

DEFLECTION MONITORING OF CAST IN-SITU BALANCED CANTILEVER  
PRESTRESSED CONCRETE BOX GIRDER BRIDGE

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For my parent, wife and son, who offered me unconditional love and support throughout the research of this thesis.

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## ABSTRACT

Monitoring of deflection in the construction of a long span segmental balanced cantilever prestressed concrete box girder bridge is very important because bridge deflection will affect the final bridge level and to avoid large level discrepancies during the joining of two cantilevers. This study presents a comparison of actual and design short-term deflection considering the effect of creep for a four span balanced cantilever prestressed concrete box girder bridge. Each span consists of 26 segments and the deflection data were obtained using leveling instruments. The actual concrete strength of the segments were also recorded. Analysis using these data and the local creep coefficient were carried out using ADAPT-ABI software. Comparisons between actual and design deflections indicate that they are similar for the first four segments of each span with very small values. Substantial values of deflection begin to develop at the fifth segment and the critical value occurred at the middle of the cantilever span. It is also observed that the deflection values are inversely proportional to the concrete strength but directly proportional to the creep coefficient. As an extension of this study, further investigations can be carried out on long term deflection of concrete box girder bridge, behaviour of box girder bridge due to temperature difference, effect of varying element thicknesses and early loading.

## ABSTRAK

Pemantauan pesongan terhadap pembinaan jambatan konkrit prategasan bentuk kekotak secara bersegmen yang panjang merupakan satu perkara yang penting kerana pesongan jambatan akan memberikan kesan terhadap aras jambatan dan bagi mengelakkan perbezaan aras yang besar ketika mencantumkan kedua-dua hujung rentang terjulur. Kajian ini menunjukkan perbandingan antara pesongan jangka pendek sebenar di tapak dan semasa rekabentuk dengan mengambilkira kesan daripada rayapan konkrit bagi empat rentang jambatan konkrit terjulur. Setiap rentang terdiri daripada 26 segmen dan data pesongan diperolehi dengan menggunakan alat aras. Kekuatan konkrit sebenar bagi setiap segmen turut direkodkan. Analisa menggunakan data-data tersebut dan pekali rayapan di Malaysia dijalankan dengan menggunakan perisian komputer ADAPT-ABI. Perbandingan antara aras jambatan sebenar dengan aras rekabentuk adalah sama bagi empat segmen pertama untuk setiap rentang dengan perbezaan aras yang kecil. Pesongan yang ketara mula terbentuk pada segmen kelima dan segmen kritikal berada di pertengahan rentang jambatan terjulur. Pemerhatian juga mendapati bahawa nilai pesongan adalah berkadar songsang dengan kekuatan konkrit tetapi berkadar terus dengan pekali rayapan konkrit. Lanjutan daripada kajian ini, siasatan lanjut boleh dijalankan terhadap pesongan jangka panjang bagi jambatan konkrit bentuk kekotak, sifat jambatan bentuk kekotak disebabkan oleh perubahan suhu, kesan daripada kepelbagaian ketebalan elemen dan beban awalan.

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## LIST OF SYMBOLS

AASHTO	-	American Association of State Highway and Transportation Officials
RH	-	Relative humidity
HPC	-	High performance concrete
$A_c$	-	Concrete section areas
$I_c$	-	Moment of inertia
$A_{ns}$	-	Non-prestressed steel area
$A_{ps1}$	-	Prestress tendon area
TBM	-	Temporary bench mark
BM	-	Bench mark
JUPEM	-	Jabatan Ukur Dan Pemetaan Malaysia
BS	-	British Standard
RHS	-	Right hand side
LHS	-	Left hand side
LLM	-	Lembaga Lebuhraya Malaysia
ASTM	-	American Society for Testing and Materials
UTS	-	Ultimate tensile strength
mm	-	Milimeter
kN	-	Kilonewton
ACI	-	American Concrete Institute
$N/mm^2$	-	Newton per millimeter square
TROPCS	-	Tropical Creep and Shrinkage
EC 2	-	Eurocode 2
CEB-FIB	-	Concrete creep and shrinkage prediction model

