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University of Diyala
College of Engineering

Structural Behavior of Reinforced Self-Compacted Concrete Box Beams

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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(B.Sc. in Civil Engineering, 2017)

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ وَقُل رَّبِّ زِدْنِي عِلْمًا ﴾

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DEDICATION

To my parents

with love and gratitude

Zahraa Sermed Zuhdiy

2021

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In the name of Allah, the most gracious, the most merciful. Before anything, I thank **ALLAH** who enabled me to achieve this study.

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Zahraa Sermed Zuhdiy
2021

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Abstract

Box beams are very commonly used structural members due to their high performance, their ability to minimize the dead load and the number of supports which lead to reduce cost. Accordingly, it became a major requirement to focus on studying the structural behavior of this type of structural members.

In this thesis, an experimental study was conducted in order to investigate and improve the structural behavior of reinforced self-compacted concrete box beams by using different number of cells with the same cross-section dimensions as well as studying the effect of using longitudinal shear steel plates that contain vertical and inclined rectangular spacings as shear reinforcement instead of using traditional reinforcement bars (stirrups). Also, the study focused on the effect of using vertical and horizontal corrugated steel plates in strengthening the cells and studying the effect of using circular-shape cell instead of rectangular-shape one with the same web width and strengthening the circular cell with steel plate in the shape of steel pipe.

The experimental program consisted of casting and testing ten reinforced self-compacted concrete box beam specimens with identical cross-section of overall depth of (320mm), top flange width of (420mm), bottom flange width of (270mm), web width of (60mm) and overall length of (1500mm). The specimens were divided into five groups according to the number of cells, reinforcement type, strengthening and the shape of cell. All the specimens

were tested under four-point monotonic-static load to obtain the ultimate load capacity, crack pattern, mode of failure, crack width, central vertical deflection, ductility and strain in concrete and steel.

The test results showed that increasing the number of cells from one cell into two and four cells has increased the ultimate load capacity by (20.12% and 23.37%) respectively and has increased the ultimate deflection by (30.65% and 13.82%) respectively.

Also, the use of longitudinal shear steel plates that contain vertical and inclined rectangular spacings instead of vertical stirrups has increased the ultimate load capacity by (7.14% and 20.12%) respectively and has increased the ultimate deflection by (20.73% and 38.23%) respectively.

It was found that using corrugated steel plates strengthening with vertical and horizontal corrugation has increased the ultimate load by (7.14% and 11.03%) respectively and has increased the ultimate deflection by (10.92% and 2.67%) respectively.

Also, the use of circular cell without and with steel strengthening instead of rectangular cell has increased the ultimate load capacity by (17.85% and 29.22%) respectively and has increased the ultimate deflection by (63.54% and 33.77%) respectively.

Finally, the use of horizontally corrugated steel plate strengthening and circular cell with steel plate strengthening has increased the ultimate load by (3.63% and 20.60%) respectively, with a decrement in the ultimate deflection for the use of horizontally corrugated steel plate strengthening by (7.43%) and an increment in the ultimate deflection by (20.60%) for the use of circular cell with steel plate strengthening compared with the use of vertical corrugated steel plate strengthening.

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LIST OF SYMBOLS

Symbol	Title
A	Depth of rectangular stress block, mm
A_b	Area of an individual bar, mm^2
A_c	Area of concrete section, mm^2
A_s	Area of main longitudinal tension reinforcement, mm^2
A_v	Area of shear reinforcement, mm^2
bf	Effective flange width, mm
bw	Web width, mm
c	Distance from extreme compression fiber to neutral axis found by equating the internal tension and compression forces, mm
C	Compressive force
d	Effective depth of beam, distance from extreme compression fiber to centroid of longitudinal tension reinforcement, mm
E_c	Modulus of elasticity of concrete, MPa
E_s	Modulus of elasticity of steel reinforcement, MPa
f'_c	150mm*300mm Cylinder compressive strength of concrete, MPa
f_{ct}	Indirect tensile strength (splitting tensile strength), MPa
f_{cu}	Compressive strength of standard cube, MPa
f_r	Modulus of rapture, MPa
f_y	Yield stress, MPa
h	Total depth of box beam
P_{cr}	First crack load, kN
P_u	Ultimate load of box beam, kN
P_y	Yield load of box beam, kN
S	Center-to-center spacing between reinforcement bars, mm
V_c	Nominal shear strength provided by concrete, kN
V_s	Nominal shear strength provided by shear reinforcement, kN
V_n	Nominal shear strength, kN
Δ_u	Deflection at ultimate load
Δ_y	Deflection at yield load
ϵ_c	Compressive strain in concrete
ϵ_s	Tensile strain in steel at theoretical moment strength of beam
β_1	Factor relating depth of equivalent rectangular compressive stress block to depth of neutral axis
ϕ	Diameter of bar, mm
φ_u	Curvature at ultimate
φ_y	Curvature yield

