Linear Polarization Resistance & Degradation Rate Monitoring
Hazard Mitigation

• Concrete exposed to sea water is susceptible to corrosion
  • Degradation of concrete
  • Corrosion of rebar

• Corroded concrete and rebar significantly reduce strength capacity of structural members
  • Structure may be damaged beyond repair; or
  • Structure may have to undergo costly repairs
Corroded Structures

- A structure on the shore of Playa Bonita in Panama
- During high tide, the structure would become partially inundated by sea water
- Evident concrete degradation and steel corrosion
Mitigating the Issue

• It is necessary to understand how various types of concrete mixes react during constant and heavy exposure to seawater
• Ideally generate a mix which is not susceptible to corrosion and infiltration during seawater exposure; and that is also sustainable and environmentally efficient
In The Lab

• Dr. Rafael Calabuig is currently researching how various concrete mixes react during long-term exposure in various solutions, all of which simulate seawater exposure

• Linear polarization resistance technique is being used to analyze the corrosion rate of reinforcement bars within a concrete member; and

• Concrete cubes of various mixes are being also exposed to various solutions in order to observe and analyze the durability of the concrete over long-term exposure
The Mixes

• Five different types of concrete mixes are being analyzed; these mixes are:
  • 100% Portland Cement Mix
  • 50% Portland Cement Mix with 50% Fly Ash
  • 50% Portland Cement Mix with 50% Fly Ash with 10% added Cl
  • 50% Portland Cement Mix with 50% Fly Ash with 20% added Cl
  • 40% Portland Cement Mix with 60% Fly Ash with 20% added Cl
The Solutions

• The concrete samples are being immersed in three different solutions
  • Tap Water – as a control/reference solution
  • Sodium Chloride – has a direct corrosive effect on the steel reinforcement bar; little effect on the concrete sample. 35 g/L of NaCl
  • Sodium Chloride + Sulfate – the added sulfate has a direct corrosive effect on the concrete; little effect on the steel reinforcement bar. 35 g/L of NaCl added 35 g/L MgSO4

• The solutions simulate the effect that seawater will have on the concrete and the steel
Testing Concrete For Durability and Analyzing Infiltration of Solution

• Concrete cubes (of the various mixes) are submerged in the different solutions under the following cycle:
  • Two day immersion at 20° C
  • One day drying in oven at 60° C
• Every 8 weeks, the cubes are cracked in half
• Spraying the inside of the cubes with silver nitrate reveals the extents of infiltration
The Procedure
The Procedure
The Procedure
The Procedure
Results

3,5% Cloruro-3,5% sulfato 16 semanas

<table>
<thead>
<tr>
<th></th>
<th>CP</th>
<th>CV</th>
<th>CV10CL</th>
<th>CV20CL</th>
<th>CV60CL</th>
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</thead>
<tbody>
<tr>
<td>16 sem</td>
<td>5.4</td>
<td>3.8</td>
<td>3.3</td>
<td>3.9</td>
<td>3.0</td>
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</table>

3,5% Cloruro 16 semanas

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Measuring Corrosion Rate of Reinforcement Steel Within Concrete

- Upon measuring the infiltration of solution within a concrete sample, it is now paramount to understand how the steel within the concrete is affected against the attacks
- Linear polarization resistance method is used to observe the rate of corrosion of the steel within the concrete
- A reinforced cylindrical concrete sample is used.
The Samples
About the Experiment

• In applying voltage to a reinforced concrete sample, relations are established amongst current (A) vs. potential applied (V) which are used to determine the state of corrosion of the reinforcement bar.

• Range of the potential applied is -10 to 10 mV from the OCP.
Electrode and Cell Setup

• Working electrode – the reinforcement bar
• Current electrode – wire mesh wrapped around concrete cylinder
• Control electrode – the reference electrode containing Potassium Chloride solution and Potassium Chloride salts
Electrode and Cell Setup
Electrode and Cell Setup
Current (A) vs. Potential (V)
Current (A) vs. Potential (V)
Interpreting the Results

• From the graph, the slope of a selected range (points 20-31) is obtained

• Knowing the slope, the Polarization Resistance \( (R_p) \) may be computed as

\[
R_p = 1/m
\]

• Once \( R_p \) has been computed, instantaneous corrosion current density \( (i_{corr}) \) may be calculated as

\[
i_{corr} = B/ R_p
\]

• \( B \) is a constant and is equal to 26 mV for these experiments
• Knowing \( i_{corr} \) provides information pertaining to the corrosion state of the rebar
Interpreting the Results

• Knowing $i_{corr}$ provides information pertaining to the corrosion state of the rebar. Table is as per Norma Española UNE 112072.

<table>
<thead>
<tr>
<th>Intensity of Corrosion ($i_{corr}$)</th>
<th>Level of Corrosion</th>
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</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>Negligible</td>
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<tr>
<td>0.1 - 0.5</td>
<td>Low</td>
</tr>
<tr>
<td>0.5 - 1</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>High</td>
</tr>
</tbody>
</table>
Results

[Cropped graph showing results over time for different conditions]
In Conclusion

• This research internship has been a great opportunity to work in a lab with very educated and hard-working professionals;
• This internship has made me aware of how broad civil engineering is; and how you can solve real-world problems with dedication.
• I’ve enjoyed my time working at UPV; and I looked forward to taking these skillsets home and applying them to my future endeavors.