COST OPTIMIZATION ASPECTS OF RCC BOX GIRDER BRIDGE

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CANDIDATE`S DECLARATION

I **Madhav Singla**, Roll no **2K17/STE/09** student of **M.Tech**, Structural Engineering, hereby declare that the project dissertation titled “**Cost Optimization Aspects of RCC Box Girder Bridge**” which is submitted by me to the Department of Civil Engineering, Delhi Technological university, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship or any similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation Titled "**Cost Optimization Aspects of RCC Box Girder Bridge**" which is submitted by **Madhav Singla**, Roll no: **2K17/STE/09**, Civil Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

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Date: SUPERVISOR

ACKNOWLEDGEMENT

"It is not possible to work upon a project without the assistance & encouragement of other people. This one is certainly no exception."

On the very outset of this dissertation, I would like to extend my sincere & heartfelt obligation towards all the personages who have helped me in this endeavor. Without their active guidance, help, cooperation & encouragement, I would not have made headway in the project.

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Thanking You

Madhav Singla

ABSTRACT

The importance of transportation for the prosperity of any country cannot be disregarded. The transportation system is the major guiding wheel for the development of any country. Bridge engineering is one of the most important part of the transportation industry and an utmost fascinating field in civil engineering. In today's world, bridge construction and engineering has achieved a worldwide level of significance, due to its ability to disseminate congested traffic, economic contemplations and visual appearances.

The behaviour of a structure depends upon the span arrangement and its stiffness. Apart from the structural significance, the economy plays a vital role. The criterion of finding the best and cost-efficient results with maximum possible advantage is called optimization. As a result of past and present advancements in structural engineering field it is easier to adopt a safe design but it is certainly difficult to find the economical design, hence optimization technique is necessary to get most cost-efficient design.

There are a lot of parameters which controls the design of a bridge structure, such as the span to depth ratio of the bridge, span length, cross section, material properties etc. The major components that affect the cost of the bridge were selected on the basis of parametric study performed on all variables. The major variables were selected for their effect on cost and the performance of reinforced concrete box girder bridges. The slenderness ratio is generally being selected by the designers by the past experiences or from the construction projects executed in the past, but there is a need to identify the most optimum values so as to control the economy of the structure.

This thesis considers the important aspects related to cost optimization of box girder bridge structure. In this study, a Box girder section of different spans such as 30m,40m and 50m for the both cases of single cell and double cell is considered. It is then iterated with the span/depth ratios of 15,20 and 25. Total 18 no. of cases are formulated and a thorough design and analysis is carried out. The dead load and the live load effects have been taken into the consideration according to latest IRC 6:2016 recommendation. The analysis is taken out on the software Staad.Pro to get the maximum deflection, and the maximum bending moment and shear stresses.

The deflection which is obtained from the analysis is compared with the permissible deflection and the percentage variation in each case is attained. The detailed design of the Box girder section for each span is carried out on the spreadsheet. The cost optimization is carried out by calculating cost for each configuration by calculating the material quantities in each case and then by applying rates as per Government of India Schedule.

The results are taken out in the form of graphs and the most optimum values for each case of span depth ratio is iterated. From the study it is found that with increase in the span depth ratio the deflection increases, but the unit cost of RCC box girder decreases. The trend is similar for the increase in span lengths with constant depth. It is contemplated that the decrease in cost with respect to material quantity is significant only up to a specific ratio of span-depth. It is pragmatic that after a certain span-depth ratio considered in this study, the deflection increases beyond permissible limit. It is also observed that the number of cells plays a significant role in the structural behaviour and the economy of the structure.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Figure 1.1 Image showing Bridge of Box Girder type

In todays world, bridge construction and engineering has achieved a worldwide level of significance, due to ability to disseminate congested traffic, economic contemplations, and visual appearance .The history of bridge engineering is closely associated with the progress of human civilization spread over several centuries. A bridge can be constructed on various kinds of objects such as on rivers,railway lines,a link between two demographics etc.

