

# Performance Comparison of Rectangular and Trapezoidal Pre-Stressed Box Girders Through SAP2000 Modeling

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## Abstract

The continuous expansion of global bridge networks, driven by population growth and urban development, has necessitated the use of structurally efficient and economical bridge systems. Among these, the prestressed concrete box girder stands out for its superior torsional stiffness and material efficiency, particularly in long-span and wide-deck applications. This thesis explores the structural behavior, historical evolution, and comparative performance of various box girder configurations.

The research focuses on a comparative study of **rectangular** and **trapezoidal** prestressed concrete box girders (two-cell and three-cell) with a span of **35m**. Using **SAP2000** bridge wizard software, the study employs **Linear Static Analysis** to evaluate responses under **IRC Class 70R Tracked Loading** and **Dynamic Analysis (Modal Analysis)** to determine the seismic and vibration characteristics of the structures.

A comprehensive literature review highlights the technical viability of box girders over traditional T-beam girders, noting their efficiency in resisting flexure, shear, and torsion. Key parameters such as web thickness, flange dimensions, and cell height are considered in accordance with **IRC:18-2000** specifications. The study further examines the complexities of **torsional warping** and **cross-sectional distortion** caused by eccentric loading.

The ultimate objective of this research is to identify the optimum girder configuration for the specified span by analyzing shear force, bending moments, torsion, and longitudinal stresses. The findings provide a technical basis for selecting bridge superstructures that balance aesthetic elegance with structural integrity and economic feasibility in modern transportation infrastructure.

**Keywords:** Box Girder, Prestressed Concrete, SAP2000, Finite Element Method, IRC 70R Loading, Torsional Stiffness, Trapezoidal Section, Structural Analysis.

## 1. Introduction

### 1.1 General

The continuous expansion of bridge network throughout the globe is mainly due to increase in traffic, population and extensive growth of the metropolitan areas. This growth has led to many changes in use and development of various kinds of bridges, girders etc. There are various types of bridges such as beam, truss, cantilever, suspension and cable stayed bridges where box girders can be used. The bridge type is related to maximum use of material properties and construction techniques for particular span

and application. As span increases, dead also increases and it is an important factor. To reduce the dead load, the ineffective zone materials, which is not utilized to its full capacity are removed out of cross-section. Thus it leads to cellular structure or box girder. As studied span range of box girder are more than T-beam girder when compared as lesser number of pier for same valley width and hence results in economy.

### 1.2 Historical Development and Description

The first girder box cross section possessed deck slabs that cantilevered out slightly from the box to the position using the prestressed concrete the length of cantilever could be increased and the number of members could reduce in the form of work cost that will caused the reduction in the number of cells. To reduce the construction loads to the minimum possible extent one longitudinal girder is sufficient for multiple traffic lanes.

Due to the development of high strength prestressing steel that it became possible span longer distance. The first prestressed concrete bridges were most of I-sections and were build towards the end of the 1920's. After that the great breakthrough was achieved after 1945. The bridge over the river Maas "THE SCLAYN" which was built by magnel in 1948, was the first continuous prestressed concrete box – girder bridge with 2 spans of 62.70m. Within the following years the ratio of wages to the costs of girder cross-section evolved structurally from the hollow cell-deck bridge or T-beam bridges, so the area of compression zone extended throughout the entire length of the bridge according to the requirement at the central piers and because of the advantages transverse load-carrying characteristics.

### 1.3 Evolution

The spanning of bridges started with simple slabs. As the span of the slab increased the design of the slab also increased. It is known that the material near the centre of gravity contributes very little for flexure and hence it can be removed. This leads to beam and slab systems. The reinforcement in the bottom bulb of the beam provides capacity for the tensile forces and top slab concrete, the capacity combats the compression. They formed a couple to resist flexure.

As the width of slab increases, more amount of longitudinal girders is required leading to the reduction of stiffness of beam in transverse direction and comparatively to the high transverse curvature. The webs of beams get open out by spreading radially from the top slab. Under the high transverse bending will leads no longer to be in their original position. The bulbs at the bottom tied together to keep it in their original position which in-turn leads to evolution of box girder. suffer in curvature in longitudinal and transvers direction causes heavy distortion of cross-section deck to a minimum occurs due to long span with wider decks and eccentric loading on cross-section.

