# Software Requirements Specification for CRLP: Concrete Remaining Life Prediction

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## Contents

# Revision History

| Date | Version | Notes |
|---|---|---|
| February 5 | 1.0 | Initial Documentation |
| February 26 | 2.0 | Updates Following Feedback |

# 1 Reference Material

This section records information for easy reference.

## 1.1 Table of Units

Throughout this document SI (Système International d'Unités) is employed as the unit system. In addition to the basic units, several derived units are used as described below. For each unit, the symbol is given followed by a description of the unit and the SI name.

| symbol | unit | SI |
|---|---|---|
| A | electric current | ampere |
| cm | length | centimeter |
| L | volume | liter |
| m | length | metre |
| mg | mass | milligram |
| mm | length | millimeter |
| s | time | second |
| y | time | year |

## 1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The symbols are listed in alphabetical order.

| symbol | unit | description |
|---|---|---|
| $A_{\mathrm{cr}}$ | $\mu A/cm^2$ | average corrosion rate during one year |
| $A_d$ | mm | cumulative depth of deterioration after $t_{use}$ years |
| $A_{\mathrm{df}}$ | mm | concrete cover thickness after $t_{use}$ years |
| $C_x$ | mg/L | chloride concentration at depth $x$ |
| $C_{const}$ | mg/L | constant chloride concentration at the concrete surface |
| $C_R$ | cm | thickness of concrete cover |
| $D_{\mathrm{cl}}$ | $m^2$/s | chloride ion diffusion coefficient |
| $erf$ | - | error function |
| $H_r$ | % | relative humidity |
| $k_a$ | - | coefficient of active corrosion |
| $k_c$ | - | quality coefficient of concrete |

| | | |
|---|---|---|
| $k_d$ | mm/y | constant encapsulates various factors affecting the degradation of concrete |
| $k_e$ | - | coefficient of environment |
| $L$ | cm | remaining uncarbonated cover |
| $n$ | - | time order |
| $R_c$ | cm/y | rate of carbonation |
| $R_d$ | m/s | Rate of concrete degradation |
| $t$ | y | time required to reach a sufficient depth $x$ to obtain complete chloride concentration |
| $t_{cover}$ | y | time to be fully covered by carbonation |
| $t_{remain}$ | y | remaining service life of concrete |
| $t_{use}$ | y | Years of concrete usage |
| $t_y$ | y | total lifespan of concrete |
| $x$ | m | depth |

## 1.3 Abbreviations and Acronyms

| symbol | description |
|---|---|
| A | Assumption |
| CRLP | Concrete remaining life prediction |
| DD | Data Definition |
| GD | General Definition |
| GS | Goal Statement |
| IM | Instance Model |
| LC | Likely Change |
| PS | Physical System Description |
| R | Requirement |
| SRS | Software Requirements Specification |
| TM | Theoretical Model |
| UI | User Interface |

# 2 Introduction

In response to the critical need for predicting the remaining life of concrete structures, this project aims to develop a program that implements theories introduced by a United States laboratory in 1992. (5) Their work emphasized the importance of estimating remaining service life to enable property owners to plan for repairs or demolitions proactively. By predicting the remaining service life of concrete structures, it offers a valuable tool for effective maintenance and decision-making.

The upcoming section will present a roadmap for the Software Requirements Specification (SRS) of CRLP. This segment elucidates the document's purpose, outlines the scope of the requirements, and describes the characteristics of the target audience for this document.

## 2.1 Purpose of Document

The primary aim of this document is to outline the requirements of the CRLP program. This encompasses background information, goals, assumptions, theoretical models, definitions, and other details related to model derivation. These components collectively enable the audience to gain a clear understanding and verify the purpose and scientific basis of this program.

## 2.2 Scope of Requirements

The scope of requirements assumes that parameters from different equations will not influence each other. In other words, if an equation only requires two specific parameters, $L$ and $R_c$ to calculate time, the result will not be affected by relative humidity from other equations.

## 2.3 Characteristics of Intended Reader

The intended reviewers of this documentation should possess a background in meteorology or have completed university-level courses related to concrete construction or materials introduction. Additionally, a basic grasp of high-school level mathematics and chemistry is recommended. For users of the prediction program can have a lower level of expertise, as further explained in the "User Characteristics" section (Section 3.2).

## 2.4 Organization of Document

The organization of this document follows the SRS template (2) provided by Dr. Smith and the GlassBR SRS document (1).

