# Comparative Study on Concrete Box Girder (Single & Double Cells) Bridges Using Finite Element Method

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**Abstract:** ***Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of reinforced girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, aesthetic appearance and structural efficiency. Generally for long span Box girder bridges are more structural efficient. Box girder resists the torsional rigidity and suited for significant curvature. For this study, Four different bridge girders are considered namely Rectangular Single and Double cell Box Girder (RSBG & RDBG), Trapezoidal Single and Double cell Box Girder (TSBG & TDBG) of spans 20 m, 30 m , 40m and 50m. Linear Static and Modal Analysis are performed on all the considered bridge girders using SAP2000 bridge wizard. IRC Class AA Tracked Loading system is considered for the analysis. A comparative report on dynamic Characteristics of all the considered bridge girders using SAP2000.***

**Keywords:** Stiffness, modal analysis, Linear Static analysis, Loading system, Dynamic Characteristics

## 1. Introduction

### 1.1 General

Bridges are defined as structures which are provided a passage over a gap without closing way beneath. They may be needed for a passage of railway, roadway, footpath and even for carriage of fluid, bridge site should be so chosen that it gives maximum commercial and social benefits, efficiency, effectiveness and equality. Bridges are nation's lifelines and backbones in the event of war. Bridges symbolize ideals and aspirations of humanity. They span barriers that divide, bring people, communities and nations into closer proximity. Bridge construction constitutes an importance element in communication and is an important factor in progress of civilization, bridges stand as tributes to the work of civil engineers.

### 1.2 Box Girder Bridge Deck

A box girder bridge is a bridge in which the main beams comprise girders in the shape of a hollow box. The box girder normally comprises either prestressed concrete, structural steel, or a composite of steel and reinforced concrete. It is typically rectangular or trapezoidal in cross section. Box girder bridges are commonly used for highway flyovers and for modern elevated structures of light rail transport. The box girder can also be part of portal frame bridges, arch bridges, cable-stayed and suspension bridges of all kinds. Box girder decks are cast-in-place units that can be constructed to follow any desired alignment in plan, so that straight, skew and curved bridges of various shapes are common in the highway system. Because of high torsional resistance, a box girder structure is particularly suited to bridges with significant curvature.

**Figure 1.1:** Box Girder Bridge

SAP2000 can perform both linear static and multi-step static analysis. Certain types of load patterns are multi-stepped, meaning that they actually represent many separate spatial loading patterns applied in sequence. These include the vehicle, live, and wave types of load patterns. SAP2000 dynamic analysis capabilities include the calculation of vibration modes using Ritz or Eigen vectors, response-spectrum analysis, and time-history analysis for both linear and nonlinear behavior.

## 2. Geometrical Configuration of the Bridge Decks

### 2.1.1 Rectangular Single cell Box Girder

**Table 2.1:** Geometrical parameters of the Rectangular Single cell Box Girder (RSBG)

| Geometrical Parameter | Dimensions (m) |
|---|---|
| Span of the Bridge Deck | 20 |
| Total Width of the Deck | 8.7 |
| Carriage way Width of the Deck | 7.5 |
| Overall Depth of deck | 1.2 |
| Width of the Beam | 0.3 |
| Thickness of the Deck slab | 0.25 |
| Cross girder width | 0.3 |
| No. of cross girders | 5 |


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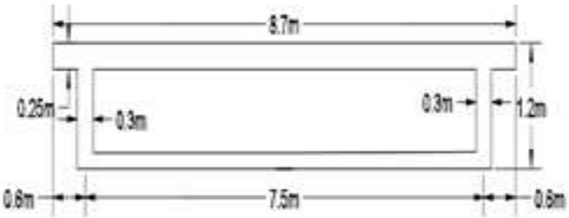


**Figure 2.1:** Cross section of Rectangular Single cell Box Girder.

Considered different span of the girder is 20m, 30m, 40m and 50m with a total depth of 1.2m, 1.8m, 2.4m and 3.0m respectively.