The importance of transportation for the prosperity of any country cannot be overemphasied . Bridge engineering is one of the most fascinating fields in civil engineering ,calling for expertise in many areas,ranging from surveying to statistics,runoff calculations to rubble masonary,steel to structural concrete and materials to modern methods of construction.A bridge designer needs to take care of all the parameters such the visual appearances of the bridge,cost optimisation along with the general aspects such as servicibilty , performance and durability of the structure. The materials and procedures involved in construction of any sizeable bridge are quite varied.For instance,a prestressed concrete road bridge would require a proprietary system of prestressing,high grade concrete and high tensile steel girders,normal reinforced concrete for deck slab,stome masonary for substructure,piling or caisoons for foundations,neoprene for bearings,bituminous mastic and copper sheet for expansion joints,aluminium tubing for road signs and lightining posts,steel and wooden shuttering,diffetent construction machinery,etc.

It is built for the purpose of having passageway over the hindrance, usually something that can be disadvantageous to pass otherwise. There are many types of designs that provide a particular advantage to the particular type of design needed. The bridge designing process differs on the basis of the budget allocation for the particular structure,type of topographical conditions available,geological conditions and terrain,artistic values,national importance of the structure etc.

The bridge structures are of various types.The different types of bridges are the balanced cantilever type,truss bridge,Beam Girder bridges,cable stayed bridges etc. Every type of bridge structure involves different process of forces transfer to the substructure and also the stresses vary in nature.The slection of a bridge type depends upon many factors and the most important is the cost. However the other factors play a significant role depending upon the complicacy in the particular project such as need for the special requirements,the type of the foundations,location ,aesthatics and the topographical conditions.The most common type of bridge structure is the simply supported structure because of simplicity in the design,lesser complicacy and higher durability.It is found that the cost of the construction of a bridge is much greater than the cost of the construction of a highway of same length.Therefore the bridge strcutues are provided only in the cases of extreme importance.So, the bridge structures are an important part of the infrastructure of the country but also an cost intensive unit.

Last years have witnessed the development of reinforced concrete as a suitable material for the small and medium span bridge with the additional benefits of durability against aggressive environmental condition in comparison with steel.

Figure 1.2 Box Girder Bridge,DMRC,Delhi

Delhi the capital of India,has shown drastic growth in terms of population and infrastructure as well.Due the the reason of increasing population the traffic demands has considerably increased.Delhi metro rail cooperation took the initiative to meet the growing traffic demands by providing a network of metro rail across the length and width of the national capital region and it has shown an exemplary performance.The bridge portion on which the metro travels is known as the viaduct.Delhi metro has constructed the hundreds of kilometres of length of the viaduct in the union territory.In most of the portion of the viaduct ,box griders has been provided as the superstructure.The reason the ability to carry highers loads,cost efficient ,more serviceable and ability to be provided for higher spans.In engineering terms the analysis is design of the box girders bridges is also a cumbersome work.The reason for that is,the stresses which incur in a bridge structure are in all the three directions and of different types such as torsional stresses, bending stresses ,shear stresses..One example of the box bridge in Delhi constructed the Delhi metro rail cooperation is shown in the figure above.

1.2 CLASSIFICATION OF STRUCTURAL APECTS OF A BRIDGE.

The composition of a bridge structure are as mentioned below:

