Ain Shams University

Faculty of Engineering

ASPECTS AFFECTING THE TORSIONAL BEHAVIOUR OF CURVED R.C. BOX GIRDER BRIDGES

By

ABDEL WAHAB AHMED EL-GHANDOUR

B.Sc. (Honours) 1991, Structural Division

Civil Engineering Department

Ain Shams University

A Thesis

Submitted In Partial Fulfillment

For The Requirements Of The Degree Of

Master Of Science In Civil Engineering (Structural)

Supervised By

Prof. Dr.	Prof. Dr.	Dr.
Mohamed I. Soliman	**Shaker A. El-Behairy**	**Abdallah A. Abou Zeid**
State Minister of new Urban Communities and Prof. of R. C. Structures Ain Shams University	Prof. of R. C. Structures Ain Shams University	Ass. Prof. in Structural Department Ain Shams University

CAIRO - 1994

Examiner Committee

Name, Title and Affiliation	**Signature**
1- Prof. Dr. MOHAMED I. SOLIMAN State minister of new urban communities and professor of R. C. structures, Ain Shams University. (Supervisor)	....
2- Prof. Dr. HASSAN M. HOSNY Vice president of Helwan University and Professor of R. C. Structures, Helwan University.	....
3- Prof. Dr. KAMAL N. GHALI Professor of R. C. Structures, Ain Shams University.	....
4- Prof. Dr. SHAKER A. EL-BEHAIRY Professor of R. C. Structures, Ain Shams University (Supervisor)	....

Date: / / 1994

بسم الله الرحمن الرحيم

TO MY PARENTS,

MY GRAND MOTHER

and

MY DEAR PROF. DR. MOHAMED I.SOLIMAN

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INTRODUCTION

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General

Reinforced concrete box girder highway bridges have proven to be a most economic structural solution particularly in spans of 18 to 30 meters (60 to 100 ft). Their high torsional stiffness, the favorable pattern of flexural stresses, and the arising of small shear stresses can be considered their greatest advantages. At the same time these bridges are aesthetically attractive since any desired alignment can be satisfied.

Reinforced concrete box girders or hollow girder type bridges were first used in Europe and North America some forty years ago in an effort to develop new economical design and construction techniques. Compared with other types of concrete bridges, the box girder section is more economical and aesthetically attractive. Also, it has high resistance to torsional loading.

Dictated by the highway alignment layout and the site conditions, horizontally curved box girder bridges have been increasingly popular in recent years. In cases where the radius of curvature is small compared with the span, it will be more economical to have a curved structural system in which both the flanges and webs are curved horizontally, than having a curved deck that is placed on a serious of straight girders.

In the analysis and design of concrete bridges, the commonly used approach, is to assume the concrete to be uncracked and linearly elastic, and thus ignoring the reinforcement. This approach has the advantage of simplicity and closely modeling the behaviour of box girder within the service load level, also giving a valid lower bound to the ultimate load condition. However, this approach lacks accuracy, and may lead to unnecessary overestimation in the box girder bridge dimensions. In addition, it cannot predict the nonlinear behaviour of reinforced concrete box girder bridges up to failure.

Also, earlier design methods for the analysis of box girder bridges were conservative and employed large wall thickness to render distortional and warping effects negligible, so that simple beam theory and St.Venant torsion theory were considered an adequate analytical tools. However, with the present tendency to use thin wall thickness, to reduce self weight of bridge, the associated, prestressing, distortional and warping effects become significant and must be considered in the analysis.

The intermediate and the end diaphragms, which are normally placed between the girders within the span, and at abutments and piers, improves the load distribution between the critical sections of the box girder bridges. These diaphragms are normally subjected to a high bending and torsional stresses. The influence and behaviour of these diaphragms in the curved reinforced concrete box girder bridges seems to have been misunderstood till recent years.

The side cantilevers which are normally used in box girder bridges, increase the distortional warping stresses and the effect of the shear lag phenomenon. The effect of these cantilevers on the torsional and distortional behaviour, and also on the shear lag phenomenon in curved R.C. box girder bridges has been overemphasized till recent years.

Therefore, the main purposes of the present research work are to investigate the effect of the cantilever width on the torsional and distortional behaviour of curved reinforced concrete box girder bridges. Also, the present work aims to investigate the effect of the warping restraint at the supports on the general deformational behaviour, and cracking of curved R.C. box girder bridges from zero up to the failure load. A non linear F.E.A. will be formulated to consider the actual response of R.C.sections. This will lead to a more realistic and economic design for this type of structures.