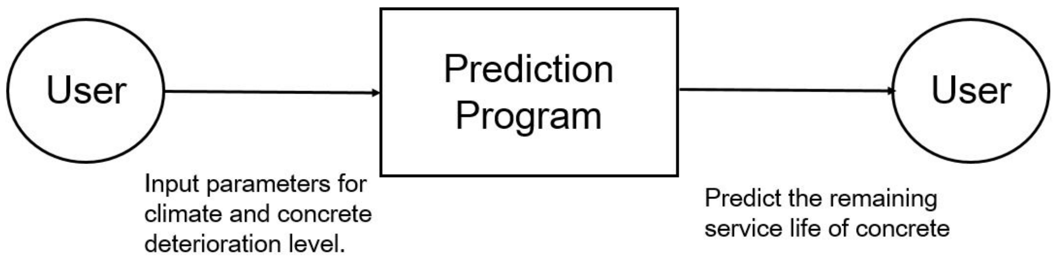


Figure 1: System Context

# 3 General System Description

This section provides general information about the system. It identifies the interfaces between the system and its environment, describes the user characteristics and lists the system constraints.

## 3.1 System Context

Figure 1 illustrates the system context. In this representation, a circle signifies an external entity, which, in this case, is the user. The rectangle represents the prediction program, and arrows depict the data flow between the system and its environment.

The interaction between the product and the user is through a UI. The responsibilities of the user and the system are as follows:

- User Responsibilities: Provide the input data related to climate and concrete deterioration level.
- Prediction Program Responsibilities:
  - Determine if the inputs satisfy the required program constraints.
  - Predict the remaining service life of concrete.

## 3.2 User Characteristics

- The end user is expected to have a fundamental level of computer literacy in order to effectively navigate the software interface and input concrete details accurately. This includes basic skills such as opening the software application and correctly entering concrete parameters into the system.
- The end user is expected to have completed university-level civil engineering courses related to concrete introduction or concrete construction. This background knowledge is necessary to comprehend the theoretical aspects of concrete degradation measurement and its underlying causes.

## 3.3 System Constraints

There are no system constraints.

# 4 Specific System Description

This section first presents the problem description, which gives a high-level view of the problem to be solved. This is followed by the solution characteristics specification, which presents the assumptions, theories, definitions and finally the instance models.

## 4.1 Problem Description

A system is required to predict the remaining service life of concrete by integrating climate data and concrete degradation levels.

### 4.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements:

1. Corrosion rates (Icorr): As states on Corrosionpedia (6) website (2019), "Corrosion rate is the speed at which any metal in a specific environment deteriorates. It also can be defined as the amount of corrosion loss per year in thickness."

2. Deterioration Factors:

    - Carbonation: "It reduces its alkalinity sufficiently to depassivate the steel and initiate corrosion. Carbonation involves the reaction of gaseous carbon dioxide with calcium hydroxide of concrete to form calcium carbonate. The steel's pH becomes susceptible to corrosion when fully carbonated." (J.R. Clifton, 1991, p.19)(4)

    - Diffusion of chloride ions: It refers to the process by which chloride ions permeate or spread through concrete structures. Once present in concrete, chloride ions can initiate corrosion of steel reinforcement. The diffusion of chloride ions through concrete is influenced by factors such as the presence of entrained air, the spacing of air bubbles, and the pore structure of the concrete matrix. (J.R. Clifton, 1991, p.6)(4)

    - Acid attack (siliceous aggregate): It occurs as a result of alkali-silica reaction (ASR). ASR is a type of alkali-aggregate reaction where the reactive components, namely silica in the aggregate, interact with alkalis in the cement. This reaction leads to the formation of expansive products, causing serious cracking in concrete due to the imbibition of water by the reaction products. (J.R. Clifton, 1991, p.15)(4)

- Acid attack (carbonate aggregate): It involves alkali-carbonate reaction (ACR). Similar to alkali-silica reaction, alkali-carbonate reaction occurs between alkalis in the cement and certain carbonate aggregates, such as dolomitic limestone aggregates. This reaction can also lead to the formation of expansive products and subsequent cracking of concrete.(J.R. Clifton, 1991, p.15)(4)

- Sulfate attack: As J.R. Clifton (1991) (4) states, "Sulfate attack of concrete can result in cracking or disintegration of the material. Naturally occurring sulfates of sodium, potassium, calcium, and magnesium are commonly found in groundwater and soil, particularly in areas with high clay content."(p.25)