### 1.4 Box Girder

A cellular structure that contains hollow sections which reduce the dead load and focuses only on effective portion and thus ensuring greater span and economy. Box girder is an element of bridge in which the main beams comprises in box shaped structure and this type of bridge is called box girder bridge. A box girder can be reinforced concrete, structural steel, prestressed concrete and composite steel material. Its cross-section is of different shapes such as rectangular, trapezoidal, circular, clipped circular and girders with maximum slope.

A box girder is a monolithic structure with two slabs, top and bottom slabs connected by two or more vertical stems called web that may be inclined or vertically placed as desired. This closed structure is efficient to deliver greater torsional stiffness and strength than typical open structure.

Generally, box girders are used in Arch bridges, portal frame bridges, cable- stayed bridges and suspension bridges of all kinds. Box girders are cast-in-place as per desired requirements. Box girders are best suited for straight, curves, and skew bridges due to its high torsional rigidity. There are following cross-sections of box girders:

1. Rectangular cross-section
2. Trapezoidal cross-section
3. Circular cross-section

In box girders web are placed vertically or inclined such that to reduce the size of bottom flange. Box girders are more suitable for larger span and wider deck and are oftenly used due to its elegant, economy and aesthetic. box girder is more efficient for flexure, shear, torsion, distortion.

#### 1.4.1 Classification of Box Girders

Box girders can be classified in four different categories that are as follows.

- A. Based On Cross-Section
- B. Based On Geometry
- C. Based On Materials
- D. Based On Reinforcement

#### 1.4.2 Methods for Analysis of Box Girders

There are some methods for the analysis of box girder bridges are as follows:

1. Simple line analysis or beam analysis
2. Grillage analysis
3. BEF Analysis (Beams on elastic foundation)
4. Space frame analysis
5. Finite element method
6. Finite Element Analysis -

The finite element method is a technique for analysing complicated structure by nationality cutting up the continuum of the prototype into a number of small elements which are connected at discrete joints called nodes. For each element, approximate stiffness equation are derived relating the displacements of the nodes to the node forces between elements and, in the same way that slope deflection equations can be solved for joints in a continuous beam, an electronic computer is used to solved the very large number of simultaneous equations that relate node forces and displacements.

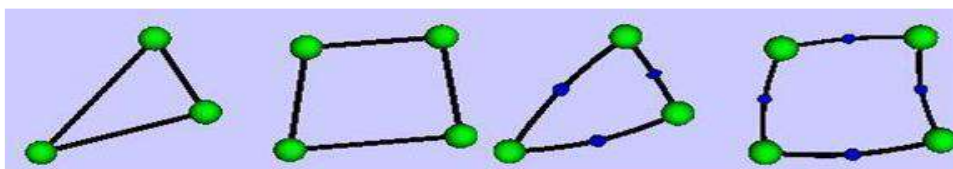


Fig: 1.12- 3 Noded Triangle, 4 Noded Quadrilateral, 6 Noded Triangle, 8 Noded Quadrilateral