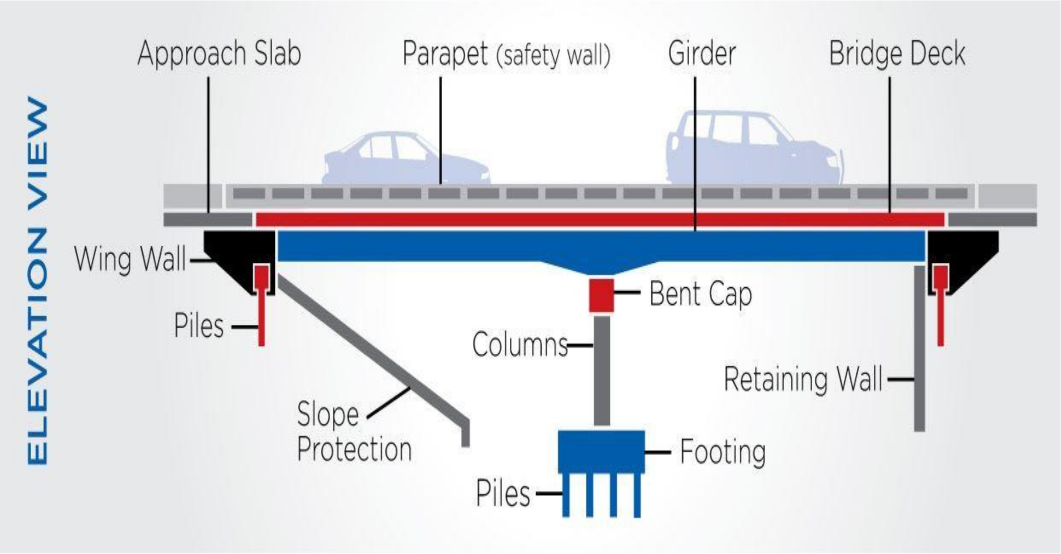

Figure 1.3 Structural Aspects of a Bridge Structure

1.Abutment- Abutment is a sub-structure unit which supports the end of superstructure and holds part or whole of the bridge structure approach earthfills.

2. Approach-A part of the pavement which connects the road to the abutment of the bridge.

3. Approach slab- It is the slab of which end rests on the dirt wall or the abutment of the bridge and the other rests on the approach.It is the transition between the approaches to the bridge.

4. Bearing-Bearing is a part of the bridge which has a very important part in the bridge structure ,it carries and transfer all the forces of the superstructure and transfer it to substructure below which is not importantly designed to have the requisite direct force bearing capacity.

5.Dirt wall- It is a vertical wall projecting from the abutment cap to prevent spilling of the earth fill materials and it also supports the approach slab.

6. Pier- It is an intermediate support to the bridge superstructure.

7. Superstructure- This part of the bridge consists of different elements such as trusses, slabs, , hand railings, girders kerb etc. This is the part of the bridge on which the vehicle loading is acted upon and that load including all the other loads such as dead load ,Foot path live load and all the other forces are then transferred to the substructure which is then transferred to the foundation.

8. Carraigeway width-Carraige way width is the minimum clear distance between the end to end faces of the carsh barriers or the kerbs of the bridge measured at right angle to the direction of the flow of the traffic.If the carriageway is divided then it is the distance between the inside face of the crash barrier or the meadian.

9.Parapet-The barriers which are put at the ends of the bridge from safety point of view and restricts the person from toppling over the bridge structure.

10. Foundation- The part of the surface which is usually in contact with the ground and transfers all the forces which are acted upon to the other part of the structure to the soil starata.

11. Retaining wall-It is a wall parallel to the road designed to retain the earth fill.

12. Hand rail-The Hand railing is provided so that it can be hold onto by the people so that it can provide support and stability.

13. Wearing coat-Wearing coat is the topmost layer on the deck surface of the bridge.This surface is provided to provide abrasion resist to the flow of the traffic.

14. Vertical clearance- It is the vertical clearance between the Lowest level of the bridge superstrcutre or the soffit of the bridge to the highest flood level.