### 2.1.2 Rectangular Double cell Box Girder

**Table 2.2:** Geometrical parameters of the Rectangular Double cell Box Girder(RDBG)

| Geometrical Parameter | Dimension |
|---|---|
| Span of the Bridge Deck | 20m |
| Total Width of the Deck | 8.7 m |
| Width of the Deck | 7.5 m |
| Depth of deck | 1.2m |
| Width of the beam | 0.3m |
| Thickness of the Deck slab | 0.25m |
| Thickness of the soffit slab | 0.25m |
| Cross girder | 0.3m |
| No. of cross girders | 5 |

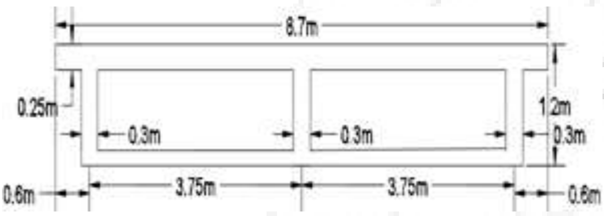


**Figure 2.2:** Cross section of Rectangular Double cell Box Girder

Considered different span of the girder is 20m, 30m, 40m and 50m with a total depth of 1.2m, 1.8m, 2.4m and 3.0m respectively.

### 2.1.3 Trapezoidal Single cell Box Girder

**Table 2.3:** Geometrical parameters of the Trapezoidal Single Cell Box Girder (TSBG)

| Geometrical Parameter | Dimension |
|---|---|
| Span of the Bridge Deck | 20m |
| Total Width of the Deck | 8.7 m |
| Width of the Deck | 7.5 m |
| Depth of deck | 1.2m |
| Width of the beam | 0.3m |
| Thickness of the Deck slab | 0.25m |
| Thickness of the soffit slab | 0.25m |
| Cross girder | 0.3m |
| No. of cross girders | 5 |

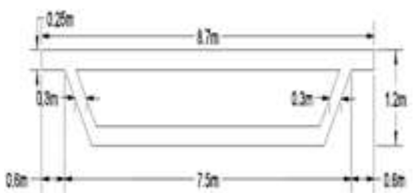


**Figure 2.3:** Cross section of Trapezoidal Single cell Box Girder

Considered different span of the girder is 20m, 30m, 40m and 50m with a total depth of 1.2m, 1.8m, 2.4m and 3.0m respectively.

### 2.1.4 Trapezoidal Double cell Box Girder

**Table 2.4:** Geometrical parameters of the Trapezoidal Double cell Box Girder (TDBG)

| **Geometrical Parameter** | **Dimension** |
|---|---|
| Span of the Bridge Deck | 20m |
| Total Width of the Deck | 8.7 m |
| Width of the Deck | 7.5 m |
| Depth of deck | 1.2m |
| Width of the beam | 0.3m |
| Thickness of the Deck slab | 0.25m |
| Thickness of the soffit slab | 0.25m |
| Cross girder | 0.3m |
| No. of cross girders | 5 |

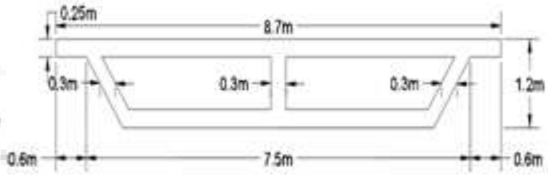


**Figure 2.4:** Cross section of Trapezoidal Double cell Box Girder

Considered different span of the girder is 20m, 30m, 40m and 50m with a total depth of 1.2m, 1.8m, 2.4m and 3.0m respectively.

### 2.2 Material Properties of the Bridge Girders

Table 3.5, shows the material properties of the bridge girders.

**Table 2.5:** Properties of the bridge girders

| | | |
|---|---|---|
| Concrete | Density | 25 kN/m$^3$ |
| | Poisson's Ratio | 0.2 |
| | Young's Modulus | 33.5E+06 kN/m$^2$ |
| | Grade Of Concrete | M25 |
| Steel | Density | 78.5 kN/m$^3$ |
| | Poisson's Ratio | 0.3 |
| | Young's Modulus | 200E+06 kN/m$^2$ |
| | Yield Stress, $F_y$ | 0.6 GPa |

### 2.3 Loads Considered for the Study

Dead load and moving loads are considered based on IRC: 6-2010.

According to IRC: 6-2010, and other parameters we considered
Dead Load (IRC 875 Part I)
Moving Load (IRC 6 – 2010)
IRC Class AA Tracked Vehicle is considered for this study.