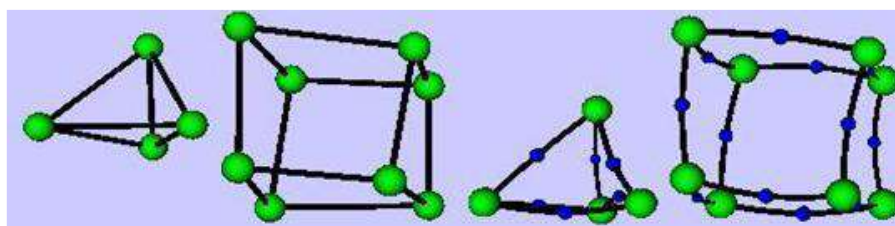


Fig:1.13- b) 9 Noded Hexahedron, 10 Noded tetrahedron, 20 Noded Curved solid

The finite-element method is a numerical procedure for solving problems in engineering and mathematical physics. In structural problems, the solution is typically concerned with determining stresses and displacements. Finite element model gives approximate values of the unknowns at discrete number of points in a continuum. This numerical method of analysis starts by discretizing a model. Discretization is the process where a body is divided into an equivalent system of smaller bodies or units called elements. These elements are interconnected with each other by means of certain points called nodes. In the case of small displacements and linear material response, using a displacement formulation, the stiffness matrix of each element is derived and the global stiffness matrix of the entire structure can be formulated by assembling the stiffness matrices of all elements using direct stiffness method. The global stiffness matrix represents the nodal force-displacement relationships and can be expressed by the following equilibrium equation in matrix form:

$[F] = [K] [U]$  Where,

$[K]$ =global stiffness matrix assembled from the element stiffness matrices,

$[U]$ =nodal displacement vector and

$[F]$ =nodal load vector.

### 1.5 Objectives

- The objective of this study is to analyze the structural behavior of prestressed Rectangular and Trapezoidal (two and three) cell Box Girder of spans 35m.
- To analyze the performance of bridge girders via **Linear Static Analysis** for IRC Class 70R Tracked Loading system using SAP2000 bridge wizard software.
- To analyze the performance of bridge girders via Dynamic Analysis (**Modalanalysis**) for IRC Class 70R Tracked Loading system using SAP2000 bridge wizard software.
- To prepare comparative report and hence the outcomes of all the considered bridge girders and identify the optimum girder for the span using SAP2000.

### 1.6 Scope of study

The present work is about the study of the behavior of box girder. The cross section is limited to the rectangular and trapezoidal shape. This study is limited to constant cell divisions i.e. two cell and three cell box girders. This study is limited to three different spans. The super elevation is not considered in the modeling. Only linear static and dynamic analysis is considered for the study. The different responses like shear force, bending moment, moment about vertical axis and about horizontal axis, torsion, deflection, longitudinal stress etc. program sap2000 is used throughout this study for the structural modeling and analysis of box girders. This study is employed by the finite element method for analysis.

## 2. Methodology

### 2.1 Analysis of Box Girder Bridges

Study of box girder bridges finite element method is more accurate method. The study is performed to compare the rectangular and trapezoidal (two and three) box cell girder. In that 35 m span will be taken for static analysis and dynamic analysis will be performed. In dynamic the dead load, live (vehicle) load, prestressed load and earthquake load will be considered. box girders will be analyzed using the model and the results for the deformation, moment, shear and stresses, Deflection, will be tabulated and plotted.

### 2.2 Modeling of Box Girder Bridge for Parametric Study

- All the models will be modeled in SAP 2000 software for parametric study. Different lengths of multicellular box girders will be formed of two shapes rectangular and trapezoidal of straight viaduct.

- Then the different responses like shear force, bending moment about horizontal axis, bending moment about vertical axis, deflection, longitudinal stresses and fundamental frequencies would be studied.

### 2.3 Design Loads for Bridge Design as Per IRC 6:2016 Section II

The loads that are to be considered on the superstructure of a box girder bridge as per IRC 6:2000 are listed below: -

#### A. Permanent Loads:

- Dead loads
- Superimposed dead loads

#### B. Temporary Loads

- Vehicle loads
- Earthquakes loads
- Wind forces
- Channel forces
- Centrifugal forces
- Impact forces
- Construction loads

#### C. Deformation Loads

- Creep
- Shrinkage
- Settlement
- Uplift forces
- Thermal forces

#### D. Group Loading Combinations

All these loads are present in bridge construction, for present study of multi-cell box girders, the scope is limited to dead load, live load, prestressed load and earthquake load only.

### 2.4 Load considered:

In this study the loads considered are limited to only dead load and live loads.

#### 1. Dead load:

The dead load carried by the girder is its own weight and any permanent loads. The dead load can be calculated fairly during design and can be controlled during construction. The dead load is always considered with the safety factor so during construction any increase of load should not affect any work.

#### 2. Live load:

Live loads are those caused by vehicles which pass over the bridge and are transient in nature. These loads cannot be estimated precisely, and the designer has very little control over them once the bridge is opened to traffic. However, hypothetical loadings which are reasonably realistic need to be evolved and specified to serve as design criteria. There are four types of standard loadings for which road bridges are designed.

