

LB/DON/07/02

3

STRUCTURAL DESIGN OF PRESTRESSED CONCRETE CONTINUOUS DOUBLE TEE BEAM BRIDGES

A Thesis submitted for the partial fulfillment
of the degree of Master of Engineering in Structural
Engineering Design



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

Submitted by

W.M.D.N. Ranasinghe

June 2001

පුස්තකාලය
මහාචාර්ය වි. එස්. ඩී. ජයසිංහ. ශ්‍රී ලංකාව
මහාචාර්ය

2001

Supervised by

Dr. M.T.R. Jayasinghe

Senior Lecturer

Department of Civil Engineering

University of Moratuwa

074334



University of Moratuwa

74334

624 "01"

624.215

74334

TH

Abstract

One of the applications of prestressed concrete is in continuous bridges. These can be either double tee or box girders. The longitudinal shape can be prismatic, semi-prismatic or non-prismatic. The design of these bridges offer a considerable challenge to the design engineer due to the presence of secondary moments which are induced due to the prestressing forces. These introduce a considerable complexity to the design process. In this research, an attempt is made to develop a design method that would minimize the complexity associated with the design of prismatic prestressed concrete double tee bridges.

In concrete bridges, generally the minimization of self weight is important. This is used as the criterion to start the design process. The governing criteria for the various components of the cross section is used to determine the smallest section that is practically possible. The methods to take account of short term and long term effects such as creep and shrinkage are also included for the cross section selected. Once the cross section is available, it is necessary to find appropriate cable forces. Design methods for both constant and variable cable forces are presented based on the line of thrust. It is shown that the use of variable cable forces could reduce the total cable forces thus leading to a saving in tendons.

For the selected cable forces, it is necessary to ensure that cable profile will be available within the selected section. The line of thrust can be transformed to fit within the section by selecting a suitable set of secondary moments. Thus, the secondary moment can be selected in a straightforward manner for both constant and variable cable forces.

Thus the cable profile selected should ensure that it fits within the limits of cable profile zone and also generate the selected secondary moments. This is not a trivial task. In order to simplify this task, a design method was introduced for both constant and variable cable forces. In the case of variable cable forces, there is a possibility to have point moments and forces acting at the cable force change points. A method to deal with such forces is also introduced.

Therefore, it is possible to consider that this thesis presents a complete design method for the preliminary design of prismatic double tee prestressed concrete beam bridges either with constant or variable cable forces. It has also shown that it is possible to minimize the complexity of difficult design tasks by approaching the problem in modular fashion.

Keywords - Prestressed Concrete, Double Tee bridges

Acknowledgements

Sincere thank and gratefulness to the Project Supervisor Dr. M.T.R. Jayasinghe, for introducing me to a topic related to bridge designs and for devoting his valuable time, his interest, guidance and friendship without which I will not be able to complete the research work.

I wish to thank the Vice Chancellor, Dean Faculty of Engineering and Head, Department of Civil Engineering for allowing the use of the facilities available at University of Moratuwa for this research project. I am grateful to the Western Provincial Council for the financial support and Deputy Chief Secretary (Engineering) for granting duty leave to follow the course and for research.

I also wish to thank Dr. (Mrs) M.T.P.Hettiarachchi, the course coordinator for the encouragement given. A special gratitude is due for all the lecturers of the post graduate course on Structural Engineering Design that helped to enhance the knowledge.

I would like to thank my wife and two sons for their support and understanding. Last, but not least, I wish to thank every person who has helped in this research project.



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

W.M.D.N. RANASINGHE

Engineering Organization

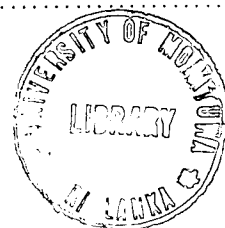
Western Province – Provincial Council.

