Comparative Study of Structural Behaviour of Reinforced Concrete Box Girder with Different Numbers of Cells

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Abstract. The aim of this research is to study the experimental effect of the number of cells on the structural behaviour of reinforced concrete box girder. Three simply supported box girder specimens with different numbers of cells were cast by using self-compacting concrete and experimentally tested under four-point load, the first reference specimen is with one cell, the second specimen is with two cells and the last specimen is with four cells. The testing results show that the ultimate load in the two-cell and four-cell specimens is higher compared with the one-cell specimen by (20.1% and 23.3%) respectively. Increasing the number of cells decrease the cracks width and increase the number of cracks, all the specimens failed with diagonal shear.

Keywords: reinforced concrete, box girder, multi-cell, SCC

1. Introduction

The box girder is a very commonly used superstructure, it consists of two or more webs that either vertical or inclined, connected with top and bottom flanges to produce the single-cell or multi-cell box girder, the cross-section of this structure is rectangular or trapezoidal [1]. the cellular shape of the box girder is resulted by removing the unnecessary materials which leads to reduce the dead weight, therefore, reducing the dead load and the cost, the box girder have many features compared with the other sections, it has more strength and torsional stiffness compared with the open section, the span range of the box girder is more than in the t-beam, hence, the number of piers is lesser, the box girder is more economical due to its hollow section [2,3]. There are many previous studies, for example Samaan, et al. [4] presented a study of multi-cell and multiple-spine box girder models with different bracing techniques by using ABAQUS, the study compared between the corresponding mode, dynamic characteristics and natural frequencies. The results showed that the curved bridge with the cellular cross-section was more economical. Ali Laftah Abbas [5] Presented a finite element study about composite concrete-steel beams subjected to cycling loading by using ANSYS, the study investigated the nonlinear behaviour of the beam. Bagherifaez, et al. [6] presented an experimental study of three reinforced concrete box girder specimens with single, double and triple cells with different cross-sections, the specimens were 3000mm total span length and 350mm total height and subjected to torsional load, the torsional fracture was characterized by employing (AE) monitoring. Ezeokpube, et al. [7] presented a study of six reinforced concrete box girder specimens of three groups with different flange width subjected to two-point load to study the effect of the flange width on the response of the specimens and to study the validation between the experimental work and the finite strips. Chourasia, et al. [8] presented parametric study of two prestressed concrete box girder models with different two cross-sections of...
single cell and four cells by using MIDAS civil, the results showed that multi-cell is more costly compared with single cell. Khadiranaikar, et al. [3] presented a comparative study of the number of cells of pre-stressed concrete box girder bridge by using SAP2000, the study compared between the deflection, moment and shear force of two cells, three cells and four cells box girder bridge models with rectangular shape, the results showed that the box girder with two cells is more efficient compared with the others. Ali Laftah Abbas and Qassim Yehya Hamood [9] presented a finite element study of modelling existed composite bridge in Iraq, the bridge was simulated by using a real dimension in order to examine the connectors performance and strengths performance of the composite girder under the worst static load condition. Abbas Sadiq Mohammed and Ali Laftah Abbas [10] presented a study that investigated the behaviour of the lap splice by using recycled coarse aggregate in the structural members. The objective of this study is studying the effect of the number of cells on the structural behaviour of reinforced concrete box girder of the Ultimate loads, load-deflection, crack patterns, compressive strain and tensile strain.

2. Experimental program

2.1. Testing specimens

the experimental program consists of casting and testing three simply supported rectangular reinforced concrete box girder specimens with different numbers of rectangular cells (one cell, two cells and four cells), the reference specimen is with one cell (BRVS) the other specimens are with two cells (B2CVS) and with four cells (B4CVS), all the specimens are with the same dimensions of 1500mm total length, 320mm total height, 420mm total width of top flange, 270mm total width of bottom flange, 60mm web width and flange height, the dimensions of the cells are 1200mm length for all the cells, 200mm height and 150 mm width in the one-cell specimen, 200mm height and 55mm width for the two-cell specimen and 80mm height and 55mm width for the four-cell specimen, the distance between the cells is 40mm, all the specimens have solid ends with 150mm thickness. Figure 1, 2, and 3 show the dimension and the reinforcement details.

![Figure 1. Dimensions and reinforcement details of (BRVS) (all units in mm)](image-url)
2.2. Materials
In this study, the deformed steel bars that used to reinforce the specimens are steel bar with diameter of 12mm and yield stress of 566 MPa, steel bar with diameter of 8mm and yield stress of 541 MPa and steel bar with diameter of 4mm and yield stress of 442 MPa. self-compacting Concrete with compressive strength of $f'_c=25$MPa is used to cast all the test specimens, ordinary Portland cement, fine aggregate, coarse aggregate with 10mm maximum size of particles, limestone powder, tap water and High Performance Superplasticizer Concrete Admixture (HPSCA) that known commercially as “Sika Viscocrete 5930” are used in the concrete mix, Table 1. shows the mixing proportions of the concrete.

| Materials  | Cement (Kg/m³) | Sand (Kg/m³) | Gravel (Kg/m³) | Limestone (Kg/m³) | Water (Kg/m³) | Superplasticizer (Kg/m³) |
|------------|----------------|--------------|----------------|-------------------|---------------|-------------------------|
| $f'_c=25$MPa | 430            | 760          | 700            | 200               | 218           | 4                       |

2.3. Testing procedure
The specimens are tested after 28 days from the casting, after the casting process, the specimens are taken out of the moulds and cured by covering the specimens with blankets and sprinkling them continuously with tap water for 28 days, after the curing process is over, the specimens are painted with
white in order to make it easier to observe the crack development during the test, the specimens are placed on the testing machine and simply supported at the ends over span of 1300mm centre-to-centre of the supports, all the specimens are subjected to four-point load. LVDT is attached in the centre of the bottom of the specimens to measure the vertical deflection at one central point. Ultimate loads, load-deflection, crack patterns, compressive strain and tensile strain will be studied in this study. All the specimens are tested by using laboratory testing machine of structural laboratory of engineering college of Diyala University.

