

LB/DON/73/00

①

# DEVELOPMENT AND EVALUATION OF THE AESTHETICS OF STRUCTURAL FORM

මොරටුව විශ්ව විද්‍යාලය, ශ්‍රී ලංකාව  
සමාජ සේවකයාණන් විද්‍යාලය

By

**Chandana Kulasuriya**  
BSc.(Hons.)-Civil Eng., CEng.-Civil Eng.  
BA -Fine Arts & Philosophy with Social Stat.



72464  
200106  
200106



Supervised By

**Prof. W.P.S. Dias**  
&  
**Dr. (Mrs.) M.T.P. Hettiarchchi**

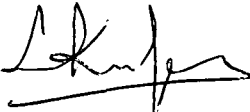
Th

A Dissertation submitted in partial fulfillment for the award of the Master of Engineering Degree in Structural Engineering Design of the University of Moratuwa, Sri Lanka.

72464

## DECLARATION

*This dissertation has not been previously presented in whole or part to any University or Institution for a Higher Degree.*

Signature of the Candidate :   
Name of the Candidate : CHANDANA KULASURIYA  
Date : 20.11.2000



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

## PREFACE

The Master of Engineering Degree in Structural Engineering Design at the University of Moratuwa, Sri Lanka, consists of three major components – Examinations preceded by Lectures, Courseworks and a Research Project. On completion of the Research Project, a Dissertation has to be submitted by the candidate.

As a candidate for the above Masters' Degree, I have carried out a research study on Structural Engineering relating to Aesthetics. This Dissertation is the outcome of my research study.

**Chandana Kulasuriya**

410, Nawala Road  
Rajagiriya  
Sri Lanka.



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

October 2000

## ACKNOWLEDGEMENTS

First of all I wish to thank the University of Moratuwa, Sri Lanka, for providing me the opportunity to read for the Master of Engineering Degree in Structural Engineering Design.

Secondly, I wish to express my gratitude and indebtedness to my Supervisors, **Prof. W.P.S. Dias** and **Dr. (Mrs.) M.T.P. Hettiarachchi**, Senior Lecturers in Structural Engineering at the University of Moratuwa, for their scholarly guidance. Without Prof. Dias' inspiration, I would not have embarked on a research study on Structural Engineering relating to Aesthetics. Dr. (Mrs.) Hettiarachchi unhesitatingly provided me the support and encouragement that was needed to complete my research project as envisaged.

Next, my thanks also go to **Mr. V.S. Nammuni**, Senior Lecturer in Architecture, at the University of Moratuwa, for his comments, suggestions and constructive criticisms.

I am deeply indebted to **Prof. A.P.K. De Zoysa**, Senior Lecturer in Philosophy of Science, at the Open University of Sri Lanka for his interpretations of philosophical concepts which helped me in analysing the philosophical models of aesthetics.

Next, my sincere thanks go to **Mr. C. Thenuwara**, Senior Lecturer in Fine Arts, at the University of Kelaniya, for his invaluable reflections about aesthetics.

I take this opportunity to express my gratitude to **Dr. B. Weerasinghe**, the Director, Educational Technology Division, and **Dr. (Mrs.) W.A.R. Wijeratne**, Senior Lecturer in Education/Psychology at the Open University of Sri Lanka. Their ideas on psychology were very useful in conducting the psychological experiments (perceptual experiments), the results of which were used to analyse psychological reactions to structures.

A word of thanks is also due to all the respondents who participated in the perceptual experiments.

Finally, I would like to thank my parents, brother, colleagues, and friends for the encouragement, support and for their forbearance – all of which facilitated my Research Study.

## ABSTRACT

This study demonstrates that the aesthetic concepts of engineering design do not just arise; but that they are derived from various models of aesthetics. It also presents various Proportioning Systems and their application in Structures, through case studies, notably the use of the Golden Proportion.

The research includes two perceptual experiments. The first experiment was about the perception of rectangular shapes using one hundred respondents. The second experiment was about the perception of simple structures using fifty respondents. The results of these perceptual experiments confirm the fact that respondents' preferences are linked with the various philosophical models.