## 3. Results

### 3.1 Natural Time Period and Frequencies

Modal analysis is performed on different types of girders namely T-Bridge girder, Box Girder single cell, Box girder multi cell, box girder slope single cell and box girder slope


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multi cell and the resulting mode shapes are noted down for different spans. In the present analysis, only 3 modes are considered.Table 4. shows the values of time period and frequencies for different girders and for different spans. As time period is inversely proportional to frequency, the Bridge with higher frequency values showed lower time period values

$$f \alpha \frac{1}{T}$$

**Table 3.1:** Natural Time Period and Frequencies for Different girders for 20m Span

| GIRDERS | Time Period (sec) | Frequency (cyc/sec) |
|---|---|---|
| RSBG | 0.18 | 5.32 |
| RDBG | 0.17 | 5.73 |
| TSBG | 0.19 | 5.29 |
| TDBG | 0.17 | 5.69 |

### 3.2 Mode Shapes

Modal analysis is performed on different spans and different types of bridge girders and mode shapes are shown below.

### 3.3 For 20m Span

#### 3.3.1 (a) Rectangular Single cell Box Girder

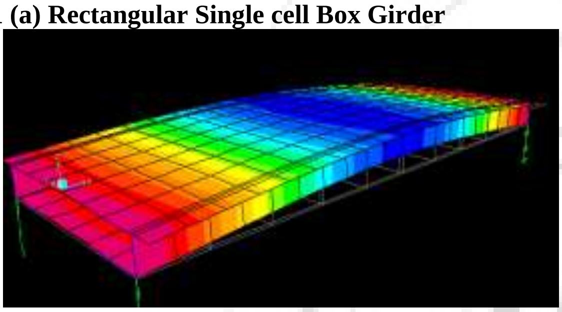

**Figure 3.1:** First Mode Shape for Rectangular Single cell Box Girder 20m Span.

#### 3.3.1 (b) Rectangular Double cell Box Girder

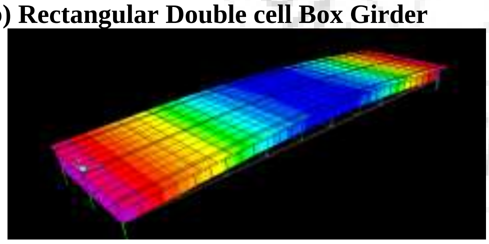

**Figure 3.2:** First Mode Shape for Rectangular Double cell Box Girder 20m Span.

#### 3.3.1 (c) Trapezoidal Single cell Box Girder

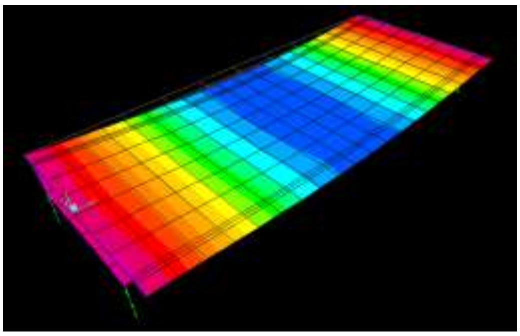

**Figure 3.3:** First Mode Shape for Trapezoidal Single cell Box Girder 20m Span

#### 3.3.1 (d) Trapezoidal Double cell Box Girder

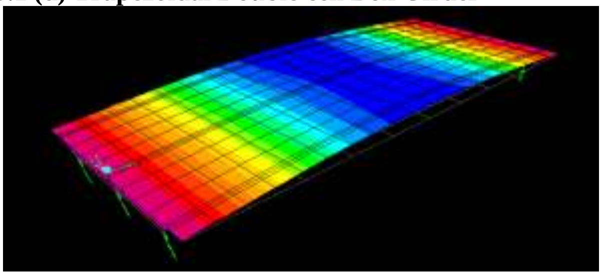

**Figure 3.4:** FirstMode Shape for Trapezoidal Double cell Box Girder 20m Span.

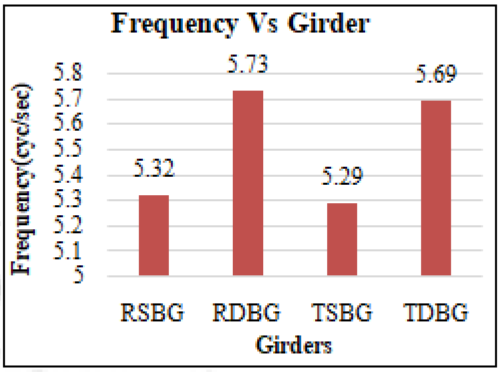


**Figure 3.5** Frequency (cyc/sec) Values For different girders shapes for 20m Span

From figure 3.5, it is observed that the maximum frequency is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 2%, 1% for RDBG and TDBG and decrease of 0.07% for TSBG when compared to RSBG.

