

# **ESTIMATION OF FATIGUE LIFE OF STEEL MASTS USING FINITE ELEMENT MODELLING**

K.K.G.K. Danushka



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

**Bachelor of Science of Engineering (Honours)**

Department of Civil Engineering

University of Moratuwa

Moratuwa

Sri Lanka

May, 2015

# ESTIMATION OF FATIGUE LIFE OF STEEL MASTS USING FINITE ELEMENT MODELLING

K.K.G.K. Danushka

The Research Thesis was submitted in partial fulfilment of the requirements for the  
Degree of Bachelor of Science of Engineering

Supervised by: Dr. H.M.Y.C. Mallikarachchi



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)



Department of Civil Engineering

University of Moratuwa

Moratuwa

Sri Lanka

May, 2015

## DECLARATION

“I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, we hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute our thesis, in whole or in part in print electronic or other medium. We retain the right to use this content in whole or part in future works (such as articles or books)

.....

Date: May 10, 2015

K.K.G.K. Danushka

“The undersigned hereby certified that they have read and recommended the thesis for the acceptance in partial fulfilment of the requirements for the Degree of Bachelor of Science of Engineering”



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

.....

Date: May 10, 2015

Dr. H.M.Y.C. Mallikarachchi

# ABSTRACT

## **Estimation of Fatigue Life of Steel Masts using Finite Element Modelling**

Fatigue is an important design consideration for tall steel structures. Accurate prediction of fatigue endurance is essential to design the elements subjected to wind and earthquake induced fatigue. The design guidelines given in codes of practices are applicable only to simple shapes and laboratory experimental verification is costly. Therefore, simulation using finite element software is becoming popular.

An attempt is made to couple Abaqus finite element analysis software and fe-safe software to estimate the fatigue life of a structure. First, the accuracy of the techniques and idealizations used in simulation are validated by simulating experiments available in the literature. Standard Uni-Axial fatigue experiments which were conducted at several strain amplitudes showed a closer relationship to simulation results. Moreover sensitivity of fatigue life to surface finish and stress strain dataset importing method in fe-safe software were evaluated. It was found that the surface finish is a highly sensitive parameter and it should be estimated accurately. Elastic plastic block method gave good results while elastic block method with neuter's rule results were poor. This indicates the importance of using elastic plastic block method for low cycle fatigue especially when stress redistribution is high. Simulation result of multi-axial fatigue experiment showed similar results to results obtained from physical experiments.

The verified technique was the applied to estimate the fatigue life of a 64 m tall steel mast with an opening located at the top of a 285 m tall concrete tower. The sensitivity of the plate thickness and shape of the opening of the mast were studied. It was found that small increase in plate thickness rapidly increases the fatigue endurance. This shows the importance of using stiffeners in fatigue prone areas. Comparison of the shape of the opening showed that square shape would have higher endurance than a circular shape of same opening area. However only monolithic sections were studied here and effects on welds and bolted connections are beyond the scope of this research.

### **Key Words:**

Fatigue simulation, Abaqus, fe-safe, mast with an opening

## DEDICATION

I dedicate my thesis to my family, friends and teachers. First of all a special feeling of gratitude to my loving parents, Upali Kariyawasm and Swarnalatha Kariyawasam whose good examples have taught me to work hard for the things that I aspire to achieve . My brother Ruchira and sister Ushara were always by my side and they are very special.

I want to dedicate this also to all my friends at the university who encouraged me and made my life at the university an interesting experience with a lot of memories.

Last but not least I dedicate this work to all the teachers who helped me build up my academic life and moral values. I was really lucky to have such supportive teachers and lecturers throughout my academic life. Their encouragements and supports meant a lot for everything I have achieved.



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

## ACKNOWLEDGEMENT

The research project (CE 4942) was conducted under the curriculum of civil engineering and financially supported by University of Moratuwa. I want to thank the department of Civil Engineering and University of Moratuwa for giving this opportunity to initiate my first research work.

