UNIVERSITI PUTRA MALAYSIA

ANALYSIS OF PRECAST SEGMENTAL BOX GIRDER BRIDGES

MOHAMED ABDELFATAH ELMAHADI

ANALYSIS OF PRECAST SEGMENTAL BOX GIRDER BRIDGES

By
Mohamed Abdelfatah Elmahadi

A Project report submitted in partial fulfillment of requirements for the degree of Master of Science in Structural and Construction in the Department of Civil Engineering, Universiti Putra Malaysia
May 2008

DEDICATION

This work is dedicated to my family, my beloved wife Rumiesaa Mohamed Elmahadi and my daughter Mryam Mohamed.

I love you so much!!
May 2008

Abstract of thesis presented to Senate of Universiti Putra Malaysia in partial fulfillment of the requirement for the degree of Master of science

ANALYSIS OF PRECAST SEGMENTAL BOX GIRDER BRIDGES

By
Mohamed Abdelfatah Elmahadi

May 2008

Chairman: Assc.Prof.Dr. Jamalodin Noorzaie

Faculty: Engineering

When analyzing prestressed concrete bridges, the self weight, applied loading and prestress have to be combined in the overall structural behavior and the time-dependent effects, such as creep, shrinkage and loss of prestress force should be included. Traditionally these effects are considered separately and then combined with to give the overall design requirements although, in recent years, computer software packages have been developed to combine the effects within a single analysis.

The project studies the principles behind structural analysis of the precast segmental box girder bridges. Structural manual analysis was performed in this project to explain the behavior of precast segmental box girder bridges under self-weight of segments unit and prestressing load. Moments due to these loads were computed and compared with the allowable moments that computed using the specifications given in the British code.

Analysis of construction stages using this method was conducted using LUSAS (FE computer software). The loads that were taken into account are the self-weight of the cantilever during construction, the prestressig loads, the loss of the prestress, creep, shrinkage and relaxation. The stresses in each construction stage are compared with the specifications given in the British code to ensure that they falls well within acceptable limits.

Abstrak tentang tesis dipersembahkan kepada Senate Universiti Putra Malaysia dalam pencapaian keperluan untuk ijazah Master Sains

ANALISA BAGI JAMBATAN KONKRIT BERSEGMEN UNIT KEKOTAK CUCUR-DULU

Oleh

Mohamed Abdelfatah Elmahadi
Mei 2008

Pengerusi : Profesor Madya Jamaloddin Noorzai

Fakulti : kejuruteraan

Bagi menganalisa struktur jambatan konkrit prategasan, faktor-faktor berikut perlu sekaligus di ambilkira :-

i) Bagi kelakuan keseluruhan struktur

a) Beban mati struktur

b) Beban kenaan

c) Prategasan

ii) Bagi kesan bahan bersandar masa

a) Rayapan konkrit

b) Pengecutan konkrit

c) Kehilangan daya prategasan

Lazimnya, factor-factor ini di nilai secara berasingan yakni satu per satu dan kemudian di satukan untuk mendapatkan ketetapan rekabentuk keseluruhan. Dengan adanya perkembangan pesat dunia computer, pekej – pekej program boleh hitung telah di ujudkan, di mana ianya dapat sekaligus mengambilkira factor-faktor yang tersebut di atas dengan hanya memerlukan satu analisa.

Kertas kerja ini mengutarakan teknik-teknik penting bagi tatacara kerja untuk pembinaan jambatan segmen kekotak konkrit prategasan pratuang dan juga prinsip-prinsip menganalisa struktur tersebut. Untuk memahami dengan mendalam kelakuan struktur jambatan ini, analisa di buat secara lazimnya di bawah pengaruh bebanan mati segmen kekotak konkrit prategasan pratuang dan bebanan prategasan. Momen lentur yang terhasil daripada kedua pengaruh tadi di kira dan di bandingkan dengan spesifikasi yang terdapat di dalam Piawian British (British Code). Selain itu, analisa semasa kerja pembinaan jambatan secara "balanced cantilever method" juga di buat dengan menggunakan program boleh hitung bernama LUSAS ("FE computer software with nonlinear option") dengan mengambilkira bebanan mati "cantilever", bebanan prategasan, rayapan konkrit, pengecutan konkrit dan santaian keluli. Nilai tegasan yang di perolehi dari analisa setiap tahap pembinaan di bandingkan dengan spesifikasi yang terdapat di dalam Piawian British (British Code) bagi memastikan ianya berada di dalam linkungan had yang di benarkan.

