of snowmelt, we observed evidence of excess water incorporation in one core to a depth of ~1/4 in.
  • The slab in this entire area was later removed.
  • This weak zone could have been removed via the planned shot blasting.

• The remaining portion (areas subject to minor amounts of snowmelt) of the concrete slab did not exhibit evidence of snowmelt incorporation.
  • Hard, densified layer in the uppermost ~1/8 in. of each core.
  • Minor plastic tear cracks and some bleed water incorporation in the uppermost densified layer, which may explain the few surface imperfections observed onsite.
    • The minor surface imperfections were addressed via the planned shot blasting.
Case Study 2 – Lessons Learned

• By stopping finishing activities, the effect of the snowmelt was confined to the near-surface (~1/4 in. depth) in one small region.

• After removal of the excess water, finishing activities achieved a densified, hard-troweled surface throughout the rest of the areas.

• The planned shot blasting may have addressed the upper weak surface in the heavily water-affected area.

• The planned shot blasting removed the minor surface imperfections in the remaining portion of the slab.
Concluding Remarks

• Stop finishing activities until the precipitation/excess water is dealt with.
• Even when exposed to a high volume of water, the incorporation of excess water is confined to the near-surface region of concrete.
• Concrete petrography is an invaluable tool to determine the extent of incorporation of snowmelt/rain and to inform potential removal/replacement/repair.
Questions?

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