I was really lucky to have Dr. Chinthanka Mallikarachchi as my research supervisor. He is an ardent researcher and his expertise in high end research at Caltec and Cambridge University have helped him to be a good supervisor. His encouragements and supports were the best motivation I had to do a successful research. With his help, I could publish a paper with my research findings at an international symposium. I want to thank him for all of the supports throughout the research project.

National Research Council of Sri Lanka funded us to buy required software and a workstation which cost millions of rupees. I want to thank them for the funding which meant a lot.

The lecturers of department of Civil Engineering taught us all civil engineering subject matter well. Those were very useful while doing this research. I want to thank them for all of the subject matter they taught and all other supports and encouragements.

Research project was one of the most interesting works that I did and I found the passion of mine in doing research after doing my first research work. I want to thank everyone who helped in any way possible to make this a success.



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
www.lib.mrt.ac.lk

# TABLE OF CONTENTS

DECLARATION .....	i
ABSTRACT .....	ii
DEDICATION .....	iii
ACKNOWLEDGEMENT .....	iv
TABLE OF CONTENTS.....	v
LIST OF FIGURES .....	vii
LIST OF TABLES .....	viii
LIST OF ABBREVIATIONS .....	ix
LIST OF SYMBOLS .....	x
1 Introduction .....	1
1.1 Objectives .....	2
1.1.1 Overall Objective .....	2
1.1.2 Specific Objectives.....	2
1.2 Methodology.....	3
1.2.1 Methodology flowchart.....	3
1.2.2 Description of methodology.....	4
2 Literature Review.....	5
2.1 Introduction.....	5
2.2 Phases of fatigue life.....	5
2.3 Fatigue induce loading on tall structures .....	6
2.3.1 Wind induce loading .....	6
2.3.2 Earthquake induce loading .....	6
2.4 Endurance curves (S-N curve).....	7
2.4.1 Generalised Fatigue data .....	7
2.5 Uniaxial strain life fatigue analysis.....	10
2.5.1 True stress and strain.....	10
2.5.2 Low cycle fatigue and high cycle fatigue.....	11
2.6 Multi-axial fatigue .....	13
2.6.1 Introduction .....	13
2.6.2 Brown miller combined strain criterion.....	13
2.7 Codes of practices .....	14
3 Finite element modelling .....	15
3.1 Abaqus FEA.....	15
3.1.1 Introduction .....	15
3.1.2 Material properties .....	15

3.1.3	Boundary condition and loading .....	17
3.2	FE-safe .....	18
4	Software Verification .....	19
4.1	Simulation of uniaxial fatigue .....	19
4.1.1	Material Properties .....	20
4.1.2	Material model .....	20
4.1.3	Modelling with ABAQUS .....	20
4.1.4	Fatigue analysis using FE-safe .....	22
4.1.5	Results and Discussion .....	22
4.2	Simulation of multi-axial fatigue .....	24
4.2.1	Modelling with ABAQUS .....	25
4.2.2	Fatigue analysis using FE-safe .....	27
4.2.3	Comparison of Results .....	27
5	Case study.....	28
5.1	Introduction.....	28
5.2	Dimensions and properties.....	29
5.3	Finite element modelling .....	30
5.3.1	Loading and boundary conditions .....	30
5.3.2	Mesh.....	31
5.4	Fatigue analysis.....	31
5.5	Results and Discussion.....	32
6	Conclusion.....	35
7	Recommendations for Future Reseach .....	36
	REFERENCES .....	37
	APPENDIX .....	I
	APPENDIX 1: Surface roughness values for different materials .....	I
	APPENDIX 2: Wind Load calculation for the mast .....	II
	APPENDIX 3: Fatigue design methodology used in AS4100:1990 .....	IV



University of Moratuwa, Sri Lanka  
 Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)