- Frost attack: This is the damage incurred by concrete when it is exposed to cycles of freezing and thawing. Frost damage can occur even if the concrete is not fully saturated with water, as the critical level of saturation for most concretes is around 85 percent. (J.R. Clifton, 1991, p.18)(4)

- Active corrosion of steel: It refers to the phase in which corrosion is actively occurring, leading to the deterioration of the reinforcing steel within concrete structures.(J.R. Clifton, 1991, p.40)(4)

- Reinforcement (propagation): It refers to the process of corrosion spreading or advancing within the steel reinforcement embedded in concrete structures. It encompasses the progression of corrosion beyond the initial stage of initiation and extends to the broader understanding of how corrosion develops and spreads over time.(Andrade. C, 2018) (7)

3. Rain: Precipitation in the form of liquid water droplets greater than 0.5 mm.

4. Relative Humidity: Relative humidity in percent (%) is the ratio of the quantity of water vapour the air contains compared to the maximum amount it can hold at that particular temperature.

### 4.1.2 Physical System Description

The physical system regarding how deterioration occurs is not discussed in this study.

### 4.1.3 Goal Statements

Develop a prediction program that implements the theories, with the goal of predicting the remaining service life of concrete structures.

## 4.2 Solution Characteristics Specification

The instance models that govern this program are presented in Subsection 4.2.5. The information to understand the meaning of the instance models and their derivation is also presented, so that the instance models can be verified.

### 4.2.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical model by filling in the missing information for the physical system. The numbers given in the square brackets refer to the theoretical model [TM], general definition [GD], data definition [DD], instance model [IM], or likely change [LC], in which the respective assumption is used.

A1: The values of $k_d$ remain constant throughout the entire deterioration period.

A2: The factors influencing the remaining life of concrete and causing degradation are restricted to the following: carbonation, diffusion of chloride ions, acid attack (siliceous aggregate), acid attack (carbonate aggregate), sulfate attack, frost attack, active corrosion of steel and reinforcement (propagation).

A3: If only one degradation process occurs, implicitly refer to Figure 4 to determine the exact value of n; Multiple degradation processes occurring simultaneously, making the time order n=1.

A4: When using weather data to predict results, relative humidity is considered the only factor that influences Icorr.

A5: The relative humidity value needs to remain consistently below 70% for a month to be considered in the calculation of the $M_1$ value. The same applies to the $M_2$ and $M_3$ values.

A6: The relationship between $M_1$ and $M_2$ is mutually exclusive to $M_3$. In other words, there is no rain during the $M_1$ and $M_2$ periods.

### 4.2.2 Theoretical Models

There are no theoretical models.

### 4.2.3 General Definitions

There are no general definitions.

### 4.2.4 Data Definitions

This section collects and defines all the data needed to build the instance models. The dimension of each quantity is also given.

| Number | DD1 |
|---|---|
| Label | Coefficient weighing the impact of corrosion rates (Icorr) in $M$ |
| Symbol | $M_1$, $M_2$, $M_3$, $C_1$, $C_2$, $C_3$ |
| SI Units | - |
| Equation | $\begin{cases} M_1, C_1 = 0.1 \\ M_2, C_2 = 1.0 \\ M_3, C_3 = 10 \end{cases}$ |
| Description | The coefficient for $M_1$ will be 0.1, for $M_2$ it will be 1.0, and for $M_3$ it will be 10. |
| Sources | James Clifton et al. (1) |
| Ref. By | IM?? |

| Number | DD2 |
|---|---|
| Label | Average corrosion rate of year |
| Symbol | $A_{\text{cr}}$ |
| SI Units | - |
| Equation | $A_{\text{cr}} = \frac{C_1 \cdot M_1 + C_2 \cdot M_2 + C_3 \cdot M_3}{12}$ |
| Description | $M_1$ is month Number of months that relative humidity is below 70%<br>$M_2$ is month Number of months that relative humidity is between 70 and 100%<br>$M_3$ is month Number of months that rain occurs<br>$C_1$ is coefficient weighing the impact of corrosion rates (Icorr) in $M_1$<br>$C_2$ is coefficient weighing the impact of corrosion rates (Icorr) in $M_2$<br>$C_1$ is coefficient weighing the impact of corrosion rates (Icorr) in $M_3$ |
| Sources | James Clifton et al. (1) |
| Ref. By | IM?? |