The research also deals with optimisation of simple structures. Optimisation curves are obtained by varying the dimensions (or proportions) of the structure concerned.

Finally, the dissertation also describes the possibility of making initial design decisions relating to dimensions (or proportions), using plots of optimisation and plots of aesthetic preferences.

# CONTENTS

	Page
<i>PREFACE</i>	i
<i>ACKNOWLEDGEMENTS</i>	ii
<i>ABSTRACT</i>	iii
<i>CONTENTS</i>	iv
<i>LIST OF FIGURES</i>	vii
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 General	2
1.2 Background of the Problem	2
1.3 Previous Studies	3
1.4 Intended Study	4
1.5 Objectives of the Study	5
1.6 Methodologies used in the Study	5
<b>2. AESTHETICS IN STRUCTURAL DESIGN</b>	<b>7</b>
2.1 General	8
2.2 Nature of Aesthetics	8
2.3 Models of Aesthetics	9
2.4 Paradigms of Aesthetic Beauty	10
2.5 Aesthetic Concepts in Structural Design	12
2.6 Aesthetic Beauty and Proportions	14
2.7 Proportioning Systems	16
2.8 Application of Proportioning Systems in Structures	25
2.9 Visual Perception of Proportions of Structures	28
<b>3. GOLDEN PROPORTION AND ITS APPLICATION IN STRUCTURES</b>	<b>30</b>
3.1 General	31
3.2 Golden Proportion	31
3.3 Golden Proportion in Geometric Shapes	32
3.4 Golden Rectangle and its Properties	33

3.5	Golden Spiral	34
3.6	Golden Proportion in nature	35
3.7	Application of Golden Proportion in Structures	38
<b>4.</b>	<b>EVALUATION OF AESTHETICS</b>	<b>45</b>
4.1	General	46
4.2	Perception of Proportions of Geometric Shapes	46
4.2.1	Methodology	47
	-Experiment 1 : Rectangles	47
4.3	Perception of Proportions of Structures	49
4.3.1	Methodology	50
	-Experiment 1 : Three –span Bridges	51
	-Experiment 2 : Parabolic Arched Bridges	53
	-Experiment 3 : Circular Arched Bridges	54
	-Experiment 4 : Parallel Chorded Trusses	56
<b>5.</b>	<b>OPTIMISATION OF SIMPLE STRUCTURES</b>	<b>61</b>
5.1	General	62
5.2	Optimisation	62
	-Structure 1 : Three Span Continuous Beam	62
	-Structure 2 : Two-pinned Parabolic Arch	65
	-Structure 3 : Two-pinned Circular Arch	67
	-Structure 4 : Parallel Chorded Trusse	69
<b>6.</b>	<b>DISCUSSION</b>	<b>74</b>
<b>7.</b>	<b>CONCLUSIONS</b>	<b>82</b>
<b>8.</b>	<b>SUGGESTIONS FOR FUTURE STUDY</b>	<b>87</b>
	<b>REFERENCES</b>	<b>90</b>

<b>APPENDICES</b>	<b>94</b>
Appendix 1 : Fundamental Mathematical Progressions	95
Appendix 2 : Nomenclature of Proportions using Musical Theory	97
Appendix 3 : Questionnaire 1: Perception of Proportions	100
Appendix 4 : Perception of Rectangles	101
Appendix 5 : Questionnaire 2: Perception of Structures	102
Appendix 6 : Perception of Three-span Bridges	103
Appendix 7 : Perception of Parabolic-arched Bridges	104
Appendix 8 : Perception of Circular-arched Bridges	105
Appendix 9 : Perception of Parallel-chorded Trusses	106
Appendix 10: Design Quality Assessment (DQA) Table	107
Appendix 11: Specimen Calculations –Three-span Beam	108
Appendix 12: Specimen Calculations – Parabolic Arch	110
Appendix 13: Specimen Calculations – Circular Arch	113
Appendix 14: Specimen Calculations – Parallel-chorded Truss	116



