ABSTRACT

CALDERON, VICTOR ALEJANDRO. Time Dependent Performance Based Design. (Under the direction of Dr. Mervyn Kowalsky.)

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque,

augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Time Dependent Performance Based Design

by
Victor Alejandro Calderon

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Civil Construction and Environmental Engineering

Raleigh, North Carolina

2019

APPROVED BY:

_____   _____
Dr. James Nau   Dr. Mohammad Pour-Ghaz

_____   _____
Dr. Rudolf Seracino   Dr. Thomas Birkland

_____
Dr. Mervyn Kowalsky
Chair of Advisory Committee

DEDICATION

To my parents. To God.

BIOGRAPHY

The author was born in land far away where the earth rocks like a hammock. That land name is El Salvador. . . .

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Bridges are designed based on discrete events with minimal consideration of interactions between hazards/loading, material aging (or more accurately condition) and bridge performance. The purpose of the research described is to study Time Dependent Performance Based Design that considers the effects of cumulative damage on the properties of the materials both as a function of time and current condition. Specific items of interest include corrosion, strain aging, low cycle fatigue and strength aging. In addition, since there is a high likelihood for a structure in a high seismic region to be subjected to more than one main shock throughout its life, it is deemed important to consider the effects of multiple earthquakes. As a consequence, the effects of repairs on the structural response are also of great importance. An analytical procedure is implemented such that it considers the effect of aging on structures, more specifically this study starts by evaluating an RC bridge Column. A series of condition dependent nonlinear time history analysis are performed assuming that a series of earthquakes occurs throughout the lifetime of the structure while at the same time changing the properties of the structure as time progresses. To achieve this a library of time dependent materials are developed. At the end of each series the main variables of study are the the limit state that was reached, the controlling mode of response (flexural or shear controlled), Equivalent Viscous Damping and the accumulated deformations. The series of earthquake proposed consists of (1) equally spaced main shocks only, (2) main shock-aftershocks series and (3) main shock-aftershock-repair series. At the end of the presentation recommendations on design of new structures and assessment of existing structures will be provided.

1.1 Properties that change with time

- Corrosion

- Strain Aging

- Concrete Strength

- Creep

- Low-cycle Fatigue

- Repairs

Chapter 2

LITERATURE REVIEW

In Chapter 1 we did some typesetting and equations; now let's look at tables, figures, and matrices.

2.1 Cumulative Damage

Cumulative Damage in structures have been tried to be established for structures to identify the state of a structure

The best-known and most widely used of all the cumulative damage index is that of Park and Ang (1985). This consists of a simple linear combination of normalized deformation and energy absorption:

The first term here is a simple, pseudo-static displacement measure. It takes no account of cumulative damage, which is accounted for solely by the energy term. The advantages of this model are its simplicity, and the fact that it has been calibrated against a significant amount of observed seismic damage, included some instances of shear and bond failures. Park, Ang and Wen (1985) suggested D = 0.4 as a threshold value between repairable and irreparable damage, while the same authors in 1987 suggested the following more detailed classification:

2.2 Corrosion

One of the main phenomenon that affect the long term behavior of structures is corrosion of the reinforcing steel. Two types of corrosion are possible in reinforced concrete:

- Carbonation

- Chloride attack

The main source of corrosion in most RC structures is Chloride Attack and is the one that is assumed in the present study.

Corrosion of steel in concrete is an electrochemical process [MM14] this corrosion mat be generated in two ways:

- Composition cells may be formed when to dissimilar metals are embedded in concrete or when significant variations exist in the surface characteristics of steel

- In the vicinity of steel concentration cells may be formed due to differences in the concentration of dissolved ions, such as alkalies and **chlorides**.

The corrosion process under chloride attack type of corrosion consists in first the protective film on the reinforcing steel surface is destroyed, a process known as **depassivation**, then the electrical resistivity and the oxygen content control corrosion.