| | |
|---|---|
| Number | DD3 |
| Label | Amount of concrete degradation |
| Symbol | $k_d$, $A_d$, $t_y$, n |
| SI Units | s |
| Equation | $k_d = \left(\frac{A_d}{t_y}\right)^n$ |
| Description | $A_d$ is Accumulated deterioration at time $t_y$.<br>$k_d$ is Factors influencing deterioration.<br>$t_y$ is Service life of concrete.<br>n is time order<br>The above equation calculate the amount of concrete degradation. |
| Sources | James Clifton et al. (1) |
| Ref. By | IM?? |

| | |
|---|---|
| Number | DD4 |
| Label | **Time to failure** |
| Symbol | $t_y$, $A_{\mathrm{df}}$, $k_d$ , n |
| SI Units | s |
| Equation | $t_y = \left(\frac{A_{df}}{k_d}\right)^{\frac{1}{n}})$ |
| Description | $t_y$ is Service life of concrete<br>$A_d$ is the amount of damage at failure<br>$k_d$ is the factor influencing deterioration<br>$n$ is the time order<br>The above equation calculates the time to failure |
| Sources | James Clifton et al. (1) |
| Ref. By | IM?? |

#### 4.2.5 Instance Models

This section transforms the problem defined in Section 4.1 into one which is expressed in mathematical terms. It uses concrete symbols defined in Section 4.2.4 to replace the abstract symbols in the models identified in Sections 4.2.2 and 4.2.3.

| Number | IM1 |
|---|---|
| Label | **By using chloride concentration at depth x to derive time t** |
| Input | $C_o$, x, $D_{\text{cl}}, t$ |
| Output | t |
| Description | $C_o$ is constant chloride concentration at the surface.(mg/L)<br>x is the depth of chloride concentration.(m)<br>$D_{\text{cl}}$ is Chloride ion diffusion coefficient.($m^2/s$)<br>t is the time required to reach a sufficient depth x to obtain complete chloride concentration.(year)<br>The time t to reach depth x can be used to derive the remaining service life. |
| Sources | James Clifton et al. (1) |
| Ref. By | - |

| Number | IM2 |
|---|---|
| Label | **Predict remaining service life of carbonation model** |
| Input | L, x, $R_c$ |
| Output | $t_c$ |
| Description | $t_c$ is the time to be fully covered by carbonation.(year)<br>L is the the remaining uncarbonated cover.(cm)<br>$R_c$ is the rate of carbonation.(cm/year)<br>The above equation predict remaining service life of carbonation model. |
| Sources | James Clifton et al. (1) |
| Ref. By | - |

| Number | IM3 |
|---|---|
| Label | **Prediction of remaining service life with respect to chloride attack** |
| Input | $k_c$, $k_e$, CR, $k_a$ |
| Output | $t_r$ |
| Description | $t_r$ is the remaining service life of concrete.(year)<br>$k_c$ is the quality coefficient of concrete.(unitless)<br>$k_e$ is the coefficient of environment.(unitless)<br>CR is the thickness of concrete cove.(cm)<br>$k_a$ is the coefficient of active corrosion.(unitless)<br>The above equation prediction of remaining service life with respect to chloride attack. |
| Sources | James Clifton et al. (1) |
| Ref. By | - |

| Number | IM4 |
|---|---|
| Label | **Prediction of remaining service life with weather data** |
| Input | $A_{\text{df}}$, $A_{\text{d}}$ |
| Output | $t_r$ |
| Description | $t_r$ is the remaining service life of concrete. (year)<br>$A_{\text{df}}$ is the amount of damage at failure.(mm)<br>$A_{\text{d}}$ is the accumulated deterioration right now.(mm)<br>The above equation predicts the remaining service life with weather data. |
| Sources | James Clifton et al. (1) |
| Ref. By | - |

| Number | IM5 |
|---|---|
| Label | **Predict the remaining service life based on the age at failure up to the time of inspection** |
| Input | $t_f$, $t_i$ |
| Output | $t_r$ |
| Description | $t_r$ is the remaining service life of concrete.(year)<br>$t_f$ is the average corrosion rate of a year.(year)<br>$t_i$ is the age of the concrete at the time of condition inspection.(year)<br>The above equation predict the remaining service life based on the age at failure up to the time of inspection. |
| Sources | James Clifton et al. (1) |
| Ref. By | - |

#### 4.2.6 Input Data Constraints

There are no constraints regarding input variables or specification parameter values.

#### 4.2.7 Properties of a Correct Solution

There are no constraints regarding output variables.

# 5 Requirements

This section provides the functional requirements, the business tasks that the software is expected to complete, and the nonfunctional requirements, the qualities that the software is expected to exhibit.