According to IRC6-2016, bridges should be designed for IRC Class 70R loading and should also be checked for IRC class A loading. Clause 204.1.

2 Earthquake load: As per IS 1893 2002 the earthquake load and its parameters is considered for zone

3 Prestressed load: The load of prestressing is applied by tendons.

4 load combination: The load combinations would be considered as per IRC 6:2016 clause 204.3.

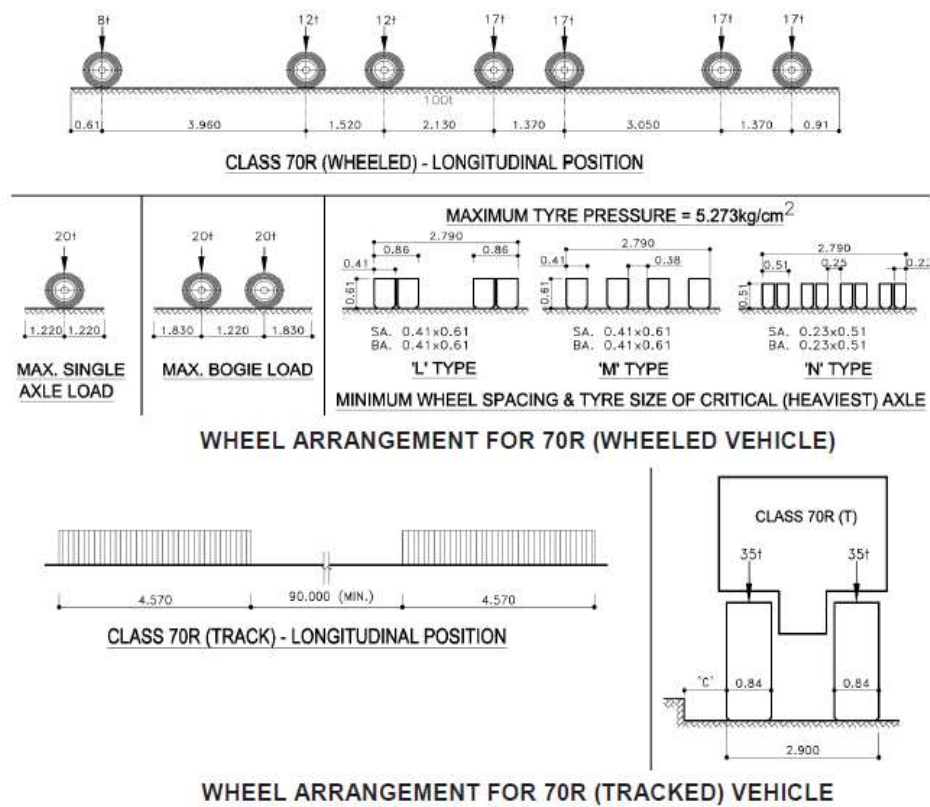


fig:3.1 wheel arrangement for 70R tracked loading as per IRC

## 2.5 Problem Formulation

- **Problem Statement:**
- A box girder for 2 lane national highway bridge of total 10.98 m wide deck and further data given below as per IRC 6 table 6:
- Type of support: - simply supported.
- length: - 35 m
- Carriageway width: - 8.75m
- foot path width: - 1.45m
- load type: - IRC class 70R loading system.
- concrete grade: M40 for both the cell types.

## 2.6 Design Steps of Multi Cell Box Girder Using SAP200

1. Open new file in SAP2000 software and give geometry coordinates and members of structures.
2. Give material properties of structure.
3. Give loads applied on structure and also wheeled loads on deck slab as per code in design of bridge. (IRC 6 & IRC 18:2000).
4. Now design box girders.

Run analysis and design command of sap2000 and get the whole design of multi cell box girder.

## Results and Discussion

In this project different models of cell girders having different cells and different shapes were analysed for a particular span and the results obtained for static and dynamic analysis of girder and the compari-

son was done on the basis of stresses and the displacements and the modal frequencies obtained for different models are shown in tables below.