1.3 THE BOX GIRGER BRIDGE STRUCTURES

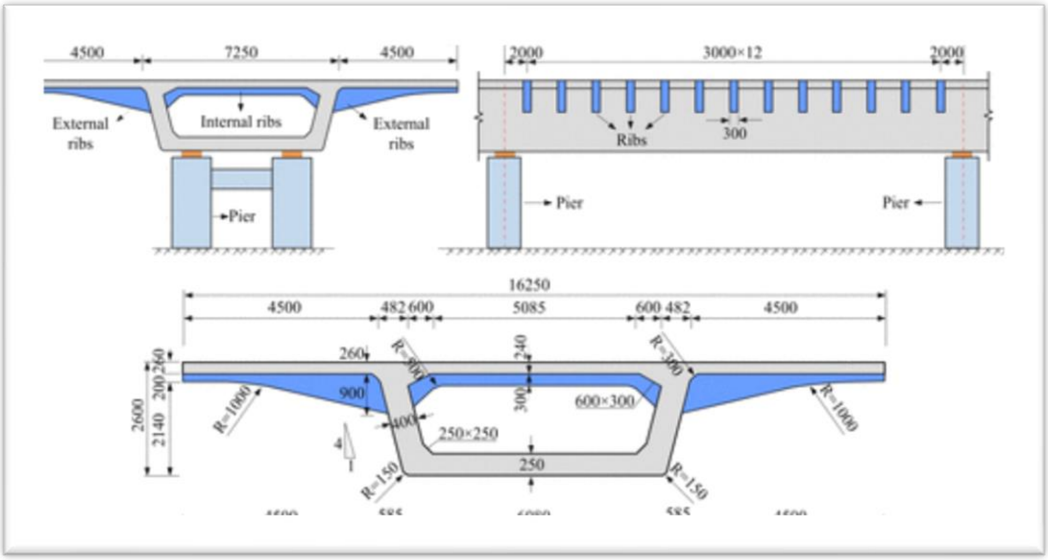

Figure 1.4 Elevation View of Box Girder Bridge

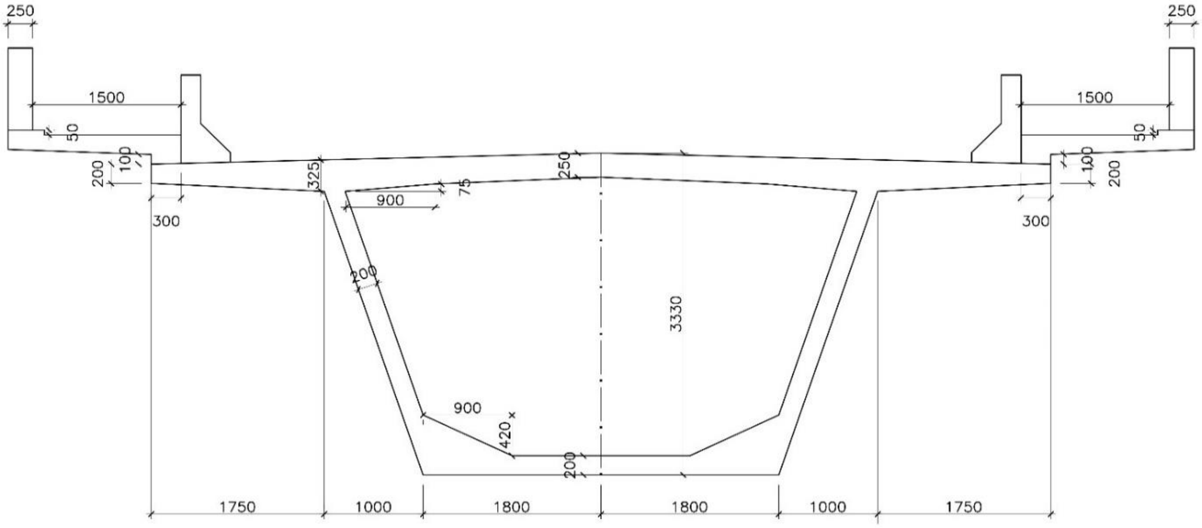

Figure 1.5 A Sectional View Single Cell Box Girder Bridge

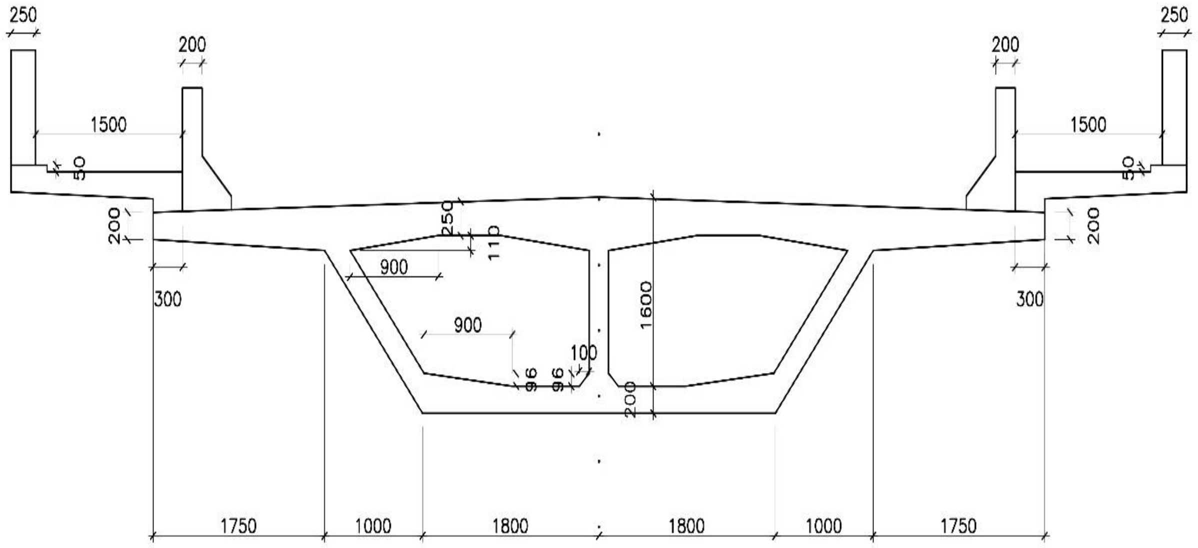

Figure 1.6 A Sectional view of Twin Cell Box Girder

A box girder bridge is a structure in the shape of a hollow box and the outer beams combiled with the web portions with soffit and deck forms a girder called box girder. The box is generally, trapezoidal , rectangular or circular in cross-section. Box girders are very commonly used in roads and bridge systems because of their high effectiveness in structures, good firmness, serviceable, fair aesthetics and economical structure. The box girder is generally reinforced concrete,Pretensioned prestressed or poststressed,composite i.e steel and concrete section. These bridges are in wide application these days with major application in road bridges,viaducts,river bridges and rail transport units.A box girder is a girder is formed with the combination of web plated attached together with two flanges at the top and the bottom,therefore in box girder the major beams comprise together to form a system to form a hollow box.The arrangement of web and the flanges form a closed cell which usually have greater torsional stiffnes and the ability to resist higher stresses and therefore due to its this ability it is more structurally preffered than the open girdes. Due to its higher torsional stiffness,box girder can transmit the load stresses in the transverse direction hence can be used in curved bridges.In case of curved thin walled sections there are chances of more torsional deformation or bending there this higher torsional rigidity in box girder they are quite convenient in this specific cases.

Box girders are not commonly used in the designing of buildings because they are mailnly used as the the axially loaded in buildings and not as bending members. They are often used in special cases such as when the loads are places eccentrically.Well when the flanges in tension are joined together with the web from both the sides,a box girder is formed.Box girder bridges are widely used because they can carry positive as well negative bending moments,they tend to have high torsional rigidity and are economic from the construction and design aspects.