ACKNOWLEDGMENT

Alhamdulillah الحمد لله, I would like to express my sincere appreciation and thousands of thank you to my project supervisor, Assc.Prof.Dr. Jamaloodin Noorzaie for his guidance, critics, advice, kindness and motivation and last not least the valuable friendship. I am also would like to thank all the lecturers who have conducted the course from the beginning and not hesitating to share their knowledge with us.

I am grateful to all my family members who are very understanding and have been patience with me during my period of absence. Special thanks to my beloved wife Rumiesaa Mohamed Elmahadi, my daughter Maryam Mohamed and my father Abdelfatah Elmahadi Mekki.

I am also grateful to my very good friends that who support me with their advices Saad, Omer, Ashkan, Ehsan, Azmi and Shamrul.

TABLE OF CONTENTS

x

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

W	Top slab width
D	Construction depth
B	Width of bottom slab
S	Web spacing
L	Segment length
a, b, c	Dimensions of haunches
e	Web thickness
f	Widening of web
g	Bottom slab thickness
μ	friction coefficient (concrete-concrete)
σ_n	compressive stress in the joint in MPa
A_{joint}	area of the joint under compression (b_w . h_w)
f_{ck}	characteristic compressive strength of concrete in MP
b_w, h_w	width / height of the web
A_k	smallest area of the base of all keys in the failure plane ($\sum h_{ne}$. b_w)
A_{sn}	area of contact between smooth surfaces on the failure plane
b_n	width of a shear key
h_{ne}	height of a shear key
C_t	Distance from neutral axis to the top fibre
C_b	Distance from neutral axis to the bottom fibre
I	Second moment of area
Z_t	Section modulus for top fibre
Z_b	Section modulus for bottom fibre
γfl, γf3	Load factors defined in the British code
P_h	Horizontal component of the prestressing force
α_2	Angle of friction at the joint
*f*cu	Cube strength of concrete for 150 x 150 x 150 mm sample
*f*ci	The strength of concrete at any time
RH	Relative humidity

Ø	Creep factor
Δc	Loss of stress in the tendons due to concrete creep
∠s	Loss of stress in the tendons due to concrete shrinkage
K	Wobble friction
xA	Length of prestress tendon from the jacking end to the point considered
rps	Radius of curvature of the prestress tendon
W_{DL}	Dead load of the segment member
M_{DL}	Moment due to dead load of the segment member
l	Length of cantilever at each stage of construction
e	Eccentricity of the prestress tendon
F_p	Prestress force
M_p	Moment due to prestressing
A	Cross sectional area of segment member
Z	Section modulus
M_{top}	Moment on top slab
M_{bottom}	Moment on bottom slab
A	Cross sectional area.
Iyy, Izz	2nd moments of area about local y, z axes
Kt	Torsional constant
Asz, Asy	Effective shear areas on local yz plane in local z, y directions
ez	Eccentricity from beam xy-plane to nodal line. (+ve in the local Z direction).
Ms	Secondary moment
ULS	Ultimate limit state
SLS	Serviceability limit state
BS	British standard
UK	United Kingdom
FE	Finite element
m	meter
mm	millimeter
N/mm^2	Newton per millimeter square
MPa	Mega Pascal

KN	Kilo Newton
K.m	Kilo Newton meter

CHAPTER 1

INTRODUCION

1.1 Background

Bridges are built where there is water, mountains, or where land is hard to get across. It would take us a lot longer to get someplace if we didn't have bridges.

We cross bridges almost daily and they are almost everywhere. In both the urban and rural areas they have become part of our landscape. Except for a few, most bridges go unnoticed by our road users. Most of us are quite unaware of the engineering skills and the craftsmanship that went into the design and the construction of each bridge. Many are also unaware that before a bridge is constructed, the bridge designer has to consider various factors that will influence its form and construction. These include factors such as traffic that is going to use the bridge which will determine the dimensional cross-section and life load effects, hydrology and hydraulics if the bridges were to cross waterways, navigated requirements, and of cost economics and cost effectiveness.

Bridges not only show the development of technology in design and construction, but also reflect the progress of the nation. In the early days of independence, the stress was more in providing basic infrastructure, thus bridges were of simple construction. But in the present decade and approaching the next millennium, the nation aspires to be at the forefront of development and seeks more sophisticated technology and would be more innovative in bridge design and construction.