Contents

| | | |
|----------------------|--|----------|
| Abstract | | i |
| Acknowledgements | | ii |
| Contents | | iii |
| List of Figures | | vii |
| List of Tables | | ix |
| Notation | | x |
| Chapter - 1.0 | Introduction..... | 1 |
| 1.1 | General | 1 |
| 1.2 | Main objectives | 2 |
| 1.3 | Methodology | 3 |
| 1.4 | Main findings | 3 |
| 1.5 | Overview of the Chapters | 4 |
| Chapter - 2.0 | Literature review. | 5 |
| 2.1 | General | 5 |
| 2.2 | Design of prestressed concrete bridges | 6 |
| 2.3 | Assumptions of Moratuwa, Sri Lanka | 6 |
| 2.4 | Design criteria | 6 |
| 2.4.1 | Sign conventions | 7 |
| 2.4.2 | Determinate beams | 7 |
| 2.4.3 | Indeterminate beams | 8 |
| 2.5 | Secondary moment effects | 8 |
| 2.5.1 | Linear transformation | 8 |
| 2.5.2 | Advantages of secondary moments | 9 |
| 2.5.3 | Secondary moment ratio | 9 |
| 2.5.4 | Calculation of secondary moments | 9 |
| 2.6 | Loading stages | 12 |
| 2.7 | Current design techniques | 12 |
| 2.7.1 | Line of thrust design method | 13 |
| 2.7.2 | Cable profile design method | 14 |
| 2.7.3 | Load balancing approach | 15 |
| 2.8 | Prestress losses | 16 |
| 2.9 | Effects to be considered at preliminary design | 17 |
| 2.9.1 | The selection of cross sections | 17 |
| 2.9.2 | The selection of cable forces | 17 |

| | | |
|---------------------|---|-----------|
| 2.9.3 | Methods of dealing with secondary moments | 18 |
| 2.9.4 | The effects of construction techniques and sequence... | 18 |
| 2.9.5 | The effects of long term creep..... | 18 |
| 2.9.6 | The effects of temperature | 19 |
| 2.9.7 | The effects of transverse load distribution..... | 19 |
| 2.10 | Design Methodology | 19 |
| 2.10.1 | Managing uncertainty in design | 20 |
| 2.10.2 | Managing complexity in design | 20 |
| 2.11 | Discussion | 22 |
| Chapter- 3.0 | Selection of section dimensions of double tee bridges..... | 27 |
| 3.1 | General..... | 27 |
| 3.2 | Selection of Preliminary dimensions. | 28 |
| 3.2.1 | Overall depth of the section | 28 |
| 3.2.2 | Width of the top flange..... | 29 |
| 3.2.3 | Web spacing. | 29 |
| 3.2.4 | Cantilever overhang. | 29 |
| 3.2.5 | The thickness of the top flange. | 30 |
| 3.2.6 | The thickness of the webs. | 30 |
| 3.3 | Selection of optimum section dimensions..... | 32 |
| 3.4 | The design example | 33 |
| 3.4.1 | Determination of Bending moments. | 34 |
| 3.4.1.1 | Bending moments due to as-built condition.. | 34 |
| 3.4.1.2 | Bending moments due to monolithic condition. | 34 |
| 3.4.1.3 | Bending moments due to superimposed dead loads..... | 36 |
| 3.4.1.4 | Bending moments due to live loads..... | 36 |
| 3.4.2 | Use of grillage analysis..... | 36 |
| 3.5 | Determination of required section..... | 38 |
| 3.6 | The Parametric study..... | 38 |
| 3.7 | Summary..... | 39 |
| Chapter- 4.0 | Selection of cable forces..... | 41 |
| 4.1 | General | 41 |
| 4.2 | Design Criteria for a Constant cable force..... | 41 |
| 4.2.1 | The design example..... | 42 |
| 4.2.2 | Summary of the design method..... | 42 |
| 4.3 | Design criteria for variable cable forces..... | 43 |

