**INTRODUCTION**

The porous nature of concrete makes it vulnerable to deterioration caused by a structure’s surroundings. Carbonation is a form of deterioration caused by the interaction between carbon dioxide and the constituents inside concrete. Carbonation exposes the inner reinforcing steel in a concrete member to corrosion susceptibility, leading to undesirable effects:

- Corrosion increases the internal stresses inside concrete, which causes cracks, and therefore more frequent maintenance repairs during a member’s design life.
- Corrosion reduces the structural capacity of a member by decreasing the cross-sectional area of steel reinforcement. This could cause structural failure, or worse, human injury or death.
- In prestressed concrete structures, corrosion is even more of a concern, since each steel tendon carries significantly greater loads.

**MOTIVATION**

- Current ACI building code is based on the full strength capacity of steel and concrete and does not account for the effects of carbonation.
- Carbonation is expected to have a greater effect for existing concrete structures as atmospheric CO2 concentration increases with temperature.
- Past research mainly investigates concrete carbonation at a material level and does not extend to its structural implications.
- Predicting the carbonation impact on structural capacity reduction is part of understanding of program.

**PRESENT OBJECTIVES**

- Obtain comprehensive information on the concrete degradation mechanism and corrosion process in prestressed concrete structures.
- Familiarize self with OpenSees in order to simulate effect of carbonation degradation on concrete marine pile.
- Develop probabilistic model of degradation process in MATLAB to predict the time to corrosion initiation, and ultimately the total amount of cross-section of the inner steel tendons that has corroded.
- All present objectives are being completed in preparation of assessing structural implications of carbonation in the future.

**DATA COLLECTION METHODS**

- Compiled information from previous research on the processes of concrete degradation.
- Studied international research groups’ reports on methods of concrete deterioration that have been incorporated in European Building Codes [4,5].
- Worked with OpenSees manual and examples to develop understanding of program.

**SERVICEABILITY MODELING**

Service life model consists of two phases as shown in Figure 2:

1. **INITIATION PHASE: CARBONATION**
   - Factors influencing carbonation:
     - Environmental Conditions
     - Material Properties
     - Design Factors
   - Carbonation is caused by a reaction between carbon dioxide and CH and CSH in concrete to form solid Calcium Carbonate:
     \[
     \text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}
     \]
   - Carbonation front forms as reactions progress. The naturally high alkalinity of concrete is destroyed once it becomes carbonated, depleting the protection around steel reinforcement.

2. **PROPAGATION PHASE: CARBONATION/CHLORIDE COUPLING**
   - It is rare that carbonation acts as the only corrosion inducing deterioration process, especially in high-chlorine marine environments.
   - Chloride penetration into concrete induces steel corrosion and the time to corrosion initiation has been shown to occur within 50 years [3].
   - Carbonation progresses more slowly than chloride penetration. Therefore, at the carbonation front:
     - Bound chlorides in the concrete are liberated, causing the total chloride content to increase [7].
     - Increased density of concrete causes chloride diffusion to reduce by 20% in carbonated concrete [2].

**3 PHASE ULTIMATE SERVICE LIFE MODEL**

1. Probabilistic model of the initiation phase: carbonation progression coupled with chloride penetration.
2. Concrete carbonation model with probabilistic model to analyze corrosion pit depth.
3. Determine time to ultimate limit state using OpenSees FE model of concrete marine pile (Figure 5).

**PROBABILISTIC MODEL**

- Reasoning: Probabilistic models account for inherent stochasticity in variables affecting carbonation and chloride penetration.
- Framework: Model 1 will model the depth of chloride penetration until it reaches the face of the steel reinforcing tendon with an inner moving boundary for the carbonation front (Figure 6).

**ACKNOWLEDGMENTS**

We would like to thank Daniel Schmuhl for his previous research concerning chloride induced corrosion and for his mentorship in OpenSees modeling methods.