A literature review to characterize corrosion in reinforcing steel is presented such that corrosion can be modeled as a function of time, the corrosion process is an extensive field of research and to characterize it the literature review on this subject is categorized as follows:

1. Time to Initiation of Corrosion (Tcorr)

2. Corrosion growth in reinforcing steel

3. Mechanical Properties of Corroded Reinforcing Steel (fycorr, fucorr)

4. Cyclic Test on Columns

5. Flowchart of Corrosion Model Implemented

2.2.1 Time to Corrosion

Time to corrosion refers to the corrosion initiation at which the passivation of steel is destroyed and reinforcement starts corroding actively.

Christensen Model

Christensen [TC] main goal was to generate a corrosion model that was general for all concrete elements, additionally the authors tried to generate a model that also included the appearance of cracks due to corrosion that would evetually grow and the spall the concrete.

More specifically related to reinforcing steel corrosion they developed a model based on Fick's law of diffusion to model the rate of chloride penetration into concrete as a function of concrete cover and time.

$$\frac{\partial C(x,t)}{\partial t} = D_c \frac{\partial C(x,t)}{\partial x^2} \tag{2.1}$$

After solving equation 2.1 the following expression results:

$$T_{corr} = \frac{d^2}{4D_c}\left[erf^{-1}\left(\frac{C_{cr} - C_0}{C_1 - C_0}\right)\right] \tag{2.2}$$

d: Concrete cover

D_0: Diffusion coefficient

C_0: Equilibrium Chloride Concentration

C_{cr}: Critical chloride corrosion concentration

While this model provides a means to calculate the Time for initiation of corrosion as a function of Concrete Cover and Diffusion concentration, the estimation of the Diffusion concentration depends on several factors such as environment, curing and water to cement ratio it is not a reliable method to estimate the Time to Corrosion.

Gosh & Padgett Model

Ghosh et al calculate time to corrosion based on Thoft-Christensen model, considering infield corrosion related studies of existing bridge components in the United States exposed to deicing salts to obtain mean values of chlorides concentration and put them in a modified version of the Thoft-Christensen Model.

$$T_{corr} = \frac{x^2}{4D_c}\left[erf^{-1}\left(\frac{C_0 - C_c r}{C_0}\right)\right]^{-2} \tag{2.3}$$

D_c 1.29 $frac cm^2 year$ Diffusion Coefficient

C_0 0.10 Surface Chloride Concentration

C_r 0.04 Critical Chloride Concentration

While this model provides mean values for the time of initiation of corrosion, it is limited to environments that are controlled by **dicing salts only**.

Life 365

Is a software developed by a consortium of companies of the cementitious materials industries and academic institutions. This software relies on the studies summarized above, mainly using the Thoft-Christensen model, but as opposed to assuming dicing environments only, this software uses a database of chlorides concentration for different location in the USA and Canada, which gives more accurate results depending on the location and environment in which the structure is located.

While this is a more robust model to obtain the initiation of corrosion since it considers the location and environment of the structure and it also has the ability to include other durability issues, it is difficult to implement in a batch run format since the program is in a closed format.

Liu & Weyers Model

$$T_{cr} = \frac{W_{crit}^2}{2k_p} \tag{2.4}$$

$$W_{crit} = \rho_{rust} \left[\pi \left[\frac{C f_t'}{E_{ef}} \left(\frac{a^2 + b^2}{a^2 - b^2} + \nu_c \right) + d_o \right] D + \frac{W_{st}}{\rho_{st}} \right] \tag{2.5}$$

$$k_p = 0.098(\frac{1}{\alpha})\pi D i_{corr} \tag{2.6}$$

W_{crit}: Critical amount of corrosion needed to induce cracking.
W_{st}: Mass of corroded steel.
ρ_{rust}: Density of rust material.
ρ_{st}: Density of steel.
f_t': Tensile strength of the concrete.
E_{ef}: Effective elastic modulus of concrete $E_{ef} = \frac{E_c}{1+\phi_{crit}}$
ϕ_{crit} Creep coefficient of the concrete.
D: Diameter of bar.
d_o: Thickness of pore band around the steel/concrete interface.
ν_c: Poisson's ratio of concrete.
C: Cover depth
$a = \frac{D+2d_o}{2}$

$$b = C + \frac{D + 2d_o}{2}$$

2.2.2 Rate of corrosion

Vu et al. Model

To estimate the loss of steel cross section due to corrosion a time dependent corrosion rate model was developed by [VS00], this model implies that corrosion diminishes with time since as corrosion accumulates with time around the steel, it precludes uncorroded steel to react with the environment. The model is shown in Eq. 2.5.

