Background

- Our civil infrastructure uses vast amounts of natural aggregate, resulting in large environmental demand. Recycled concrete aggregate (RCA) made from demolished concrete waste can be used as replacement for natural aggregate in new concrete construction.
- Use of RCA has been limited to non-structural applications (e.g., roadway sub-base).
- No engineering standards exist for design of reinforced concrete structures using RCA.

Research Objectives

- To develop an RCA mix design methodology that results in concrete with desirable fresh and hardened properties.
- To quantify variability of material/structural behavior due to variability of RCA properties from different sources.

Aggregate Properties

- Specific gravity (S.G.), absorption, residual mortar content (RMC), and deleterious material content studied for 2 natural aggregate (NA) types and 17 RCA sources.
- Residual mortar content measures the amount of mortar adhered to recycled aggregate; deleterious materials include asphalt, brick, wood, etc.

Aggregate Replacement Methods

- Three aggregate replacement methods studied:
  - DVR = simple volume-based aggregate replacement;
  - DWR = simple weight-based aggregate replacement;
  - EMR = aggregate replacement to ensure same amount of mortar (fresh + residual) in RCA concrete and target NA concrete mix designs.

Volumetric Diagrams

- Natural Aggregate (NA) Concrete 0% Replacement
- DVR Concrete 100% Replacement
- DWR Concrete 100% Replacement
- EMR Concrete 20% Replacement (Maximum allowed by workability limit)

RCA Concrete Test Results

<table>
<thead>
<tr>
<th>Target Natural Aggregate (NA) Mix Designs</th>
<th>RCA-ND</th>
<th>RCA-SB</th>
<th>DVR Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Units</td>
<td>NA-ND</td>
<td>NA-CL</td>
</tr>
<tr>
<td>Water</td>
<td>lb/yd³</td>
<td>253</td>
<td>253</td>
</tr>
<tr>
<td>Cement</td>
<td>lb/yd³</td>
<td>576</td>
<td>576</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>lb/yd³</td>
<td>1713</td>
<td>1713</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>lb/yd³</td>
<td>1140</td>
<td>1140</td>
</tr>
<tr>
<td>Water Reducer (HRWR)</td>
<td>fl oz/yd³</td>
<td>45.5</td>
<td>45.5</td>
</tr>
<tr>
<td>Air Entrainment (MAA)</td>
<td>lb/yd³</td>
<td>6.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Workability

- Workability measured using half-scale slump cone (mini-slump) due to limited amount of RCA from each source. Mini-slump compares to full slump test by:
  - Full Slump = 2.13 * (Mini Slump)
- DVR – similar workability to target NA mix design at any % aggregate replacement, R.
- DWR – slightly reduced workability for increased replacement.
- EMR – becomes unworkable at small replacements (R = 15-20%).

Compressive Strength

- No clear distinction between DVR, DWR, and EMR mix design methods.
- As % replacement is increased, mixes with NA-PG show slight strength gain, while mixes with NA-CL show strength loss.
- Considerable variability can be seen between different RCA sources.

Elastic Stiffness

- No clear distinction between DVR and DWR mix design methods.
- As % replacement is increased, mixes with NA-PG show no significant effect, while mixes with NA-CL show significant stiffness loss.
- Considerable variability can be seen between different RCA sources.

Conclusions

- Workability varies between replacement methods, with EMR becoming significantly less workable at low replacement levels.
- No clear effect of replacement method on compressive strength and elastic stiffness.
- Compressive strength only slightly affected by recycled aggregate, but elastic stiffness significantly reduced at high levels of replacement. Considerable variability in both compressive strength and elastic stiffness with different RCA sources.

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  - Lindahl Brothers INC.
- Material Donations
  - Transit Mix – South Bend
  - Buzzi Unicem
  - Reliable Asphalt Corporation
  - Sika Corporation
  - Vulcan Materials Company
  - Great Lakes Aggregates
  - Green Tech Transfer & Recycling

Ongoing Work

- Completion of variability testing for remaining seven RCA sources followed by statistical analysis of results.
- Determination of the effects of deleterious materials and residual mortar in RCA mixes.
- Stress-strain relationships for RCA concrete.
- Durability, creep, and shrinkage testing.
- Experimental testing of structural members with RCA concrete.