In Malaysia there are many bridges types various from road and footbridges and from concrete to steel or composite as a material. Most famous of these bridges is Penang Bridge (Fig.1.1), with a total length of 13.5Km, it was first opened to traffic in September 1985. The main attraction is the three main cable stayed spans with a total length of 440m comprising of 225m central span and 107.5 m side spans. There are also Merdeka Bridge, Kuala Kedah Bridge, Parliament Bridges, Upper Pergau Bridge and etc.

Fig.1.1: Penang Bridge in Malaysia

Special attention has to be paid to bridges because bridges are essential elements of the road system. They allow obstacles to be easily and quickly crossed, thereby bringing communities closer together and contributing towards the country's economic growth.

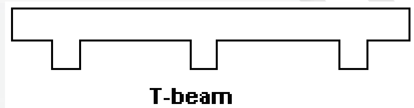
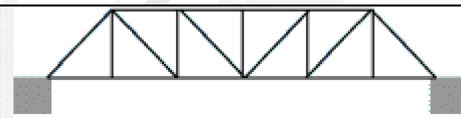
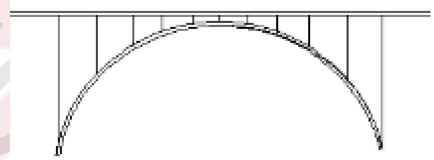
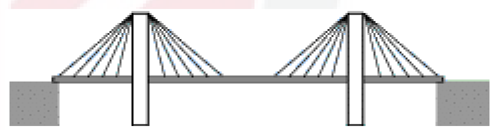
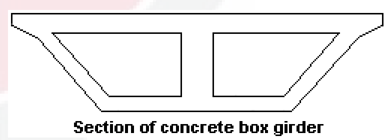
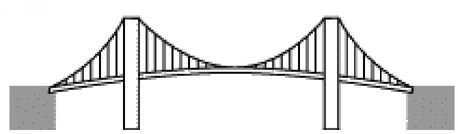
As the population and industry grew, greater demands were made on the transportation network, and in response, more roads and bridges were constructed. Many of the bridges were simple structures of little significance to the general public and went unnoticed. A few though became landmarks and attraction in themselves.

Modern road bridge construction is relatively new in Malaysia, having been started only in the early twentieth century. The earliest bridges were constructed in the 1920s. These were mostly steel bridges. The showpiece on steel bridge construction is the sultan Iskandar Bridge, which was constructed in 1932. Reinforced concrete bridges only came into use in early 1930s, starting with a reinforced concrete slab bridge. Reinforced concrete beam bridges were introduced towards the second half of 1930s, while prestressed concrete beams only started to be used after 1950s. Most of the bridges recently constructed were of prestressed concrete.

1.2 Types of bridges

Bridges can be classified according to materials (concrete, steel or wood), usage (pedestrian, highway or railroad), span (short, medium or long) or structural form (slab, girder, truss, arch, suspension or cable-stayed). None of these classifications are mutually exclusive. Table 1.1 shows the types of bridges related to material and span range.

Table 1.1: Types of bridges.

Type	Material	Span range (m)	(ft)	Figure
Slab	Concrete	0-12	0-40	
Beam	Concrete	12-210	40-700	
	Steel	30-300	100-860	
Truss	Steel	90-550	300-1800	
Arch truss	Steel	240-520	800-1700	
Cable stayed	Concrete	90-270	300-800	
	Steel	90-350	300-1100	
Box girder	Concrete	Excess 100	Excess 328	
Suspension	Steel	300-1400	1000-4500	

1.3 Precast segmental box girder bridges

Precast Segmental Bridges are one of the most common types of box girder bridges. I t became increasingly popular because of their relatively low cost when compared to suspension or cable-stayed bridges. Precast Segmental box girder bridges are quicker to construct, and less disruptive to the surrounding environment.

The first precast segmental concrete bridge was built to cross the Seine River, France in 1962. Since then the concept of segmental bridge construction has spread from Europe to all parts of the world. In 1973, the first U.S. precast segmental concrete bridge was built and opened to traffic in Corpus Christi, Texas. In 1974, the first U.S. cast-in-place segmental bridge was built and opened to traffic near San Diego, California. Since then, hundreds of precast and cast-in-place segmental concrete bridges have been constructed throughout the U.S.A. Improvements and refinements in design and construction have been made over the years.