LIST OF TERMINOLOGIES

Terminology	Title
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AE	Acoustic Emission
ASTM	American Society for Testing and Materials
B.S	British Standard
c/c	Center to Center of span, mm
CFRP	Carbon Fiber Reinforced Polymer
CFS	Carbon Fiber Sheet
CNC	Computer Numerical Control machine
DC	Double Cells
EFNARC	European Federation of National Trade Associations Representing Concrete
FE	Finite Element
HPCC	Hollow Precast Concrete Columns
I.Q.S	Iraqi Standard Specification
IRC	Indian Road Congress
kN	kilo Newton
mm	Millimeter
MPa	Mega Pascal (N/mm2)
No.	Number
PC	Precast Column
PVC	Polyvinyl Chloride
RC	Reinforced Concrete
SC	Single Cell
SCC	Self-Compacted Concrete
SP	Superplasticizer
TC	Triple Cells

CHAPTER ONE

INTRODUCTION

1.1 General

Box girder is a commonly used structural member, it consists of two or more webs that are either vertical or inclined, connected with top and bottom flanges to produce single-cell or multi-cell box girder with rectangular or trapezoidal cross-section **(Saxena and Maru, 2013)**. As the span increases, the dead load is an important increasing factor, in order to reduce the dead load, the unnecessary materials that do not utilize their full capacity are removed out of the section, which result the shape of the box girder or the cellular structure. The usual reason for choosing the box girder configuration is that the formed closed cell has a very greater torsional stiffness and strength compared to the open section **(Upadhyay and Maru, 2017)**.

The concrete box girders are cast in situ or precast in segments **(García-Segura, et al., 2015)**. Decks can be reinforced concrete or prestressed concrete or steel. The cross section of the box girder may be in the form of single cell with one box, multiple-spine with separated boxes or multicell with common bottom flange as shown in Figure (1-1) **(Sennah and Kennedy, 2002)**.

Box girder bridges are chosen for the span that is ranging from (20m to 40m) for reinforced concrete bridge and (40m to 100m) for prestressed concrete bridges **(Raju, 2016)**.

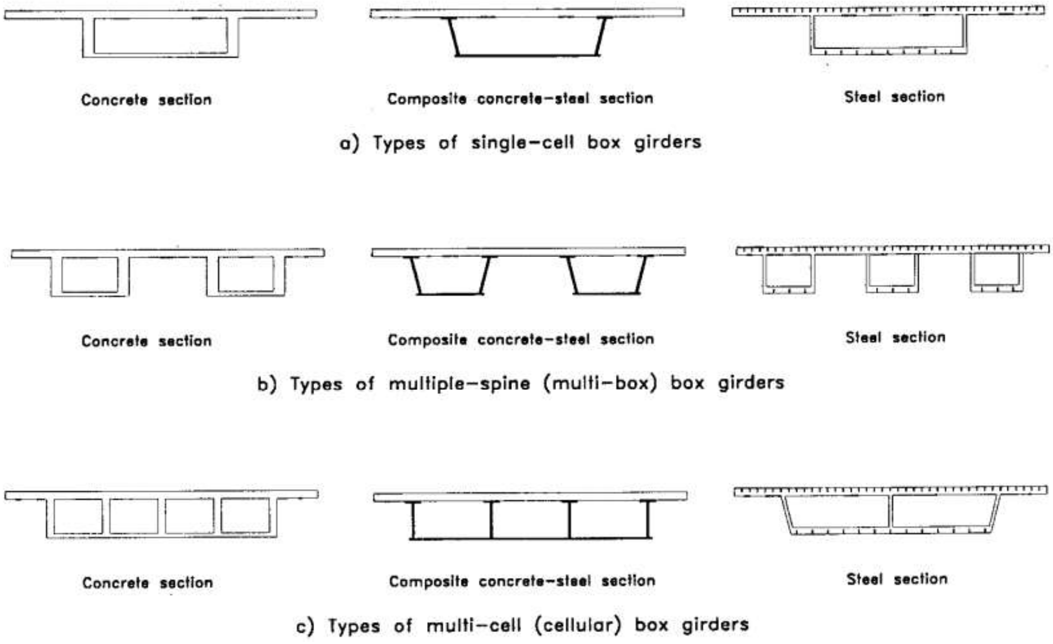

Figure (1-1): Box girder cross sections (Sennah and Kennedy, 2002)

1.1.1 Advantages of Box Girder

1. Hollow sections have been used quite often in the development of bridges, buildings, towers and offshore structures **(Hemzah, et al., 2020)**
2. Hollow cross sections are widely known for being economical, light weight and long span members. **(Waryosh, et al. 2015)**
3. Box concrete sections are commonly used beams, especially for long span bridges to reduce the dead load and save construction and materials cost **(Hemzah, et al., 2020)**. And the web can be relatively thin in order to reduce the deadweight **(Lin and Yoda, 2017)**.
4. The geometry of box girder has strength to the torsional stresses and to positive and negative bending moments because it has both of top and bottom flanges **(García-Segura, et al., 2015)** and **(Rodriguez., 2004)**.
5. Box girder has better load distribution under eccentric load **(Lin and Yoda, 2017)**.