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





## LIST OF FIGURES

	Page
Fig. 1 - Aesthetic Concepts and their application in Structures . . . . .	13
Fig. 2 - Incommensurable ratios of simple geometric shapes . . . . .	15
Fig. 3 - Plato's two number series, laid out as a Lambda ( $\lambda$ ) . . . . .	18
Fig. 4 - The completed Platonic Lambda Series . . . . .	18
Fig. 5 - Platonic Means . . . . .	19
Fig. 6 - Derivation of Sacred Square Roots . . . . .	20
Fig. 7 - Albertie's Subtractive System of proportion . . . . .	22
Fig. 8 - Palladio's favoured proportions . . . . .	22
Fig. 9 - Le Modular Proportioning System . . . . .	24
Fig. 10 - Geometric Decomposition . . . . .	26
Fig. 11 - Villard Diagram and its Application in Bern Cathedral . . . . .	27
Fig. 12 - Application of the Golden Ratio in Linear Direction . . . . .	28
Fig. 13 - Notre - Dame façade . . . . .	29
Fig. 14 - Golden Proportion in Pentagon . . . . .	32
Fig. 15 - Golden Proportion in Pentagram . . . . .	32
Fig. 16 - Golden Rectangle . . . . .	33
Fig. 17 - Gradation of Squares and Golden Rectangles . . . . .	33
Fig. 18 - Golden Spiral . . . . .	34
Fig. 19 - Intersection of curve and radii . . . . .	34
Fig. 20 - Golden Proportions of the Human Body . . . . .	35
Fig. 21 - Golden Spiral in Nautilus Shell . . . . .	36
Fig. 22 - Golden Spiral in Nature . . . . .	37
Fig. 23 - Golden Proportions of Parthenon, Greece . . . . .	38
Fig. 24 - Golden Proportions of Cistercian Abbey, Fontenay . . . . .	39
Fig. 25 - Golden Proportions of Yakushiji Temple Pagoda, Japan . . . . .	40
Fig. 26 - Golden Proportions of Redheugh bridge . . . . .	40
Fig. 27 - Ting Kau Bridge . . . . .	41
Fig. 28 - Golden Proportions of the Ting Kau Bridge composition . . . . .	41
Fig. 29 - Twin-towered Vasco da Gama bridges . . . . .	42
Fig. 30 - Golden Proportions of the Pylon of the Vasco da Gama Bridge . . . . .	42

Fig. 31 - Tsing Ma Suspension Bridge	43
Fig. 32 - Proportions of the Tsing Ma Towers	44
Fig. 33 - The Golden Proportioned double-deck section of the Tsing Ma Bridge	44
Fig. 34 - Preferences when shorter dimension is vertical	48
Fig. 35 - Preferences when shorter dimension is horizontal	48
Fig. 36 - Sample drawing of a Three-span Bridge	51
Fig. 37 - Respondents' Preferences for the Three-span Bridge	52
Fig. 38 - Sample drawing of the Parabolic-Arched Bridge	53
Fig. 39 - Respondents' Preferences for the Parabolic Arched Bridge	54
Fig. 40 - Sample drawing of the Circular-Arched Bridge	55
Fig. 41 - Respondents' Preferences for the Circular arched Bridge	55
Fig. 42 - Five types of Parallel-chorded Trusses considered	56
Fig. 43 - Sample drawing of a Truss	57
Fig. 44 - Preferences -trusses grouped according to span to height ratio	58
Fig. 45 - Preferences -trusses grouped according to number of segments	59
Fig. 46 - Bending Moments in the Three-span Beam.	63
Fig. 47 - Lengths over which sagging and hogging moments are effective	64
Fig. 48 - Optimisation Curve for Three-span Beam	65
Fig. 49 - Axial Force Envelope of a Two-pinned Parabolic Arch	66
Fig. 50 - Optimisation Curve for Two-pinned Parabolic Arch	67
Fig. 51 - Axial Force Envelope of a Two-pinned Circular Arch	68
Fig. 52 - Optimisation Curve for Two-pinned Circular Arch	69
Fig. 53 - Five Types of Parallel-chorded Trusses considered	70
Fig. 54 - Optimisation Curves -trusses grouped according to span to height ratio	72
Fig. 55 - Optimisation Curves -trusses grouped according to number of segments	72