## 5.1 Functional Requirements

R1: Input the weather data and concrete degradation data.

R2: Output the prediction result.

R3: Utilize the input from the previous step to calculate the average corrosion rate and time to failure for the concrete.

R4: Verify that the output result is generated from the input data.

### 5.2 Nonfunctional Requirements

NFR1: **Usability** With the UI, users are able to input data and generate output effortlessly.

NFR2: **Accuracy** With the given input, the system is capable of generating accurate results.

NFR3: **Reusable** The code is modularized and flexible to extend functions.

# 6 Likely Changes

LC1: The Assumption 1 restricts the category of degradations that might be experienced in the future.

LC2: The Assumption 4.2.5 restricts the weather factor to only be $R_h$ that might be experienced in the future.

# 7 Unlikely Changes

UL3: The Assumption 5 is fixed and unlikely to change.

# 8 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" may have to be modified as well. Table **??** shows the dependencies of theoretical models, general definitions, data definitions, and instance models with each other. Table 3 shows the dependencies of instance models, requirements, and data constraints on each other. Table 1 shows the dependencies of theoretical models, general definitions, data definitions, instance models, and likely changes on the assumptions.

| | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|
| DD1 | | | | | | |
| DD2 | | | | X | X | X |
| DD3 | X | X | | | | |
| DD4 | | | | | | |
| IM1 | | | | | | |
| IM2 | | | | | | |
| IM3 | | | | | | |
| IM4 | | | | X | X | X |
| IM5 | | | | | | |
| LC1 | | | | | | |
| LC2 | | | | | | |
| UL1 | | | | | | |

Table 1: Traceability Matrix Showing the Connections Between Assumptions and Other Items

# References


[1] Nikitha Krithnan and W. Spencer Smith. *Software Requirements Specification forGlassBR.* https://jacquescarette.github.io/Drasil/examples/glassbr/SRS/srs/GlassBR_SRS.html

[2] Smith, W. Spencer.(2024). *SRS*. GitHub. https://github.com/smiths/capTemplate/blob/main/docs/SRS/SRS.pdf

[3] *Historical Data.*Government of Canada. https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

[4] Clifton, J. R.(1991). *Methods for Predicting Remaining Life of Concrete in Structures.*

[5] Clifton, J. R. and Pommersheim, J. M. (1992). *Methods for Predicting Remaining Life of Concrete in Structures.* https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir4954.pdf

[6] *Corrosion Rate.*(2018, September 12) Corrosionpedia. https://www.corrosionpedia.com/definition/337/corrosion-rate

[7] Andrade, C.*Propagation of reinforcement corrosion: principles, testing and modelling.*(2018) Corrosionpedia. https://doi.org/10.1617/s11527-018-1301-1

| | DD1 | DD2 | DD3 | DD4 | IM1 | IM2 | IM3 | IM4 | IM5 | LC1 | LC2 | UC1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DD1 | | | | | | | | | | | | |
| DD2 | | | | | | | | | | | | |
| DD3 | | | | | | | | | | | | |
| DD4 | | | | | | | | | | | | |
| IM1 | | | | | | | | | | | | |
| IM2 | | | | | | | | | | | | |
| IM3 | | | | | | | | | | | | |
| IM4 | X | | | | | | | | | | | |
| IM5 | | | | | | | | | | | | |
| LC1 | | | | | | | | | | | | |
| LC2 | | | | | | | | | | | | |
| UC1 | | | | | | | | | | | | |

Table 2: Your table caption

| | IM1 | IM2 | IM3 | IM4 | IM5 | R1 | R2 | R3 |
|---|---|---|---|---|---|---|---|---|
| R4 | | | | | | | | |
| IM1 | | | | | | | | |
| IM2 | | | | | | | | |
| IM3 | | | | | | | | |
| IM4 | | | | | | | | |
| IM5 | | | | | | | | |
| R1 | | | | | | | | |
| R2 | | | | | | | | |
| R3 | | | | | | | | |
| R4 | | | | | | | | |

Table 3: Traceability Matrix Showing the Connections Between Requirements and Instance Models

| Degradation Process | Value of n |
|---|---|
| carbonation | 1/2 |
| diffusion of chloride ions | 1/2 |
| acid attack (siliceous aggregate) | 1/2 |
| acid attack (carbonate aggregate) | 1 |
| sulfate attack | 1 |
| frost attack | 1 |
| active corrosion of steel reinforcement (propagation) | 1 |

Table 4: Values of n Obtained from Models

**Appendix**