**Table 3.2:** Natural Time Period and Frequencies for Different girders for 30m Span

| GIRDERS | Time Period (sec) | Frequency (cyc/sec) |
|---|---|---|
| RSBG | 0.23 | 4.23 |
| RDBG | 0.22 | 4.51 |
| TSBG | 0.22 | 4.15 |
| TDBG | 0.21 | 4.61 |

### 3.3.2 For 30m Span

#### 3.3.2 (a) Rectangular Single cell Box Girder

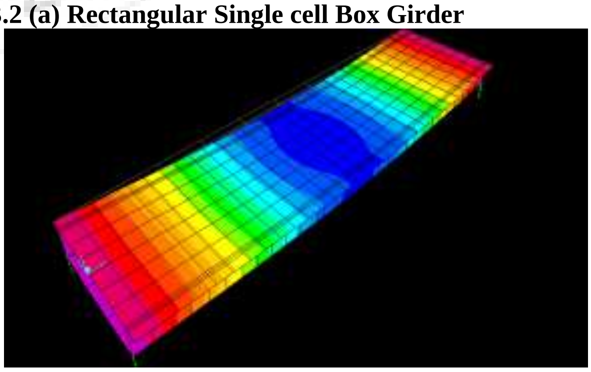

**Figure 3.6:** First Mode Shape for Rectangular Single cell Box Girder 30m Span.


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**3.3.2 (b) Rectangular Double cell Box Girder**

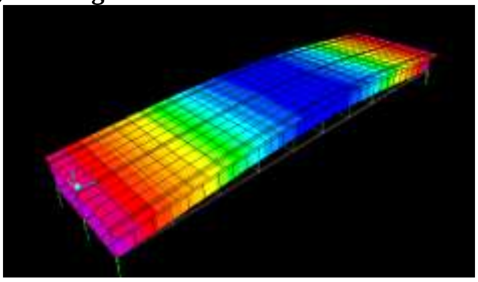

**Figure 3.7** First Mode Shape for Rectangular Double cell Box Girder 30m Span.

**3.3.2 (e) Trapezoidal Single cell Box Girder**

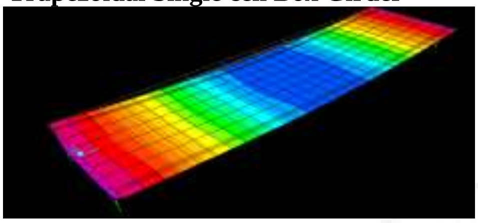

**Figure 3.8** First Mode Shape for Trapezoidal Single cell Box Girder 30m Span.

**3.3.2 (d) Trapezoidal Double cell Box Girder**

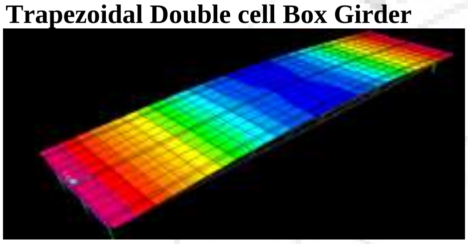

**Figure 3.9** First Mode Shape for Trapezoidal Double cell Box Girder 30m Span

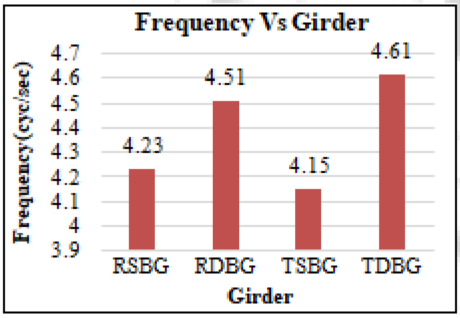


**Figure 3.10** Frequency (cyc/sec) Values For different girders shapes for 30m Span

From figure 3.10, it is observed that the maximum frequency is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 6.6%, % for RDBG and TDBG and decrease of 8.9% for TSBG when compared to RSBG.