$$i_{corr} = \frac{37.5(1 - w/c)}{d_c} \tag{2.7}$$

w/c: Water Cement ratio d_c: Cover depth

In Fig. 2.1 the behavior of this model for different values of w/c ratios is shown. It can be seen that at larger values of cover depth the rate of corrosion decreases rapidly and as the water cement ratio increases the rate of corrosion decreases.
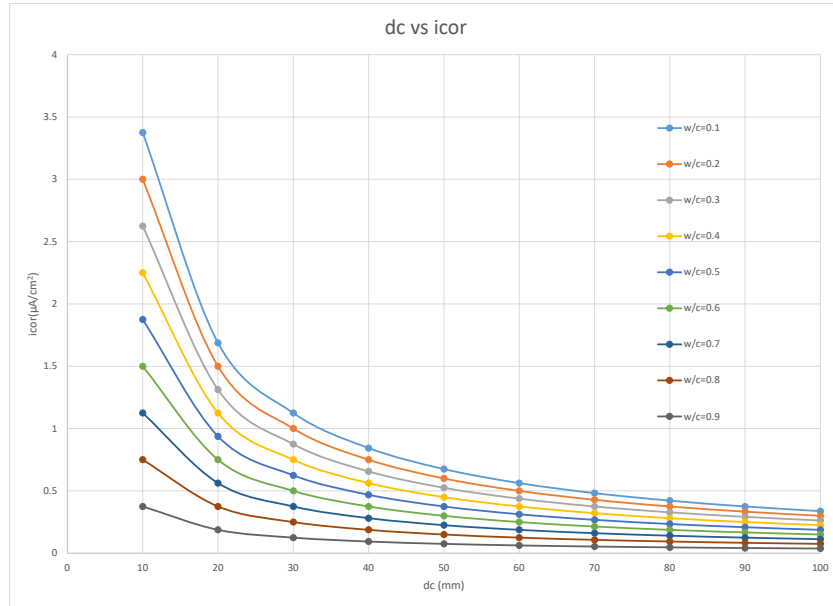

Figure 2.1 Concrete cover depth vs rate of corrosion

From the Vu et al model the diamater degradation is calculated according to Choe et al as:

$$d_{corr} = d_{bi} - \frac{1.0508(1 - w/c)}{d_c}(t - t_{corr})^{0.71} \qquad (2.8)$$

d_{bi}: Is the initial diameter of the bar

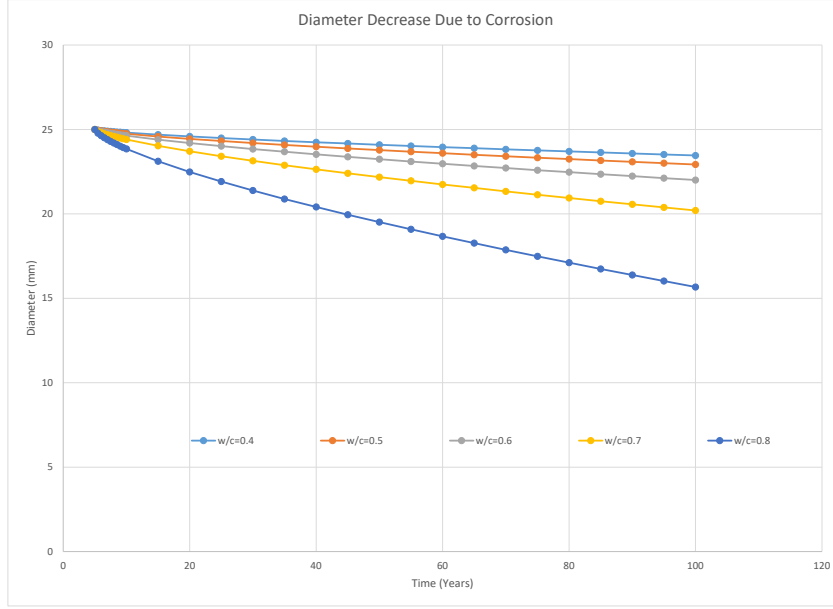The diameter is plotted in Fig. 2.2.