6. The large torsional strength and rigidity of the closed section of box girder are favorable to resist the torsional moments due to the curved alignments or the eccentric live load **(Rodriguez., 2004)**.
7. The span range for box girder bridge is more compared to T-beam girder bridge, hence, there is less requirement for support points which results in making box girder more economical **(Upadhyay and Maru, 2017)**.
8. The box girder section requires less post-tensioning compared to other sections **(Rodriguez., 2004)**.
9. Box girder has the ability to carry more load than the I-beam with equal height.
10. The interiors of box girder bridges can be used to accommodate services such as gas pipes, water mains etc.
11. The maintenance of the large box girder is easier in the interior space, it is directly accessible without the use of scaffolding.
12. The alternative space is sealed hermetically and enclosed air may be dried and provide non-corrosive atmosphere.

1.1.2 Disadvantages of Box Girder

1. greater cost associated with fabrication compared with other types of normal beams

2. hard to implement the cold forms

3. risks associated with the working within enclosed spaces

1.1.3 Multi-Cell Box Girder

Reinforced concrete box girders with a multiple cell are widely used. The closed cross-section of the multi-cell makes this structure an ideal one for carrying eccentric loads or torques that are introduced by skew supports. The high internal-statical indeterminacy of this structure allows an excellent transverse distribution for the reactions and the applied load even without intermediate transverse diaphragms. The reinforced concrete multi-cell box girders are with overload capacities features due to the availability of force redistribution through the structures. Figure (1-2) shows the box girder with three cells **(Seible and Scordelis, 1994)**.

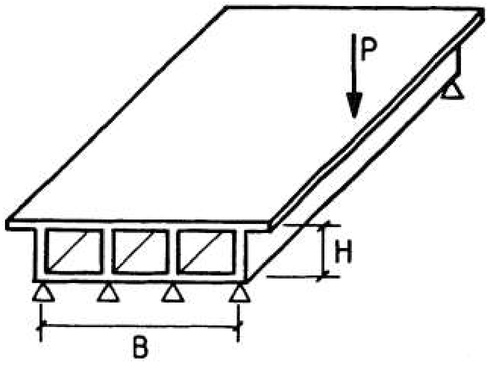

Figure (1-2): Multicell box girder (Seible and Scordelis, 1994)

1.2 Self-Compacted Concrete

Self-compacted concrete (SCC) is the kind of concrete which has the ability to flow freely through the places by its own weight and to fill the areas between the crowded steel bars without the need for vibration **(Kaszynska, 2004)**.

Self-compacted concrete has many further names such as flowing concrete **(Bui, et al., 2002)**, high-workability concrete and Self-leveling concrete **(Yang, 2004)**.

SCC has a great flow capability, can spread and fill the mold without segregation **(ACI Committee 237R-07)**.

Self-compacted concrete can be casted in a condition where it is difficult or impossible to use the vibration, for example, underwater concreting, cast in site pile foundations and walls or columns that contain congested steel bars and machine bases **(Patel, et al., 2011)**.

1.3 Steel Plates

Some efforts have been made in order to discover a new technique for shear reinforcement including the using of elongated steel plates as shear reinforcement instead of traditional stirrups due to the fast development of the manufacturing by Computer Numerical Control machine (CNC) and some difficulties in the stirrups stand with high cost and time entailed **(Ibrahim, et al., 2016)**.

1.4 Objective of Study

This research was conducted in order to experimentally investigate the structural behavior of reinforced concrete box beams. The main objectives of this study are:

1- Studying the effect of using different numbers of cells (one cell, two cells and four cells) in the box beam.
2- Studying the effect of using longitudinal shear steel plates contain vertical and inclined rectangular spacings instead of traditional stirrups in the box beam.
3- Studying the effect of using vertical and horizontal corrugated steel plates strengthening in the box beam.
4- Studying the effect of using circular cell without and with steel plates strengthening instead of rectangular cell in the box beam.

1.5 Study Justification

In recent years, the use of box beam increases significantly, this makes researchers investigate the structural behavior of this type of structural member. Yet, there are no many researches that study the number and the shape of cells in the box beam and the using of steel plates as alternative shear reinforcement as well as the use of steel plates strengthening.

1.6 Research Methodology

The experimental program of this study includes casting and testing ten reinforced concrete box beams and discussing the results in terms of ultimate load, crack pattern, mode of failure, load-deflection relationship, ductility, concrete compressive strain, steel tensile strain, strain in shear reinforcement and strain in steel plates. The experimental work consists of many variables such as:

- Number of cells
- Type of reinforcement
- Type of strengthening
- Shape of cells

1.7 Thesis Layout

The thesis consisted of five chapters:

- **Chapter One** included an introduction to box girder, its advantages and disadvantages, definition of SCC, objective of study, study justification and research methodology.
- **Chapter Two** included a review of previous studies which are related to the present study.
- **Chapter three** explained the experimental program and the properties of the used materials, details of the tested box beams, concrete mix and the test set up.
- **Chapter Four** presented the results of specimens, and the discussion of these results.
- **Chapter Five** viewed the conclusions drawn from this study, in addition to recommendations and suggestions for future research works.