Objectives and Aims of the Present Study

The present study was undertaken to investigate the effect of varying the cantilever width on the torsional and distortional behaviour of curved R.C. box section bridges, having variable end conditions (with and without end diaphragms). Similarly, this study investigates their general deformational behaviour under eccentric concentrated load condition, acting at midspan section at the mid-point of the outer web of these girders, from zero up to the failure load.

The experimental phase of the present study consisted of testing four curved box girder bridges of medium scale direct model. The overall external dimensions of these curved girders were 4.0 ms in radius and 3.0 ms arc length measured at the center line. The four curved girders had the same box dimensions but with variable cantilever widths, and the same steel reinforcement. The girder box was taken 0.4 x 0.3 ms, and the side cantilevers varied from 0.1 to 0.25 ms, while the thickness of the webs and the top and bottom slabs were 0.07 m. The tested girders were divided into two groups:

The first group included two girders of cantilever width of 0.1 m, without and with end diaphragms. The second group included two girders of cantilever width of 0.25 m, without and with end diaphragms.

All these curved girders were loaded with an eccentric concentrated load at midspan sections, upon the outer web, using rigid steel frame which provided the required load eccentricity which cause combined bending, shear, and torsion state of stresses.

A theoretical study was also conducted, to develop a mathematical model using the Finite Element Method taking the nonlinear behaviour of concrete and yielding of steel into consideration. A 20 node isoparametric three dimensional solid concrete element was used to represent concrete, while the reinforcement was represented as a smeared two dimensional layer of equivalent thickness.

The specific objectives of this research work are as following:

1- Study the distribution of loads through the span of the curved box girders under combined bending, shear and torsional loading conditions within the working and the ultimate load levels.

2- Investigate the effect of warping restraint at supports, (end diaphragms), on the following:

a) The general deformational behaviour of the curved box girders.

b) The cracking pattern and the crack propagation under the combined bending, shear and torsion at different stages of loading up to the failure.

3- To study the effect of changing the cantilever width on the torsional and distortional behaviour of the curved box girders.

4- To develop a nonlinear Finite Element Model which can define the complete nonlinear behaviour of curved R.C. box girder through the load history, (from zero up to failure).

5- To compare the results of the Finite Element analysis with those obtained experimentally.

The Scope and Contents

The present study consists of seven chapters as follows :

Introduction

The importance of the present study is presented in this chapter. Furthermore, this chapter includes the objectives and the scope of the present work.

Chapter (1) Review of Previous Work

This chapter includes the historical review of the development of the box girder bridge analysis, and a review on the most important previous research works in this field.

Chapter (2) Experimental Work

This chapter presents the experimental phase of this study which consisted of testing four curved box girders. All the experimental items including preparing, construction and testing of the four models and the control specimens, as well as the locations of measuring both the concrete and the steel strains and stresses are presented in this chapter.

Chapter (3) Experimental Results

In this chapter the results of the experimental work are presented; the crack pattern of the tested girders, the cracking load, failure load, vertical deflections of top and bottom slabs, lateral deflections of loaded and unloaded webs and the distribution of longitudinal and transverse concrete and steel stresses through the length of the models. Comparison between the results of the four curved R.C. box girders is also made.

Chapter (4) Finite Element Modeling of Box Section Girders

In this chapter, the nonlinear finite element method which was used in analysing the tested curved reinforced concrete box girder bridges is presented. Material nonlinearity was introduced, such as the nonlinear stress-strain curve of concrete under multiaxial state of stress, cracking of concrete and yielding of steel. Solution technique assured a solution of a nonlinear problem by means of the number of subsequent linear solutions. The nonlinear finite element analysis was performed in an incremental manner to avoid the problem of plastic flow and small values of load increments were used to converge the solution.

Chapter (5) Results of the Finite Element Analysis

The analysis of the tested curved box girders were carried out using the finite element program and the results are presented in this chapter. Comparisons are made between the results of the different curved box girders to study the effect of changing the cantilever widths and condition of supports, (with or without end blocks), on the general deformational behaviour of these curved girders.

Chapter (6) Comparison Between the Experimental and the Theoretical Results

In this chapter, a comparison between the experimental results, and those obtained from the finite element analysis, are made.

Chapter (7) Conclusions

Conclusions of the present study are summarized in this chapter. The conclusions concern the behaviour, analysis and design of the curved box girders. Some proposals for further study are also included in this chapter.

Appendix (A) : Structural Action and Available Methods of Analysis of Box Girder Bridges

This appendix deals with the representation of the general structural action which have to be considered when the analysis of box structures is taking place, and the available analytical tools of box girder bridges.

Appendix (B) Program Structure

In this appendix, the program functions are described as well as the main subroutines of the program.

Appendix (C) Data File

In this appendix, an example of a data file of one of the analysed curved box girders is presented.

CHAPTER (1)

REVIEW OF PREVIOUS WORK