The section of Box girder is of different geometry and forms.The box girders can be cast insitu or cast in place which are constructued to follow the required alignment,plan can be curved or skewed to desired angle,generally to follow any desired aligned in the bridge system.The bos girder are generally cat in the form of segments in the casting yard and then brought to the desired site location ,uplifted with the help of gantries or the launching girders and then joined together to form a span and then prestressed The box girder can be of stell,concrete or prestressed.Box girders have high torsional ridgity and are effective in curved bridges.High torsional ridgity help the girders to perform in the curved plan,skewed angle conditions.Since last decades there has been significant advancements in the field of material,and construction technology but there is no considerable improvement in the span to depth ratio.Recent developments in the field of material improvements such as high strength concrete(with strength of the range of 35MPA,135Mpa) has helped in increasing the slenderness ratio of girders .The slenderness in the bridge superstructure can help to reduce the significant cost in bridge because the reduction in dead load reduces .The reduction od dead load could of the range of more than 75percent and it helps to reduce the load on foundation strata ,helping in reduction of the depth of the foundation and other dimension parameters helping in saving of the overall costs.With the enhancements in the chemical and mechanical properties helps in the increasing of the modulus of the elasticity,higher strength,higher resistance to stresses,lightening the overall structure,more firmness and hence the slenderness ratio increases and the thinner sections could be provided.

Box Girder-type bridges have generally been designed using conservative slenderness ratios which have not changed considerably in spite of recent development in material strengths and construction techniques. In this paper,The optimization of cost on the basis of slenderness ratio by considering the cost of the construction and the material such as concrete and steel.

1.4 DESIGN ASPECTS

There are various different aspects which governs the designing of a bridge structure.Those aspects are the span length of a bridge,The maximum permissible deflection,Maximum allowable bending moment,maximum shear and the torsional stresses being generated ,the maximum static loads and the dynamic forces.

Considering the superstructure of a bridge,there are various factors which are important for the cost optimization of the structure.The cost of the bridge is dependent on various aspects based upon the stresses and the other design paramenters such as the area of the steel requisite in the section,the amount of steel reinforcement in the deck,the shear reinforcement,cross sectional area which governs the amount of concrete,prestressing strands in case of prestresses component and the other costs which primarily consists of the contruction cost.

In the bridge desgining process,the span/depth ratio also known as the slenderness ratio plays an important significance.In general the slenderness of the girder of the bridge is selected on the basis of the maximum permissible stresses and the deflection allowable according to the IS codes. It is important to understand that slenderness ratio not only governs the depth of the superstructure but it plays a significant role in governing the cost/economic aspects of the bridge structure,the aesthetic values and the material being used.If the slenderness ratio is more,the span length can be increases which means the number of intermediate peirs in a bridge structure can be decreased which further undertakes the cost and the visual factors.The slenderness ratio is generally being selected by the desginers by the past experiences or from the construction been made in the past,but there is a need to identify the most optimum values so as to control the economy of the structure.The span/depth ratio is not only dependent on the deflection but is also affected by section properties of the bridge.The aspects such as the number of cells in the box girder bridge changes the inertial properties of the structure which further changes the deflection .The variation in the area and the span length of the bridge affects the stresses generated in the structure.Also the material which is being used can changes the stresses to a particular level and therefore all these aspects plays a crucial role in the selection and the optimization of the span/depth ratio and the costs of the bridge.

The cost of material and other incurings of the superstructure gets proportionally affected by the slenderness ratio provided and is very important in the designing of the bridges .For instance when the span/depth is higher,depth the girder reduces, which make the component more slender and hence the volume of the concrete is reduced which helps in saving the material quantity. Also, slenderness ratio has significance in the visual point of view, because of the overall aesthetics of a bridge is majorly associated with the sectional properties of the Girder of the bridge.

1.5 ORGANIZATION OF DISSERTATION

This thesis have been divided into the 5 chapters.The 1st chapter deals with the general introduction above the bridge structures. Here the importance of the bridge structures, various types of bridges, present limitations in the design processes, The structural aspects of such structures have been discussed. Here the importance of box girder bridges and the design aspects associated with it have been elaborated.

In 2nd chapter the literature review has been mentioned about some of the papers related to this study. The objectives of this study and the present need has also been discussed here.