Where,

shear  $v_2$  = Vertical shear force

shear  $V_3$  = Horizontal shear force

moment  $M_2$  = Verticalmoment

moment  $M_3$  = Horizontalmoment

<b>TABLE: Element Forces - Links</b>					
<b>Station</b>	<b>P</b>	<b>V2</b>	<b>V3</b>	<b>M2</b>	<b>M3</b>
Text	KN	KN	KN	KN-m	KN-m
I-End	47.132	130.547	406.988	248.0998	79.5815
J-End	47.132	130.547	406.988	0	0
I-End	1537.037	793.207	4756.667	2899.6641	483.5389
J-End	1537.037	793.207	4756.667	0	0
I-End	-9184.33	-5332.289	-11473.612	-6994.314	-3250.5637
J-End	-9184.33	-5332.289	-11473.612	0	0
I-End	-4963.489	2291.886	4397.367	2680.6347	1397.134
J-End	-4963.489	2291.886	4397.367	0	0
I-End	-4232.202	13183.429	7126.824	4344.512	8036.6183
J-End	-4232.202	13183.429	7126.824	0	0
I-End	-11846.614	-14037.851	-9464.066	-5769.2944	-8557.4742
J-End	-11846.614	-14037.851	-9464.066	0	0
I-End	7385.531	7727.815	39007.804	23779.1571	4710.8762
J-End	7385.531	7727.815	39007.804	0	0
I-End	19757.364	-748.876	14107.109	8599.6935	-456.5149
J-End	19757.364	-748.876	14107.109	0	0
I-End	-14376.907	25250.963	-9301.115	-5669.9595	15392.9873
J-End	-14376.907	25250.963	-9301.115	0	0
I-End	-8867.555	3215.416	-6223.775	-3794.0134	1960.1174

TABLE: Element Forces - Links					
Station	P	V2	V3	M2	M3
Text	KN	KN	KN	KN-m	KN-m
I-End	47.132	130.547	406.988	248.0998	79.5815
J-End	47.132	130.547	406.988	0	0
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I-End	-11846.614	-14037.851	-9464.066	-5769.2944	-8557.4742
J-End	-11846.614	-14037.851	-9464.066	0	0
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I-End	-14376.907	25250.963	-9301.115	-5669.9595	15392.9873
J-End	-14376.907	25250.963	-9301.115	0	0
I-End	-8867.555	3215.416	-6223.775	-3794.0134	1960.1174