Figure 2.2 Diameter decrease due to corrosion

These values would correspond to a level of corrosion that varies from 7% corrosion to 21% of corrosion for w/c ratios that ranges from 0.4 to 0.6 The level of corrosion is calculated as:

$$C = \frac{G_o - G}{g_o l_o} * 100 \qquad (2.9)$$

Then the Corrosion level is plotted as a function of time in Fig. 2.3

2.2.3   Corrosion modified properties of reinforcing steel bars

In a study presented by Yuan et al [Yua17] it was shown from experimental results that the mechanical properties of steel for different levels of corrosion could be modified for analysis as
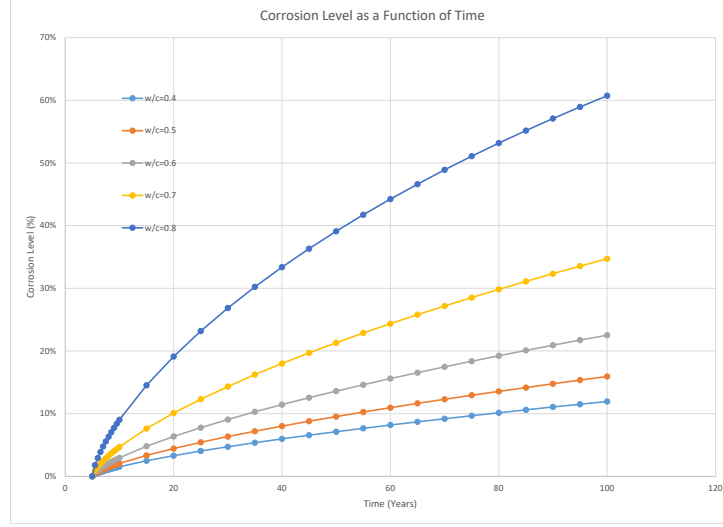
Figure 2.3 Corrosion Level vs Time (years)

follows:

$$f_{y,C} = f_{yo}(1 - 0.021C) \tag{2.10}$$

$$f_{u,C} = f_{yo}(1.018 - 0.019C)$$

$$\delta_{s,C} = \delta_{so}(1 - 0.021C)$$

$$\varepsilon_{y,C} = \varepsilon_{yo}(1 - 0.021C)$$

Choe et al. Model   Choe et al research is a seismic fragility estimates for RC columns subjected to corrosion, while the study is probabilistic in nature it defines the reduction in rebar cross section as:

$$d_b(t) = d_{bi} - 2 \int_{T_{corr}}^{t} \lambda(t)dt \tag{2.11}$$

Considering the model proposed by Vu et al the bar diameter degradation can be expressed as:

9

$$d_b(t) = d_{bi} - \frac{1.508(1 - \frac{w}{c})^-1.64}{d}(t - T_{corr})^0.71 \tag{2.12}$$

Where the diameter of the bar and the cover is in (mm). Pros: Easy way to calculate the reduction of bar diameter. Cons: The model carries out the assumptions made by Vu et al. concerning concentration of chlorides assumed and the diffusion assumed.

With this information, the corrosion level is calculated as:

$$CL = \frac{d_i - d(t)}{d_i} \tag{2.13}$$

2.2.4   Corrosion modified properties of reinforcing steel bars

Yuan et al. 2017   Yuan et al performed full-scale tests on columns with corroded longitudinal reinforcement, with which they proposed the following equation to characterize the effects of corrosion in reinforcing steel.

$$f_y(t) = f_{y0}(1 + 0.021CL) \tag{2.14}$$

While the equation showed, agreement with the test results that they performed it has not been corroborated by other researchers. In the current consensus, the model used is the one proposed by Du et al.