Precast Segmental Box Girder has become a very popular method of bridge construction in Malaysia nowadays. This method of construction started with construction of Light Rail Transit (LRT) viaduct in 1997, post-tension box girder start to gain recognition as a preferred method of construction of bridge within the urban area. This similar construction follows by construction of Second Link Bridge to Singapore (Fig.1.1), Bayan Baru By-pass, Butterworth Offshore ring Road, several bridges in Kuala Lumpur such as Ampang-Kuala Lumpur Elevated Highway, SPRINT Highway, Kerinci Link, New Pantai Expressway, Subang Kelana Link and so on.

Fig.1.1: Second Link Bridge to Singapore during construction

Precast Segmental Bridges are used for long spans (excess of 100m) box girders are, in general, the most common and efficient type of bridge superstructure. Built with an orthotropic plate deck to reduce the dead weight of the bridge, or with a concrete slab to obtain a composite cross-section, box girders have many structural advantages when compared to plate girders and truss girders. Some of the advantages are:

- High torsional rigidities.
- Wide top and bottom flanges to carry longitudinal forces.
- Large internal space to accommodate services.
- Simple maintenance due to easy access to the interior of the superstructure.
- Better appearance due to high slenderness and smooth bottom surfaces.

Due to the high torsional rigidity of this type of cross-section, box girders are a very convenient solution for bridges curved in plan. For large spans, the depth of continuous box girder bridges may vary along the span giving improved structural efficiency to accommodate the large bending moment at the supports.

The precast segmental box girder bridges are constructed stage-by-stage. If the deck is cantilevering over a pier when it is prestressed the end of the cantilever is often deflected downwards and increases the load on the falsework beneath, To avoid overstressing the falsework the prestress can be applied in stages. The first stage prestress should be just adequate to support the concrete dead load without causing any significant deflections. The falsework can then be removed after which the rest of the prestress can be installed.

1.4 Problem statement

Realistic analysis of the precast segmental box girder bridges is not easy due to the fact that many related topics to the analysis needs to be understood like geometry, sequence of construction and nature of the loadings. In the analysis of this type of structures consideration should be given to self weight and temporary loads caused by the sequence of construction stages in the analysis of precast segmental box girder bridges. Furthermore, comparisons of the analytical results obtained and the specifications given in the British code BS5400 need to be made to insure that the analysis falls well within acceptable limits.

1.5 Objectives and Scope of the study

The main objectives of the present study are:

(i) To study the structural behavior under the influence of loads based on BS5400 code.

(ii) To simulate stages of construction of a precast segmental box girder bridge built by balanced cantilever method using a finite element program with nonlinear product option (LUSAS software) and then discuss the response of the analyzed structure under combined shear and flexure.

To achieve the above objectives the following steps to be undertaken:

(i) Understand the nature of loading that can affect in the analysis of the precast segmental bridge, and how the structure behave under these loadings.

(ii) Numerical tools will be used to simulate the model of the structure and learning of the application should be understood.

1.6 Organization of the project

The second chapter shows literature review about the precast segmental bridges. The history of this type of bridges, its development, its advantages and disadvantages will be dealt with in the first part of this chapter. The design criteria, design consideration and construction methods of precast segmental box girder bridges will be introduced in the second part. How construction methods of precast segmental bridges are related to its analysis. Special attention has to be paid to balanced cantilever construction method. Different types of post-tensioning layout are introduced due to the different types of construction methods. Method of analysis using LUSAS program is also presented in this chapter.

The third chapter shall introduces the methods that can be used for two types of analysis of precast segmental box girder constructed using the balanced cantilever method. Manual and using computer software analysis methods are introduce to understand the analysis of this type of bridges under construction loadings.

The fourth chapter introduces classical analysis of the precast segmental box girder bridges and the input data for the computerized analysis. Chapter fife shows the results of the computer analysis with related discussion. Finally, the sixth chapter presents the conclusion of the objective of the project.

REFERENCES

Conrad P. Heins. Richard A. Lawrie. *Design of Modern Concrete Highway Bridges*, United State of America, John Wiley & Sons, Inc (1984).

Nigel R. Hewson, *Prestressed Concrete Bridges: Design and Construction*, Thomas Telford Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire (2006).

Charles E. Reynolds BSc (Eng), CEng, FICE and Jame C. Steedman BA, CEng, MICE, MIStructE, *Reinforced Concrete Designer's Handbook*, Tenth Edition E &FN SPON, Great Britain, TJ Press (Padstow) Ltd, Cornwall (1988).

M.J. Ryall, G.A.R. Parke and J.E. Harding, *Manual of Bridge Engineering*, The Institute of Civil Engineerings, Thomas Telford Limited, MPG Books Ltd, Bodmin, Cornwall, Great Britain (2000).