Table 4.10: Shear and moment for 3 cell trapezoidal cell box girder

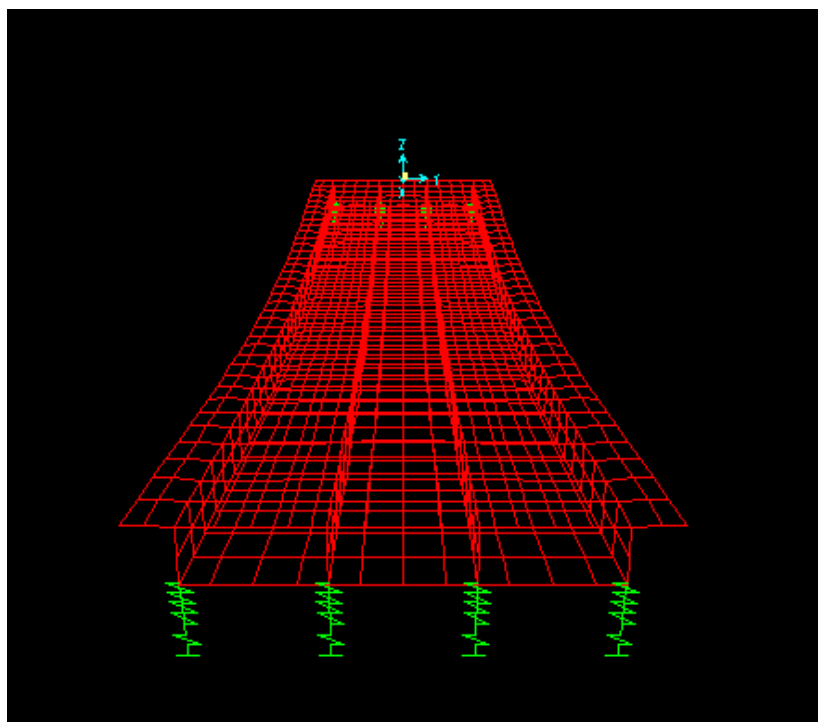
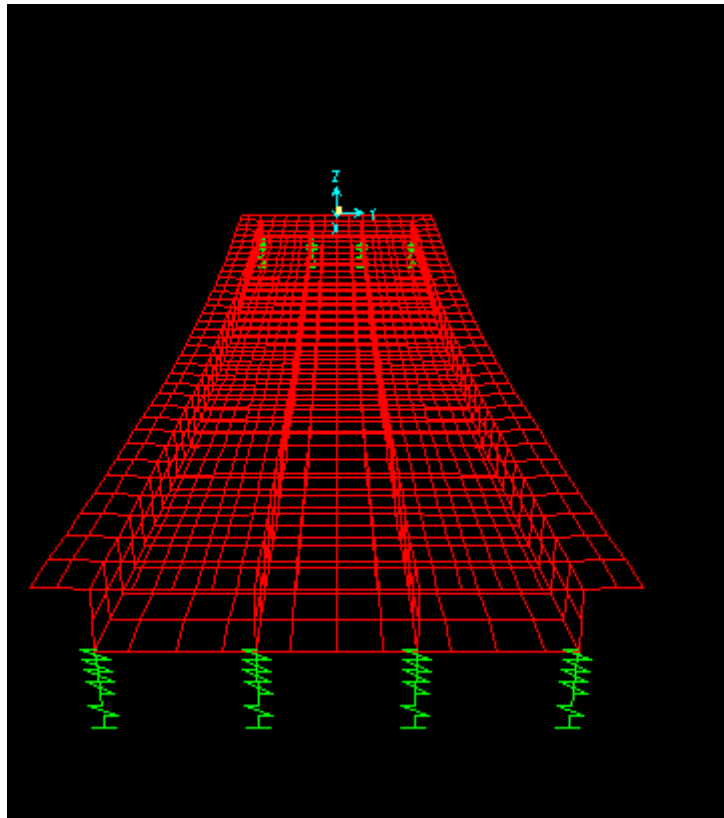
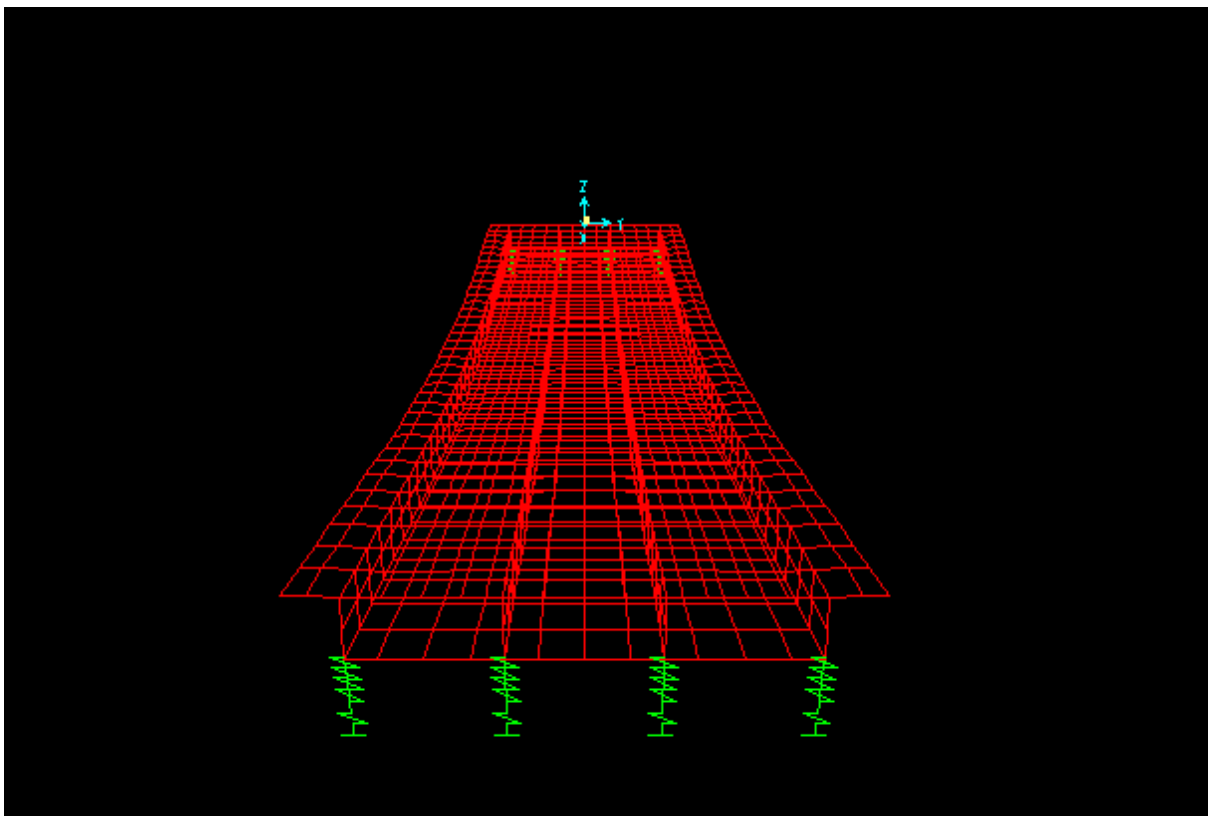