**Table 3.3:** Natural Time Period and Frequencies for Different girders for 40m Span

| GIRDERS | Time Period (sec) | Frequency (cyc/sec) |
|---|---|---|
| RSBG | 0.35 | 2.84 |
| RDBG | 0.34 | 2.86 |
| TSBG | 0.35 | 2.82 |
| TDBG | 0.35 | 2.83 |

**3.3.3 For 40m Span**

**3.3.3 (a) Rectangular Single cell Box Girder**

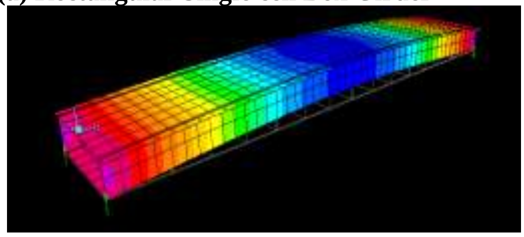

**Figure 3.11** First Mode Shape for Rectangular Single cell Box Girder 40m Span.

**3.3.3 (b) Rectangular Single cell Box Girder**

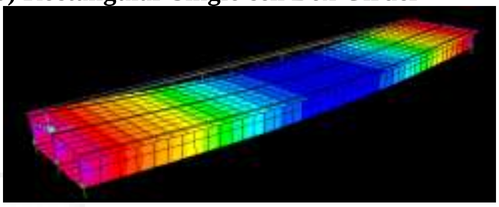

**Figure 3.12** First Mode Shape for Rectangular Single cell Box Girder 40m Span

**3.3.3 (c) Trapezoidal Single cell Box Girder**

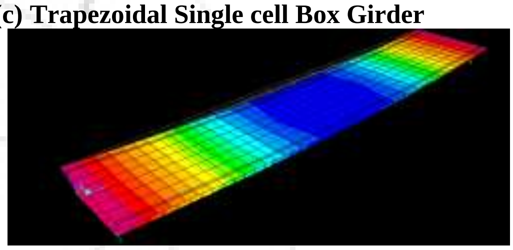

**Figure 3.13** First Mode Shape for Trapezoidal Single cell Box Girder 40m Span.

**3.3.3 (d) Trapezoidal Double cell Box Girder**

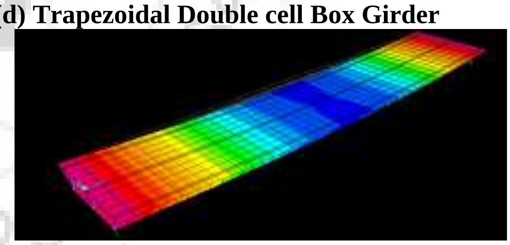

**Figure 3.14:** First Mode Shape for Trapezoidal Double cell Box Girder 40m Span

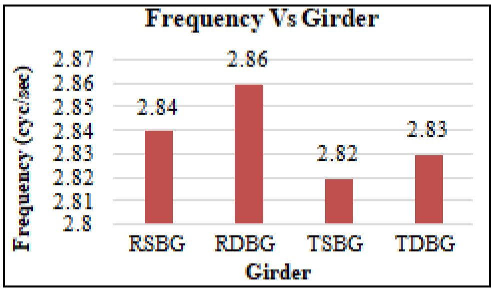


**Figure 3.15:** Frequency (cyc/sec) Values For different girders shapes for 40m Span

From figure 3.15,it is observed that the maximum frequency is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 2%, 1% for RDBG and TDBG and decrease of 0.07% for TSBG when compared to RSBG.