Du et al. 2005

Du et al investigated the effect of corrosion on the mechanical properties of steel using corrosion levels of 5

$$f_y(t) = f_{y0}(1 + 0.021CL) \tag{2.15}$$

2.3   Steel Strain Aging

2.3.1   Metallurgical Process

It is generally accepted that strain aging is due to the diffusion of carbon and/or nitrogen atoms in solution to dislocations that have been generated by plastic deformation. Initially, an atmosphere of carbon and nitrogen atoms is formed along the length of a dislocation, immobilizing it. Extended aging, however, results in sufficient carbon and nitrogen atoms for precipitates to form along the length of the dislocation.

These precipitates impede the motion of subsequent dislocations, and result in some hardening and loss in ductility. The extent of strain aging, which is a thermally activated process, depends primarily on aging time and temperature. In general, extended aging results in a saturation value above which further aging has no effect.

A second strengthening mechanism occurs when cold deformation (alone) is applied to steels. When dislocations break away for their pinning interstitial atoms and begin the movement causing slip they begin to intersect with each other. A complex series of interactions between the dislocations occurs, causing them to pin each other, decreasing their mobility. The decreased mobility also results in higher strength, lower ductility and lower toughness. As a result, cold deformed steels already have lowered ductility and toughness before any strain aging occurs and when heating follows cold deformation, the loss in ductility and toughness is greater. It is this combination of events that is the most damaging to the toughness of structural steels.

2.3.2   Strain aging effects in structures

Since it has already been established that strain aging is the process in which steel after being subjected to large strains develops an increased strength and reduced ductility with time and therefore important to include it in a time dependent analysis, considering the fact that plastic hinges will form in a ductile structure and the steel could reach high strains in this regions of the structure. Furthermore strain aging will cause an increased in the strength of the plastic hinge and as a consequence plastic hinges might be formed in regions of the structures that have not been designed for such demands. The effects of strain aging may also alter the transverse reinforcement due to both cold bending, making them susceptible to brittle failure.

According to [RP94] most strain aging occurs in the first 37 days. Also [Mom09] studied strain aging effects with respect to time for different levels of pre-strains that ranged from $2\varepsilon_y - 10\varepsilon_y$ and for a time frame of 3 days to 50 days, from this study it was determined that a significant effect of strain aging took place from pre-strains $5\varepsilon_y$ and on. Strains higher than $15\varepsilon_y$ indicate a performance level in which substantial damage has been induced in the structure such that it is deemed unrepairable and therefore pre-strains higher that $15\varepsilon_y$ are unpractical and not studied by Montahan et al[Mom09].

