Software Requirements Specification for : Concrete Remaining Life Prediction

Yi-Leng Chen

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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
°C	temperature	centigrade
m	length	metre
µ	micro	10^-6
Pa	pressure	pascal
s	time	second

1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The choice of symbols was made to be consistent with the heat transfer literature and with existing documentation for solar water heating systems. The symbols are listed in alphabetical order.

symbol	unit	description
A_{cr}	$\mu A/cm^2$	Average corrosion rate of a year
A_d	mm	Accumulated deterioration at time t_y
A_{df}	mm	Amount of damage at failure
C_o	%	Constant chloride concentration at the surface
C_R	cm	Thickness of concrete cover
C_1	-	Coefficient weighing the impact of corrosion rates (Icorr) in M_1
C_2	-	Coefficient weighing the impact of corrosion rates (Icorr) in M_2
C_3	-	Coefficient weighing the impact of corrosion rates (Icorr) in M_3
D_{cl}	-	Chloride ion diffusion coefficient
erf	-	error function
H_r	%	Relative humidity
$I_{_{\mathrm{corr}}}$	-	Corrosion Rates ()

k_a	-	Coefficient of active corrosion
k_c	-	Quality coefficient of concrete
k_d	mm/year	Factors influencing deterioration at time t_y
k_e	-	Coefficient of environment
L	cm	The remaining uncarbonated cover
M_1	month	Number of months that relative humidity is below 70%
M_2	month	Number of months that relative humidity is between 70 and 100%
M_3	month	Number of months that rain occurs
n	year	Time order
R_c	cm/year	rate of carbonation
R_d	m/s	Rate of concrete degradation
t	year	The time required to reach a sufficient depth x to obtain complete chloride concentration
t_c	year	The time to be fully covered by carbonation
t_i	year	Age of the concrete at the time of condition inspection
t_r	year	Remaining service life of concrete
t_y	year	Service life of concrete
t_f	year	Time to failure
x	m	Depth of chloride concentration

1.3 Abbreviations and Acronyms

symbol	description
A	Assumption
DD	Data Definition
GD	General Definition
GS	Goal Statement
Icorr	Corrosion rates
IM	Instance Model
LC	Likely Change
PS	Physical System Description
R	Requirement
RH	Relative humidity
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. 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 the program. 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 Concrete Remaining Life Prediction 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.

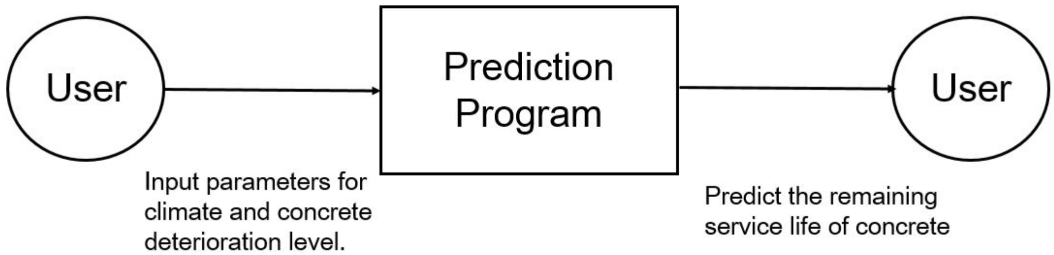

Figure 1: System Context

2.2 Scope of Requirements

This document explores the impact of climate data and the level of concrete deterioration (e.g., carbonation model) on concrete structures, aiming to implement a predictive program.

2.3 Characteristics of Intended Reader

The intended reviewers of this documentation should possess an understanding of meteorology or civil engineering. 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 provided by Dr. Smith and the GlassBR SRS document(1).

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 and predict the remaining service life of concrete.

3.2 User Characteristics

- The end user is expected to possess basic computer literacy for effectively handling the software.
- The end user is expected to have an understanding of the theory behind concrete degradation measurement and its root 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 (4) 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)(3)

- 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)(3)

- 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)(3)

- 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)(3)

- Sulfate attack: As J.R. Clifton (1991) (3) 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)(3)

- 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)(3)

- 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) (5)

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_{cr}
SI Units	-
Equation	$A_{\mathrm{cr}} = \frac{C_1 \cdot M_1 + C_2 \cdot M_2 + C_3 \cdot M_3}{12}$
Description	M_1 is month Number of months that relative humidity is below 70% M_2 is month Number of months that relative humidity is between 70 and 100% M_3 is month Number of months that rain occurs C_1 is coefficient weighing the impact of corrosion rates (Icorr) in M_1 C_2 is coefficient weighing the impact of corrosion rates (Icorr) in M_2 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. k_d is Factors influencing deterioration. t_y is Service life of concrete. n is time order 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_{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 A_d is the amount of damage at failure k_d is the factor influencing deterioration n is the time order 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_{cl}, t
Output	t
Description	C_o is constant chloride concentration at the surface.(mg/L) x is the depth of chloride concentration.(m) D_{cl} is Chloride ion diffusion coefficient.(m^2/s) t is the time required to reach a sufficient depth x to obtain complete chloride concentration.(year) 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) L is the the remaining uncarbonated cover.(cm) R_c is the rate of carbonation.(cm/year) 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) k_c is the quality coefficient of concrete.(unitless) k_e is the coefficient of environment.(unitless) CR is the thickness of concrete cove.(cm) k_a is the coefficient of active corrosion.(unitless) 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_{cr}
Output	t_r
Description	t_r is the remaining service life of concrete. A_{cr} is the average corrosion rate of a year. 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. t_f is the average corrosion rate of a year. t_i is the age of the concrete at the time of condition inspection. 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] *Historical Data.*Government of Canada. https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

[3] Clifton, J. R. and Pommersheim, J. M. (1992). *Methods for Predicting Remaining Life of Concrete in Structures.* https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir4712.pdf

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

[5] 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