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**Table 3.4:** Natural Time Period and Frequencies for Different girders for 50m Span

| GIRDERS | Time Period (sec) | Frequency (cyc/sec) |
|---|---|---|
| RSBG | 0.18 | 5.32 |
| RDBG | 0.17 | 5.73 |
| TSBG | 0.19 | 5.29 |
| TDBG | 0.17 | 5.69 |

### 3.3.4 For 50m Span

### 3.3.4 (a) Rectangular Single cell Box Girder

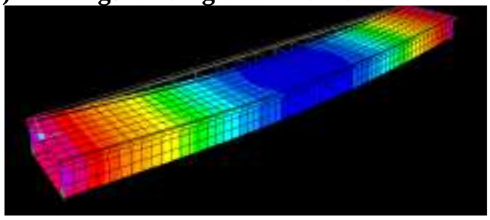

**Figure 3.16** First Mode Shape for Rectangular Single cell Box Girder 50m Span.

### 3.3.4 (b) Rectangular Double cell Box Girder

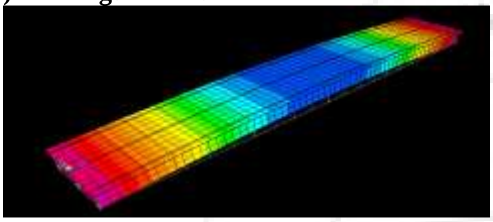

**Figure 3.17:** First Mode Shape for Rectangular Double cell Box Girder 40m Span.

### 3.3.4 (c) Trapezoidal Single cell Box Girder

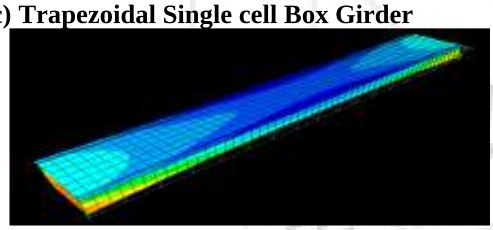

**Figure 3.18:** First Mode Shape for Trapezoidal Single cell Box Girder 50m Span.

### 3.3.4 (d)Trapezoidal Double cell Box Girder

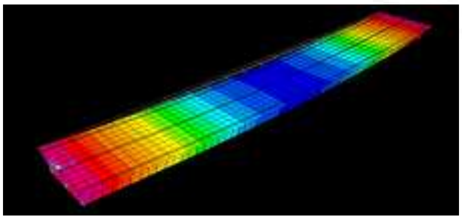

**Figure 3.19:** First Mode Shape for Trapezoidal Double cell Box Girder 50m Span.

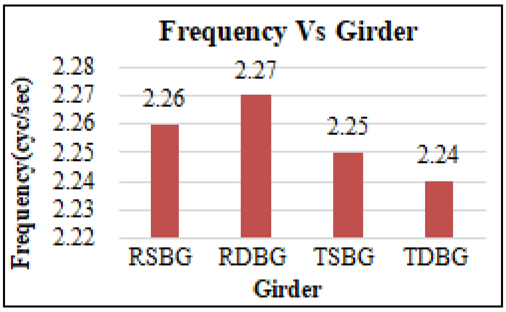


**Figure 3.20:** Frequency (cyc/sec) Values For different girders shapes for 50m Span

From figure 3.20, it is observed that the maximum frequency is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 7.7%, 6.9% for RDBG and TDBG and decrease of 0.5% for TSBG when compared to RSBG.

### 3.3 Stiffness for Different Girders

Below results shows the stiffness values obtained for different types of girders with 4 different spans subjected to Class AA Tracked Vehicle.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

f=natural frequency (cycles/sec)
m=mass (kg)
k=stiffness (N/m)

**Table 3.6:** Frequencies (cyc/sec) and Stiffness(kN/m) for Different girders for 20m Span

| GIRDERS | Frequency (cyc/sec) | Stiffness (kN/m) |
|---|---|---|
| RSBG | 5.32 | 122.20 |
| RDBG | 5.73 | 144.74 |
| TSBG | 5.29 | 116.20 |
| TDBG | 5.69 | 137.49 |

**Table 3.7:** Frequencies (cyc/sec) and Stiffness(kN/m) for Different girders for 30m Span

| GIRDERS | Frequency (cyc/sec) | Stiffness (kN/m) |
|---|---|---|
| RSBG | 4.23 | 80.03 |
| RDBG | 4.51 | 94.18 |
| TSBG | 4.35 | 81.49 |
| TDBG | 4.61 | 95.07 |

**Table 3.8.**Frequencies (cyc/sec) and Stiffness(kN/m) for Different girders for 40m Span

| GIRDERS | Frequency (cyc/sec) | Stiffness (kN/m) |
|---|---|---|
| RSBG | 2.84 | 37.46 |
| RDBG | 2.86 | 39.81 |
| TSBG | 2.82 | 35.70 |
| TDBG | 2.83 | 37.81 |