# LIST OF FIGURES

Figure 2.1: Phases of fatigue life.....	5
Figure 2.2: An example S-N curve.....	7
Figure 2.3: SN curves for notched and smooth specimen .....	8
Figure 2.4: Local stress distribution and nominal stress of a component.....	8
Figure 2.5: SN curves for different load ratios.....	9
Figure 2.6: Cyclic hardening .....	11
Figure 2.7: Cyclic softening .....	11
Figure 2.8: Stabilized cyclic response .....	11
Figure 2.9: Strain life Relationship .....	12
Figure 2.10: Hysteresis loop.....	12
Figure 3.1: cyclic softening (left) and cyclic hardening (right) for a constant amplitude cyclic strain	16
Figure 4.1: Specimen dimensions .....	19
Figure 4.2: Test apparatus .....	19
Figure 4.3: Idealized boundary condition in Abaqus .....	21
Figure 4.4: Abaqus simulation of 1.77% strain amplitude .....	21
Figure 4.5: Principle stress strain response of an element in the central region .....	21
Figure 4.6: Comparison of S-N curves of simulation and experimental results.....	23
Figure 4.7: Fatigue testing machine (a) and testing bar (b).....	25
Figure 4.8: Analytical rigid shell for bolthole .....	25
Figure 4.9: Mesh of the crane bar.....	25
Figure 4.10: Loading and boundary conditions .....	26
Figure 4.11: Applied cyclic loading .....	26
Figure 4.12: Stress variation of a node, just below the bolt hole.....	26
Figure 4.13: Misses stress distribution at the highest loading level.....	26
Figure 5.1: Proposed shape of the Steel tower .....	28
Figure 5.2: Dimensions and the shape of the steel mast.....	29
Figure 5.3: Loading on the mast FE model .....	30
Figure 5.4: Finite element mesh of the mast .....	31
Figure 5.5: Stress distribution around the circular opening.....	32
Figure 5.6: Stress distribution around the square opening .....	32
Figure 5.7: Distribution of number of reversals to failure around the circular opening .....	33
Figure 5.8: Distribution of number of reversals to failure around the square opening.....	33

## LIST OF TABLES

Table 4.1: Material properties of stainless steel 316LN test specimens .....	20
Table 4.2: Comparison of fatigue life results .....	22
Table 4.3: Material properties of S1100Q test specimens .....	24
Table 4.4: Results of the simulation and experiments .....	27
Table 5.1: Material properties .....	30
Table 5.2: Minimum number of reversals to failure for combinations considered .....	33



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

# LIST OF ABBREVIATIONS

## **Abbreviation    Description**

FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Modelling
ULCF	Ultra Low Cycle Fatigue
CAE	computer-aided engineering
C3D8R	8-node linear brick solid elements
3D	3 Dimensional
2D	2 Dimensional
S8R	Eight-node doubly curved thick shell elements



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

## LIST OF SYMBOLS

Symbol	Description	Units
$E$	The elastic modulus	Pa
$b$	The fatigue strength exponent	
$c$	Fatigue ductility exponent	
$F_{\max}$	Maximum force	kN
$F_{\min}$	Minimum force	kN
$F_m$	Detailed category	
$K$	The strain hardening coefficient	
$K'$	The cyclic strain hardening coefficient	
$K_t$	Elastic stress concentration factor	
$n$	The strain hardening exponent	
$n'$	The cyclic strain hardening exponent	
$N_f$	Number of cycles to failure	
$N_i$	cycles required to cause failure under the same amplitude	
$n_i$	the number of stress cycles of the considered amplitude	
$N_{in}$	Number of cycles to crack initiation	
$N_p$	Number of cycles to crack propagation	
$P_{\max}$	Maximum load induced	
$P_{\min}$	Minimum load induced	
$R$	Load ratio	
$R$	Radius	mm
$R_a$	Surface roughness	$\mu\text{m}$
$\Delta\gamma_{\max}$	Maximum shear strain range	
$\Delta\varepsilon$	Applied strain range	
$\Delta\varepsilon_n$	Range of strain normal to the maximum shear strain	
$\Delta\varepsilon_p$	Plastic strain range	
$\varepsilon'_f$	Fatigue ductility coefficient	
$\varepsilon$	Total stress	Pa
$\sigma'_f$	The fatigue strength coefficient	
$\sigma_m$	Mean stress	Pa



University of Moratuwa, Sri Lanka.  
 Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)