- B3 - Concrete creep and shrinkage prediction model
- AS3600 - Australian Standard for Concrete Structure
- C50/60 - Concrete grade 50

## **CHAPTER I**

### **INTRODUCTION**

#### **1.1 Introduction**

Today's modern and challenging world does not restrict only at the urban areas but also rural areas. Due to site topography and economy constraints, the need for longer bridge spans increases. Since prestressed concrete bridges are introduced into the United States in 1949, prestressed concrete bridges today represent over 50 percent of all bridges built [1]. Based on the Public Work Department Malaysia [2] database updated until December 2009, there are 9157 bridges recorded on Federal Roads, Malaysia.

Despite the conventional prestressed concrete girder such as I-beam and T-beam, the concrete box girder bridge can be built with longer span. Due to its hollow section, the weight of the girder can be reduced, therefore, the flexural capacity for the section may increase and longer span can be produced. The development of the curved beam theory by Saint-Venant (1843) and later the thin-walled beam theory by Vlasov (1965) marked the birth of all research efforts published to date on the analysis and design of straight and curved box-girder bridges [3].

Generally, the deflections of concrete are caused due to applied load and internal stress, which are creep and shrinkage. There are several standard or design manuals available such as AASHTO and British Standard used to design concrete box girder bridges. Nowadays, the deflection caused by applied loading can be calculated or predicted using commercial design software.

There are two types of deflections to be considered in box girder bridge which are short-term deflection (during construction) and long-term deflection (after bridge completed and open to traffic). According to Richard Malm and Hakan Sundquist [4], the vertical deflection of box girder bridges construct using segmental balanced cantilever method are effected by the downward deflection (due to dead load and live load) and upward deflection (due to prestress of tendons) which is known as short-term deflection.

Generally, long-term deflection is caused by creep, shrinkage and relaxation of the prestressing tendons. The three distinct but inter-related time dependent effects must be considered in the analysis of a segmental bridge [5]. The effect of these three distinct are:-

- 1) Creep is the change in strain with time due to constant stress;
- 2) Shrinkage is the change in strain with time not due to stress;
- 3) Relaxation is the change in stress with time due to constant strain [6].

Due to the construction method, it is important to be able to obtain accurate predictions of the bridge deformation during construction and their service life [6].

## **1.2 Background**

The main advantage of cast in-situ balanced cantilever box girder bridge compared to precast concrete box girder bridge is the material transportation accessibility. Due to balanced cantilever construction method, one of the main objectives is the finish level of each segment where all bridge segments must be connected to one another. Despite of smooth driving, the final segment level of each span is very important in order to connect with other spans.

The construction of balance cantilever bridge starts from the support and constructed segment by segment, connecting at both cantilever ends. If the difference of level is severe, appropriate action must be taken to make sure that the difference is within the allowable tolerance in order to joint both cantilever ends.

## **1.3 Problem Statement**

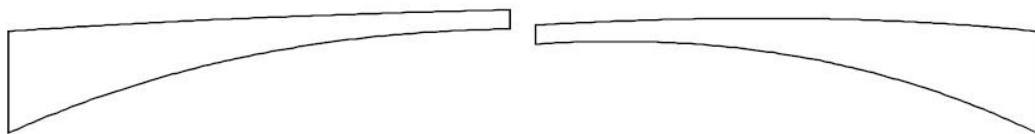
According to Mathivat [7], cast in-place (cast in-situ) cantilevering will usually have larger deflections than precast cantilevers because those segments (precast) are stored for some time before placed in the bridge's superstructure. Since the balanced cantilever box girder bridge is constructed segmentally, maximum deflection is expected to occur at the farthest segment from the pier (support). Therefore, designers and contractors may expect larger deflection to occur for longer bridge.