Momtahan et al Strain Aging Effects in Yield Strength of Steel

Momtahan et al was able to correlate the increase in yield strength as a function of time and the pre-strain in reinforcing steel bars. The proposed equations are shown below:
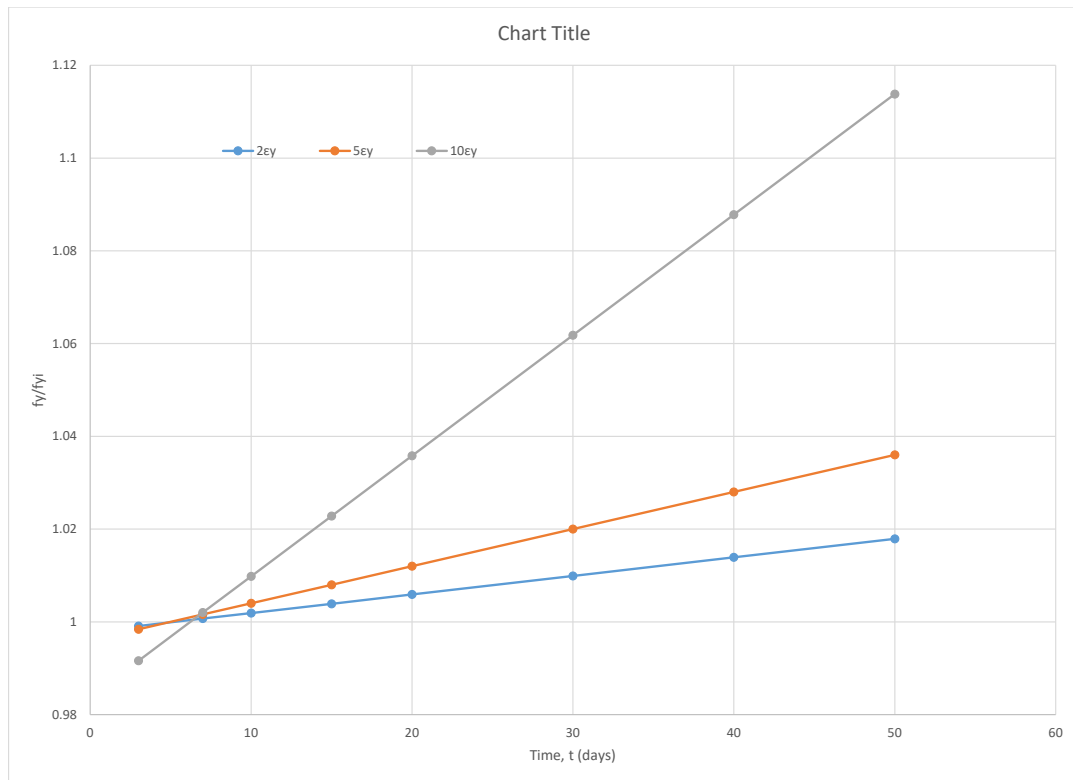
For $10\varepsilon_y$

Figure 2.4 Strain Aging effect on Yield Strength vs Time (days)

$$\frac{f_y}{f_{yi}} = 0.0026t + 0.9838 \tag{2.16}$$

For $5\varepsilon_y$

$$\frac{f_y}{f_{yi}} = 0.0008t + 0.996 \tag{2.17}$$

For $2\varepsilon_y$

$$\frac{f_y}{f_{yi}} = 0.0004t + 0.9979 \tag{2.18}$$

It is proposed to limit the increase in yield strength to the one obtained at 50 days. These equations are plotted in Fig. 2.4

2.4 Concrete Strength

2.5 Welding and Fatigue in Steel Structures

2.6 Repair Effects

2.7 Multiple Seismic Events

2.7.1 Main Shock Series

2.7.2 Main Shock - After Shock Series

2.7.3 Main Shock - After Shock Series - Repair Series

BIBLIOGRAPHY

[MM14]   Mehta, P. K. & Monteiro, P. J. M. *Concrete: Microstructure, Properties, and Materials*. 4th ed. McGraw Hill, 2014.

[Mom09]   Momtahan, A. et al. "Effects of strain-ageing on New Zealand reinforcing steel bars". *Bulletin of the New Zealand Society for Earthquake Engineering* **42**.3 (2009), pp. 179–186.

[RP94]   Restrepo-Posada, J. et al. "VARIABLES AFFECTING CYCLIC BEHAVIOR OF REINFORCING STEEL". *Journal of Structural Engineering* **120**.11 (1994), p. 31783196.

[TC]   Thoft-Christensen, P. "Corrosion and Cracking of Reinforced Concrete" ().

[VS00]   Vu, K. A. T. & Stewart, M. G. "Structural reliability of concrete bridges including improved chloride-induced corrosion models". *Structural Safety* **22**.4 (2000), pp. 313–333.

[Yua17]   Yuan, Z. et al. "Cyclic Behavior of Corroded Reinforced Concrete Bridge Piers". *Journal of Bridge Engineering* **22**.7 (2017).