M. Y. H. Bangash, *Prototype Bridge Structures: Analysis and Design*, Thomas Telford, MPG Books Ltd, Bodmin, Cornwall, Great Britain (1999).

BRITISH STANDARD: *Steel, Concrete and Composite Bridges – Part 2: Specification for loads, BS 5400-2:1978* Incorporating Amendment No. 1, British Standard Institution (BSI).

BRITISH STANDARD: *Steel, Concrete and Composite Bridges – Part 4: code of practice for design of concrete bridges, BS 5400-4:1984*, British Standard Institution (BSI).

M . K. Hurst BSc, MSc, DIC, MICE, MI Struct. E, *Prestressed Concrete Design*, Nanyang Technological Institute, Singapore. Great Britain by St Edmundsbury Press Ltd, Bury St Edmunds, Suffolk (1995).

Bridges of Malaysia , Bridge Unit, Road Branch, PWD Headquarters, Jalan Sultan Salahuddin, 50582 Kuala Lumpur.

Duan, L., Chen, K., Tan, A. *Prestressed Concrete Bridges, Bridge Engineering Handbook.* Ed. Wai-Fah Chen and Lian Duan Boca Raton: CRC Press, (2000) Ed. Wai-Fah Chen and Lian Duan, *Segmental Concrete Bridges: Bridge Engineering Handbook.*, Gerard Sauvageot, J. Muller International, Boca Raton: CRC Press, (2000)

Jazlan Bin Salleh @ Mohamed Salleh, , *Construction of precast segmental precast segmental box girder bridges using overhead gantry*. A project report in Master of Science (Construction Mangement), Universiti Teknologi Malaysia, (2006).

J. Turmo[a], G. Ramos[b], A.C. Aparicio[b], (2005), *FEM study on the structural behaviour of segmental concrete bridges with unbonded prestressing and dry joints: Simply supported bridges*

KEXNETH W. SHUSHKEH.ICH+178 Maryland Street. Winnipeg. Manitoba. RX IL3. Canada *TIME-DEPENDENT ANALYSIS OF SEGMENTAL BRIDGES*

GURDIAL CHADHA and KONSTANIIN KETCHEK, CO*MPUTERIZED STRUCTURAL DESIGN AND ANALYSIS OF CONTINUOUS PRESTRESSED CONCRETE BOX-GIRDER BRIDGES BUILT BY CANTILEVER METHOD OF CONSTRUCTION*, Erdman and Anthony, Consulting Engineers, Rochester, N.Y. 14604, U.S.A.

Lionel Bellevue P.E. & Paul J. Towell P.E, Parsons Brinckerhoff Quade & Douglas, Inc, *Creep and Shrinkage effects in segmental bridges*, (2003).

Zhou, Xiangming, Mickleborough, Neil, Li, Zongjin, *Shear Strength of Joints in Precast Concrete Segmental, Bridges,* ACI Structural Journal, (2005).

Ing. G. Rombash, Technical University, Hamburg-Harburg, Germany, *Precast segmental box girder bridges with external prestressing: design and construction*, INSA Rennes, (2002)

Richard M. Gutkowski, Colorado State University, *SHEAR KEY FOR STRENGTHENING BRIDGES*, (2002).

Do-Young Moon & Jongsung Sim & Hongseob Oh, *Practical crack control during the construction of precast segmental box girder bridges*, (2005).

LUSAS FEA Ltd Manual, LUSAS Civil & Structural and *LUSAS Bridge*, Kingston upon Thames, Surrey, KTI IHN, United Kingdom.

Gunter A. Rombash & Ra'ed Abendeh, Institute of Concrete Structures, Hamburg University of Technology, Denickestr. 17, 21073 Hamburg, Germany, *Bow-shaped segments in precast segmental bridges*, (2007).

VSL International Ltd, Bridge Construction Partner, Scheibenstrasse 70 – Bern – CH-3014 – Switzerland, www.vsl.com.

G. Rombach & A. Specker, Technical University Hamburg-Hamburg, D 20171 Hamburg, Germany, *DESIGN OF JOINTS IN SEGMENTAL HOLLOW BOX GIRDER BRIDGES*, (2002).

THE CONSTRUCTION PROCESS OF SEGMENTAL BRIDGES
http://scholar.lib.vt.edu/theses/available/etd-120199-224950/unrestricted/11lucko_chapter4.pdf