**Table 3.9:** Frequencies (cyc/sec) and Stiffness (kN/m) for Different girders for 50m Span

| GIRDERS | Frequency (cyc/sec) | Stiffness (kN/m) |
|---|---|---|
| RSBG | 2.26 | 24.72 |
| RDBG | 2.23 | 25.58 |
| TSBG | 2.25 | 23.77 |
| TDBG | 2.2 | 24.21 |


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### 3.5 Comparison of Stiffness with different Girders

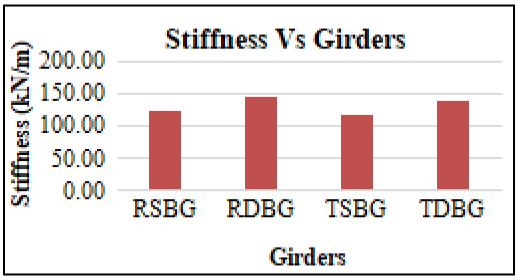


**Figure 3.21:** Stiffness (kN/m) Values for different girders shapes for 20m Span.

From figure 3.21, it is observed that the maximum stiffness is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 18.4%, 12.5% for RDBG and TDBG and decrease of 4.9% for TSBG when compared to RSBG.

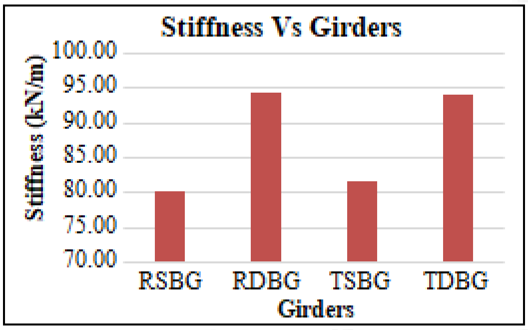


**Figure 3.22:** Stiffness(kN/m) Values For different girders shapes for 30m Span.

From figure 3.22, it is observed that the maximum stiffness is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 17.6%, 18.7% for RDBG and TDBG and decrease of 18.7% for TSBG when compared to RSBG.

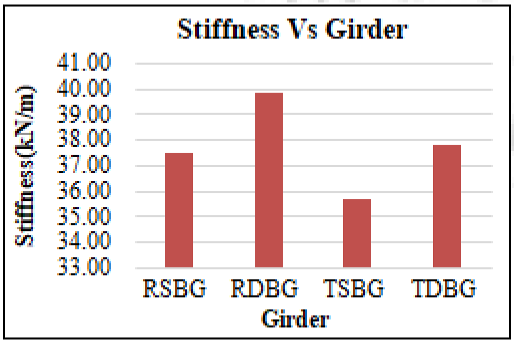


**Figure 3.23:** Stiffness (kN/m) Values for different girders shapes for 40m Span

From figure 3.23,it is observed that the maximum stiffness is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 6.2%,0.9% for RDBG and TDBG and decrease of 4.6% for TSBG when compared to RSBG.

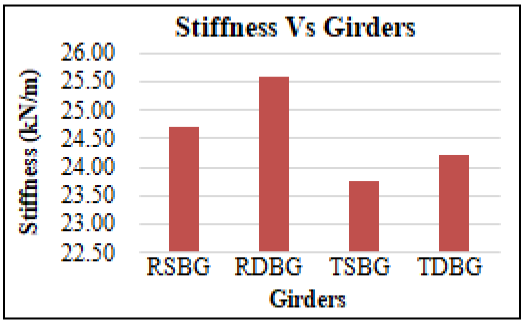


**Figure 3.24:** Stiffness (kN/m) Values for different girders shapes for 50m Span

From figure 3.24, it is observed that the maximum stiffness is for Rectangular Double cell Box Girder (RDBG) in all considered girders. It is observed that there is an increase in stiffness of 3.4%, 3.3% for RDBG and TDBG and decrease of 3.8% for TSBG when compared to RSBG

## 4. Conclusions

For all considered spans Rectangular Double cell Box Girder (RDBG) having maximum stiffness when compared to all other considered girders.

For all considered spans due to dead and moving load Rectangular Double cell Box Girder (RDBG) having minimum deflection when compared to all other considered girders.

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