The 3rd chapter consists of the methodology adopted in this thesis. Here various design parameters has been discussed and the analysis and other major aspects associated to this study are broadly elaborated.

In the 4th chapter the results obtained from the analysis and the design are mentioned and conferred.

The 5th chapter consists of the conclusion to this thesis and the future scope of the work has been stated.

CHAPTER 2

LITERATURE

1. KHALED M.[ASCE 2002] Based on the published literature on the elastic analysis of straight and curved box-girder bridges, the following comments, pertaining to box-girder bridges, are made.

1., The finite-element method is presumably the most used and time consuming, among the refined methods. Whereas for static and dynamic analysis it is still the most involves and comprehensive technique, capturing all aspects affecting the structural response. The other methods are identified to be sufficient but limited in scope and applicability.

2. . The cumulative analysis of bridge structures through the construction, service, and ultimate phases time-dependant analysis softwares survey would be beneficial for designers. This would also apply to the design of new bridges and rating of existing bridges, especially when the software can be converted from analysis to design-oriented programs.

3. The effects of various used support conditions unrestrained and restrained with respect to temperature effects can be represented only by the 3D finite-element method. These factors need further experimentation, because they affect the flexibility of the bridge structure and, then, its static and dynamic responses.

2. POON,SOOK[2009] carried out a relative study on optimization in high strength concrete Girder Bridges on the basis of span to depth ratios.Also the basic consumption of, cost ,material and their aesthetics comparisons were made, this study identifies the optimal ratios of 8 span Bridge constructed on highway with High Strength Concrete. Three types of bridges were examined: solid slabs and precasted segmental span by span box girder, cast in situ false work prestressed box girder,. Various span lengths (35m, 50m, 60m ,75m), (20m, 25, 30m, 35m) and (30m, 40m, 50m) were taken into deliberation for cast in place box girder, solid slab and precast segmental box girder bridges respectively. For these span lengths various span to depth ratios (10, 20, 25, 30, 35), (30, 40, 50) and (15, 20, 25) were considered for above mentioned bridge systems respectively. Structural response in terms of flexural strength and shear strength was studied for each bridge type and material consumption for superstructure was calculated to decide the most economic span to depth ratio. From the results, the most optimal span to depth ratios were concluded to be 25, 40 and 20 for cast in situ box girder, solid slab and precast segmental Box Girder Bridge respectively.

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4. SARODE .B,[Jan,14]: Various parameters such as, radius of curvature, span lengths and loading are carried out in this paper,for curved box girder superstructure.Models are analysed for the using LUSAS Finite Element analysis software. Accurate shear,bending moments, torsion, support reactions and mid-span deflections. The conclusions drawn in this research are as follows:

1. It is pragmatic that there is no noteworthy variation in the bending moments and the shear forces for Dead Load, Super imposed dead load and Live load for the precise span length with different radius.

2. with the decrease of the span radius, the torsional moments increase greatly in the box girder. There is higher difference in torsion with span radius under 200m, whereas less difference for span radius above 310m.

3. The deflections at mid span of the soffit of the inner and outer webs contrast pointedly with radius of curvature of the box girder. For radius lower than 200m there is extensive

difference in the deflections. While achieving the required superelevations of the deck ,such variation in mid-span deflection shall be accounted.

4. From the reactions, it is detected that the box girders having the factor of safety against overturning fewer than 1.5 are not possible . The sharp radius below 100m shall be prevented. If such sharp curves are not avoidable then structural changes may be necessary to the cross-sectional dimensions to alleviate or tension or hold-downs bearings are introduced to stabilize the box girders which may surge the construction cost

4. FATHEMA SYED[2015] The different span to depth relation was taken into consideration for the analysis of beam bridges, and for all the cases, stresses and deflections were within the permissible limits. A comparative study of a single cell prestressed box girder and four cell box girder has been done and it is found that single cell concrete box girder is the most suitable , effiecent and cost effective crosssection for a two lane road pertaining to Indian national highways. It is experimented that the deflection occurred due to at service condition and varied loading conditions is well within the permissible limits according to IRC. The maximum deflection is found to occur close at mid-span of the beam.