| | | |
|----------------------|--|-----------|
| 4.3.1 | The Governing equations | 43 |
| 4.3.2 | Determination of cable forces over the support..... | 43 |
| 4.3.3 | The design example..... | 44 |
| 4.3.4 | Importance of P_B for the existence of a cable profile.. | 45 |
| 4.4 | Summary | 46 |
| Chapter - 5.0 | Selection of cable profile | 47 |
| 5.1 | General | 47 |
| 5.2 | Selection of suitable secondary moments..... | 47 |
| 5.3 | Determination of a cable profile with constant cable force..... | 48 |
| 5.4 | Determination of a cable profile with variable cable forces..... | 50 |
| 5.4.1 | Forces and moments at cable force change points..... | 50 |
| 5.4.2 | Limits on eccentricity..... | 50 |
| 5.4.3 | Limits on inclination..... | 51 |
| 5.5 | Cable Profile for varying cable forces..... | 51 |
| 5.6 | Summary..... | 53 |
| Chapter - 6.0 | Development of computer tools..... | 69 |
| 6.1 | General..... | 69 |
| 6.2 | The design process..... | 69 |
| 6.3 | The Spread Sheet..... | 69 |
| 6.4 | The design calculations..... | 70 |
| 6.4.1 | Design calculations with constant cable force..... | 70 |
| 6.4.2 | Design calculations with variable cable forces..... | 70 |
| 6.5 | Graphics facilities provided..... | 70 |
| 6.6 | Summary | 71 |
| Chapter - 7.0 | Conclusions and future work..... | 72 |
| 7.1 | General conclusions..... | 72 |
| 7.2 | Future work..... | 73 |
| References..... | | 74 |
| Appendix - A | The spread sheet..... | 76 |
| A.1 | Flow chart..... | 76 |
| A.2 | The spread sheet..... | 77 |
| A.2.1 | Steps for the preparation of spread sheet for constant cable force | 80 |
| A.2.2 | Steps for the preparation of spread sheet for variable cable force | 84 |



| | | |
|--------------|--|----|
| Appendix - B | Grillage analysis and Loading..... | 91 |
| B.1 | Grillage analysis | 91 |
| B.2 | Loading. | 93 |
| B.2.1 | Calculation of Dead loads | 93 |
| B.2.2 | Calculation of Imposed (live) loads..... | 96 |
| B.2.3 | Load Combinations. | 97 |
| B.2.4 | Summary of live load cases considered for Grillage analysis | 98 |



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

List of Figures

| | | |
|-----|---|----|
| 2.1 | Magnel diagram showing governing conditions and the corresponding prestressing forces | 23 |
| 2.2 | Secondary moment on an indeterminate beam. (a) Shows the actual cable profile and the line of thrust | 24 |
| | (b) Secondary moment diagram. | 24 |
| 2.3 | Secondary moment ratio..... | 25 |
| 2.4 | Virtual work – equilibrium system. | 25 |
| 2.5 | Virtual work – compatibility system. | 26 |
| 2.6 | Prestress loss variation. | 26 |
| 3.1 | Cross section used for the design example. | 40 |
| 5.1 | Line of thrust zone | 54 |
| 5.2 | Force eccentricity zone | 55 |
| 5.3 | Bending moment diagram fitted in to the force x eccentricity zone. ... | 56 |
| 5.4 | Line of thrust zone and line of thrust | 57 |
| 5.5 | Selected cable profile and the upper and lower bounds of cable profile zone. | 58 |
| 5.6 | Forces and moments at a point where the cable force changes..... | 59 |
| 5.7 | Possible shape for the cable profile at a force change point to get the maximum moment..... | 59 |
| 5.8 | Possible shape for the cable profile at a force change point to get the minimum moment. | 60 |



| | | |
|------|---|-----|
| 5.9 | Line of thrust zone. | 61 |
| 5.10 | Force eccentricity zone. | 62 |
| 5.11 | Inverse of the Bending moment diagram due to point loads and moments acting at cable force change points..... | 63 |
| 5.12 | Modified force x eccentricity zone | 64 |
| 5.13 | Modified force eccentricity zone with bending moment diagram due to notional loads..... | 65 |
| 5.14 | Force eccentricity with modified bending moment diagram due to notional loads. | 66 |
| 5.15 | Line of thrust zone and line of thrust | 67 |
| 5.16 | Cable profile with varying prestressing forces and the upper and lower bounds of cable profile zone. | 68 |
| B.1 | Mathematical model used for the grillage analysis | 106 |
| B.2 | Bending moment diagrams due to HA and HB loading..... | 107 |
| B.3 | Bending moment envelope due to HA and HB loading..... | 108 |