Each segment will experience stressing and concreting, which is additional loading applied during construction stage until all segments are stressed. Therefore, pre-camber is applied to every segment during concreting to compensate the effect of

segment weight and construction equipment (form traveler, machinery and ect.). Gunnar Lucko [8] explains the reasons for compensation of the deflection caused by segment weight (dead load) as follow:-

- i. Ensuring that the two cantilever beams meet at the same midspan elevation so that the casting of the closure segment is not hindered. It is, however, possible to jack the two cantilever beams into alignment to correct minor misalignments before casting the closure segment [8].
- ii. Giving the bridge in service to the visual appearance of strength. Sagging below the vertical plane would also be detrimental to the riding comfort [8].

One of the problems with deflection is during jointing both cantilever ends. During construction, the segments level is checked at least before concreting and after stressing to ensure that the segments level is as per design and expected. However, due to excessive deflection during construction stage, it may result sagging around the middle of the bridge span as illustrated in Figure 1.1 and Figure 1.2 [9]. Peter F. Takács [9] explains the primary importance is to achieve the smooth camber in the bridge deck and to avoid sag at mid-span.



**Figure 1.1** Vertical difference between the tips of the two cantilevers before the cantilevers are connected [9].



**Figure 1.2** Excessive deflection in the completed bridge spans [9]. The dotted line represents the design level.

The segment by segment construction method has resulted in different concrete maturity rate with every segment. Since the normal construction cycle is between 7 to 9 days, the difference of concrete age in days between first segment and segment no. 13 can be 91 days to 117 days. Due to the nature of concrete, the early segment will experience more creep and shrinkage; therefore, it will affect the bridge deflection.

During cantilever state, each part of the box girder may tend to deflect downwards parallel to gravity force. The more deflection occur, the more difficult to join the final segment. In order to overcome the problem, the contractor may have to adjust the bearing at the bottom at each support (pier) or by other methods to suit the required level.

Any adjustment made by the contractor, especially using mechanical methods such as jacking will impose additional loading to the cantilever structure. If the adjustment is not carefully conducted, the whole structure may fail and may provide damage to the bridge. James M. Baker [10] explains that the construction load must not increase significantly over what has been assumed in the design. This is because the tensile stress at the top flange for the same section or segment is offset by the post-tensioning forces applied at a rate similar to the moment.

#### **1.4 Objectives of The Study**

The overall aim of this research is to study the deflection behavior of concrete box girder bridge constructed using cast in-situ concrete and balanced cantilever method. The literature review of this research explains the basic concept of constructing box girder bridge and principle of box girder deflection. Therefore, this research is focused to achieve the following objectives:-

- i. To collect and compare the level data of all box girder segments during every construction stage;
- ii. To monitor deflection behavior and identify the critical segment of cast in-situ cantilever prestressed concrete box girder;
- iii. To determine actual concrete strength and analyze the bridge deflection using the actual concrete data;
- iv. To analyze and compare deflection of each concrete box girder segment using different creep coefficient.

#### **1.5 Scope of study**

The study is conducted at a bridge over Sungai Terengganu constructed by MTD Construction Sdn. Bhd. for East Coast Expressway Phase 2. The bridge is designed to suit the state road parameter which consists of two lanes with shoulders and verge. Based on the bridge design, the scope of study is limited to the design parameter itself as listed below:-



- i. Deflection levels are measured using survey method which practically practiced by the contractor.
- ii. Certain assumptions referring to the design parameters which are temperature, relative humidity (RH), wind factor and other design parameters.
- iii. Design levels are taken as reference (datum) where upward deflection is taken as positive (deflection above datum) and downward deflection is negative (deflection below datum).
- iv. Specimens are constructed using cast in-situ concrete and balance cantilever method.

## **1.6 Significance of study**

The deflection of balanced cantilever bridge is one of the important elements during the bridge construction. On 2011, a cantilever bridge constructed using precast segment link to The New Istana Negara experienced severe level differential and adjustment had to be made in order to join both cantilever ends.

Cast in-situ segments experience larger deflections compared to pre-cast segments, and hence it is important to understand the bridge deflection behavior. Due to lack of research on deflection during construction in Malaysia, the result from this study may assist in providing better understanding to the designers and site engineers on the deflection behavior of segmental box girder bridge constructed using balanced cantilever method.



**Figure 1.3** Misalignment of pre-cast box girder bridge near The New Istana Negara.

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