fig:4.1 Behaviour of 3 cell rectangular box girder due to dead load



**fig:4.2 Behaviour of 3 cell rectangular box girder due to live load**



**Behaviour of 3 cell rectangular box girder due to load combinations**

## Discussion

The percentage variations of different accelerations static and dynamic and shear and moment and frequency between different cell girders as well as different shape of girders is observed from the graphs above and mentioned below as :

1. The percentage variation  $U_x$  between 2 cell and 3 cell rectangular girder observed as 0.01%
2. The percentage variation  $U_x$  between 2 cell and 3 cell trapezoidal girder observed as 0.0002%
3. The percentage variation  $U_x$  between 2 cell rectangular and 2 cell trapezoidal girder observed as 0.01%
4. The percentage variation  $U_x$  between 3 cell rectangular and 3 cell trapezoidal girder observed as 0.002%
5. The percentage variation  $U_y$  between 2 cell and 3 cell rectangular girder observed as 0.26%
6. The percentage variation  $U_y$  between 2 cell and 3 cell trapezoidal girder observed as 0.22%
7. The percentage variation  $U_y$  between 2 cell rectangular and 2 cell trapezoidal girder observed as 0.02%
8. The percentage variation  $U_y$  between 3 cell rectangular and 3 cell trapezoidal girder observed as 0.02 %
9. The percentage variation  $U_z$  between 2 cell and 3 cell rectangular girder observed as 0.01%

## Conclusion

In the above work, the analysis of models of two cell and three cell rectangular as well as trapezoidal box girder is performed for same load condition as per IRC specification and analysed under different parameters like shear force, moment, frequency and stiffness. The results were observed in form of graphs and discussed. Thus, following conclusions are drawn.

1. The trapezoidal section carries more shear values than rectangular section. As the cell increases the shear value increase thus increasing no. of webs will lead to increase in shear value. The two-cell rectangular box girder contains lowest shear value than other box girders.
2. The trapezoidal box girder has highest moment value among the considered girders. In this we observe that the increase of moment value when increase in no. of webs in each section. The rectangular section has least moment values than trapezoidal section. The two-cell rectangular box girder have least moment value than other girders for similar geometric parameters and loading conditions.
3. It is observed that the two-cell rectangular box girder having least natural frequency among others. The trapezoidal section has more frequency value than rectangular section and as no. of cell increases the frequency value increases.

Greater the natural frequency, higher the stiffness. Thus, among all the girders two-cell rectangular girder have least stiffness value and so on trapezoidal section consists higher stiffness than rectangular section for each cell.

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