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

www.lib.mrt.ac.lk

List of Tables

| | | |
|-------|---|----|
| 3.1 | Minimum thickness required for the top flange | 30 |
| 3.2 | Web thickness required depending on the type of ducts. | 31 |
| 3.3 | Section properties used for the analysis. | 34 |
| 3.4 | The bending moment due to monolithic, as-built and superimposed loading | 35 |
| 3.5 | The moment due to live loads and the resultant moment. | 37 |
| 3.6 | Variation of A and Z_2 for a top flange thickness of 0.30m | 38 |
| 3.7 | Variation of A and Z_2 for a web thickness of 0.55m. | 39 |
| 5.1 | The Secondary moment selected with constant cable forces. | 48 |
| 5.2 | The Secondary moment selected with variable cable forces. | 48 |
| 5.3 | Comparison of selected secondary moments and those generated. | 49 |
| 5.4 | Vertical forces and point moments at cable force change points. | 52 |
| 5.5 | Secondary moments selected and those actually occur. | 53 |
| A.2.1 | Spread sheet for constant cable force | 89 |
| A.2.2 | Spread sheet for variable cable force | 90 |
| B.2.1 | Bending moments (kNm) due to dead loads obtained from the grillage Analysis using microfeap –P2 module | 95 |



Notation

| | |
|----------------|--|
| A_c | Total cross-sectional area |
| c | Cover from edge of concrete to center of tendon |
| d | Overall depth of beam |
| e | Tendon eccentricity |
| e_{max} | Maximum eccentricity at which tendon can be placed ($y_2 - c$) |
| e_{min} | Minimum eccentricity at which tendon can be placed ($y_1 + c$) |
| e_p | Eccentricity to the line of thrust. |
| e_{p-min} | Eccentricity to the upper limit of line of thrust |
| e_s | Eccentricity to cable profile. |
| f | Limiting stress condition |
| f_{cu} | Concrete cube strength |
| f_{cw} | Permissible compressive stress at the working load (-ve) |
| f_{tw} | Permissible tensile stress at the working load (+ve if tensile) |
| I_c | Second moment of area of the section. |
| M | Applied moment |
| M_{monoli} | Dead load bending moment due to monolithic construction |
| $M_{as-built}$ | Dead load bending moment due to as-built construction |
| $M_{sup dead}$ | Bending moment due to super imposed dead load |
| $M_{live min}$ | Minimum bending moment due to live loads. |
| $M_{live max}$ | Maximum bending moment due to live loads. |
| $M_{a(act)}$ | Minimum applied moment at the working load without secondary moments |
| $M_{b(act)}$ | Maximum applied moment at the working load without secondary moments |
| M_a | Minimum applied moment at the working load with secondary moments |
| M_b | Maximum applied moment at the working load with secondary moments |

| | |
|------------|---|
| M_2 | Secondary moment. |
| $(M_2)_j$ | Secondary moment at internal support j |
| P | Prestressing force in cable at transfer |
| P_B | Cable force corresponding to point B of Magnel diagram. |
| P_i | Forces acting on i^{th} system |
| $P_{n(i)}$ | Cable force in the new cable at the i^{th} cable force change point. |
| $P_{r(i)}$ | Cable force in the running cable at i^{th} cable force change point. |
| R_{ik} | Reactions due to loading on beams. |
| y_1 | Position of top fibre (-ve) |
| y_2 | Position of bottom fibre (+ve) |
| Z_1 | Elastic section modulus of top fibre (I/y) (-ve) |
| Z_2 | Elastic section modulus of bottom fibre (I/y) (+ve) |
| R | loss ratio |
| f_c | Concrete compressive stress. |
| f_t | Concrete tensile stress. |
| Z | Elastic section modulus. |
| M_{dl} | Elastic Dead load moment. |
| E | Elastic modulus of concrete. |
| ρ | Secondary moment ratio. |
| β_1 | Distribution coefficient for secondary moment over first internal support. |
| β_2 | Distribution coefficient for secondary moment over second internal support. |