3. Results and discussions

3.1. Ultimate load capacity

The experimental testing results are listed in Table 2., the tests results show that there is increment in the ultimate load of the specimens (B2CVS and B4CVS) by (20.1% and 23.3%) respectively compared to the reference specimen (BRVS). This increment is due to the increase in the number of cells due to the increase in the area of steel and area of concrete, generally, in the specimens with two and four cells, the web thickness and the vertical reinforcement increased compared with box girder with one cell, the existence of the middle web lead to increase the shear strength of concrete ($V_c$) and shear strength of steel ($V_s$) which lead to increase the ultimate load. The ultimate load of the specimen (B4CVS) is more than in the specimen (B2CVS) by (2.7%).

| Name of specimens | Yield load $P_y$ (kN) | % diff in $P_y$ | Yield deflection $\Delta_y$ (mm) | % diff in $\Delta_y$ | Ultimate load $P_u$ (kN) | % diff in $P_u$ | Ultimate deflection $\Delta_u$ (mm) | Diff % of $\Delta_u$ | Ductility ratio $\Delta_u/\Delta_y$ | % diff in ductility | Mode of failure |
|-------------------|-----------------------|----------------|---------------------------|----------------|------------------------|----------------|-------------------------------|----------------|----------------|--------------------|---------------|
| BRVS              | 240                   | ---            | 5.298                     | ---            | 308                    | ---            | 8.977                        | ---            | 1.694                    | ---                | Diagonal shear |
| B2CVS             | 287                   | 19.58          | 6.297                     | 18.85          | 370                    | 20.1           | 11.726                       | 30.6           | 1.862                    | 9.91              | Diagonal shear |
| B4CVS             | 301                   | 25.4           | 6.276                     | 18.45          | 380                    | 23.3           | 10.219                       | 13.8           | 1.628                    | -3.89             | Diagonal shear |

3.2. Load deflection

The central deflection is measured by using the LVDT at the mid-span. Figure 4. shows that All the specimens showed linear relationship between the applied load and the deflection until they reached the yield load, after that there is a fast increase in the deflection. Table 2 shows that the deflection at the ultimate load for the specimens (B2CVS and B4CVS) increased compared with the reference specimen by (30.6% and 13.8%) respectively, this increase is due to the increase in the ultimate load in the box girder with two and four cells. Also, the ductility in the specimen (B2CVS) is higher than in the reference specimen (BRVS) by (9.91%), while in the specimen (B4CVS), it’s lower by (3.89%) compared with (BRVS).
3.3. Crack pattern and mode of failure

Figure 5. shows the crack patterns for all the tested specimens that measured by using optical micro-meter, the first visible flexural crack appeared at (17.2%, 20.2% and 13.9%) from the ultimate load of (BRVS, B2CVS and B4CVS) respectively and extended vertically upward. Figure 6. shows the relationship between the load and crack width, the results indicate that increasing the number of cells lead to decrease the crack width and increase the number of cracks and this is due to the cracks distribution caused by the high stiffness of the multi-cell specimens because the moment of inertia of these specimens is more than in the reference specimen, all the specimens failed in diagonal shear with sudden failure.
3.4. Steel tensile strain
All the specimens showed the same behaviour of the tensile strain development but the specimens (B2CVS and B4CVS) showed increase in maximum steel tensile strain compared with the reference specimen by (34.4% and 28.3%) respectively due to the ultimate load capacity of the specimens (B2CVS and B4CVS) were more than in the reference specimen. Figure 7. Shows the load-tensile strain development.
3.5. Concrete compressive strain

Figure 8. shows the concrete compressive strain development for all the specimens. The compressive strain of the specimens (B2CVS and B4CVS) was less than the reference specimen with the same load due to the increase of the moment of inertia in the multi-cell specimens. Whatever, all the specimens did not reach to the yield compressive strain of concrete.

![Compressive strain-load relationship](image)

**Figure 8.** Compressive strain-load relationship

4. Conclusions

From this study we can conclude the following:

- increasing the number of cells improves the shear behaviour of the reinforced concrete box girder.
- Increasing the number of cells lead to increase the ultimate load capacity by (20.1% and 23.3%) for the two-cells and four-cells specimens respectively compared with the one-cell specimen.
- Increasing the number of cells lead to decrease the crack width and increase the number of cracks.
- The ultimate deflection in the two-cells and four-cells specimens is higher than in the one-cell specimen by (30.6% and 13.8%) respectively.
- The ductility in the two-cells specimen is higher than the one-cell specimen by (9.91%), but it’s lower in the four cells-specimen by (3.89%) compared with the one-cell specimen.

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