APPENDIX

Appendix A

LOREM IPSUM

A.1   A First Section

A.1.0.0.1   Filler Text

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, plac-

erat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Donec odio elit, dictum in, hendrerit sit amet, egestas sed, leo. Praesent feugiat sapien aliquet odio. Integer vitae justo. Aliquam vestibulum fringilla lorem. Sed neque lectus, consectetuer at,
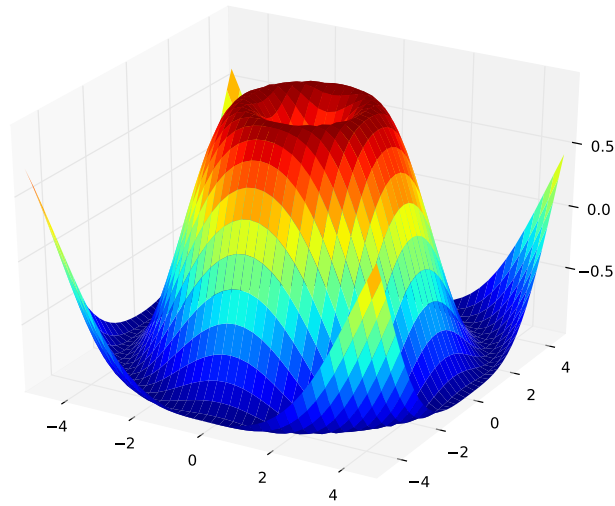
Figure A.1 A figure in the appendix.

consectetuer sed, eleifend ac, lectus. Nulla facilisi. Pellentesque eget lectus. Proin eu metus. Sed porttitor. In hac habitasse platea dictumst. Suspendisse eu lectus. Ut mi mi, lacinia sit amet, placerat et, mollis vitae, dui. Sed ante tellus, tristique ut, iaculis eu, malesuada ac, dui. Mauris nibh leo, facilisis non, adipiscing quis, ultrices a, dui.

Morbi luctus, wisi viverra faucibus pretium, nibh est placerat odio, nec commodo wisi enim eget quam. Quisque libero justo, consectetuer a, feugiat vitae, porttitor eu, libero. Suspendisse sed mauris vitae elit sollicitudin malesuada. Maecenas ultricies eros sit amet ante. Ut venenatis velit. Maecenas sed mi eget dui varius euismod. Phasellus aliquet volutpat odio. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Pellentesque sit amet pede ac sem eleifend consectetuer. Nullam elementum, urna vel imperdiet sodales, elit ipsum pharetra ligula, ac pretium ante justo a nulla. Curabitur tristique arcu eu metus. Vestibulum lectus. Proin mauris. Proin eu nunc eu urna hendrerit faucibus. Aliquam auctor, pede consequat laoreet varius, eros tellus scelerisque quam, pellentesque hendrerit ipsum dolor sed augue. Nulla nec lacus.

Suspendisse vitae elit. Aliquam arcu neque, ornare in, ullamcorper quis, commodo eu, libero. Fusce sagittis erat at erat tristique mollis. Maecenas sapien libero, molestie et, lobortis in, sodales eget, dui. Morbi ultrices rutrum lorem. Nam elementum ullamcorper leo. Morbi dui. Aliquam sagittis. Nunc placerat. Pellentesque tristique sodales est. Maecenas imperdiet lacinia velit. Cras non urna. Morbi eros pede, suscipit ac, varius vel, egestas non, eros. Praesent male-

Table A.1 A table in the appendix.

System	Author
TEX	Donald Knuth
LATEX	Leslie Lamport

suada, diam id pretium elementum, eros sem dictum tortor, vel consectetuer odio sem sed wisi.

A.2 A Second Section

Etiam ac leo a risus tristique nonummy. Donec dignissim tincidunt nulla. Vestibulum rhoncus molestie odio. Sed lobortis, justo et pretium lobortis, mauris turpis condimentum augue, nec ultricies nibh arcu pretium enim. Nunc purus neque, placerat id, imperdiet sed, pellentesque nec, nisl. Vestibulum imperdiet neque non sem accumsan laoreet. In hac habitasse platea dictumst. Etiam condimentum facilisis libero. Suspendisse in elit quis nisl aliquam dapibus. Pellentesque auctor sapien. Sed egestas sapien nec lectus. Pellentesque vel dui vel neque bibendum viverra. Aliquam porttitor nisl nec pede. Proin mattis libero vel turpis. Donec rutrum mauris et libero. Proin euismod porta felis. Nam lobortis, metus quis elementum commodo, nunc lectus elementum mauris, eget vulputate ligula tellus eu neque. Vivamus eu dolor.

Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla. Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.