5. KRKOSSAMARTIN[2015] : In their Analysis it showed that thermal effects due to vertical temperature rise impact considerably the stresses on the bridge. Majorly in the context with load due traffic movement can these effects completely set up the compressive stress of pre-stressed concrete and tensile stress may occur, what is not acceptable for example for requirement of decompression. Analysis of different actions effects for serviceability limit states shows that thermal effects cannot be fully neglected, but conversely in some cases should be taken as the leading variable action in characteristic combination for serviceability limit states.. Therefore is necessary to perform measurements and analysis of temperature gradient on more structures of various types. Measurement what was made here is not fully sufficient for accurate description and analysis of temperature gradient behavior, therefore it is necessary to perform continuous temperatures measurement, at least in periods with predicted maximum and minimum air temperatures.

6. THAKAE RAJENDAR, DESHPENDE[Jan,16]: The behavioural properties of Box girder bridges were analysed in this extensive parametric study using finite element method.The load combination of Live load(IRC 70R) loading centrally placed(zero eccentricity) and Dead

Load(self weight) for simply supported span and the continuous span were analysed on the box girder.The bending moment and the longitudinal bending stress in the bottom and top flange has been carried out along the span for different crosssections.The following conclusions can been drawn from the based study.

i. the Bending moment also increases with the increase in the depth of box girder

ii. the longitudinal bending stress in bottom flange and top flange along the span decreases with the increase in depth of box girder.

iii. Of the rectangular and trapezoidal cross section of box girders for different depths, the trapezoidal girder has the highest bending moment under the load combination of live load and dead load,live load placed (centrally) and minimum in rectangular girder. Therefore it can be drawn that the rectangular box girder section is the stiffest section among these two

7. ZHANG [2017] In this paper a non-linear finite-element method has been adopted to track the PC box bridge girder under the exposure of fire conditions. It has been found that the degree of prestressing has a considerable impact on fire resistance of PC box girder bridge. Prestressed concrete box bridge girders exposed to fire with higher degree of prestressing have lower ductility than that with less prestress degree. It has been seen that temperature variation along the girder depth is almost same and mean temperature increases significantly with fire exposure time. When the time of the girder exposed to fire is 120 min, the temperature in bottom slab and web surpass 450℃ and prestressing strands is also in high temperature, and this can lead to deterioration of mechanical properties in prestressing strands. , during first 10 min of fire exposure, mid-span deflection increased linearly, this is mainly due to significant thermal gradients that lead to high thermal stress and curvature along the girder section. The developed curvature at this stage of fire exposure is independent of structural loading on the girder due to the fact that this curvature results mostly from the coupled effect of thermal gradient.

8. AHMED[2017] In this paper the value of the acceleration coefficeint, base shear, velocity and displacement have been determined at the joints of the bridge structure. The results were shown in the form of a comparative diagram. According to the results below mentioned inference could be made. • The values, displacement, acceleration, velocity and base shear with respect to the time in the y-direction the value of the acceleration, is lesser than the displacement, velocity and base shear with respect to the time in the x-direction.. •

Acceleration response of the bridge deck dependendent on the characteristics of the bridge and applied ground motion. • Results show that the seismic response of the superstructure good agreements with recorded ground motion data in the term of the acceleration, base shear, velocity and displacement in both directions. • It also the indication that the base shear has played an important role in the seismic response of the bridge deck. It provides resistance to lateral load.

9. RAZAQPUR AG[2017] The nonlinear finite element method is used to analyze the scaled models of single-cell and two-cell box girder bridges tested to destruction at McGill University. Extensive comparison between the analytical and experimentally measured values for deflections, concrete and steel stresses, and ultimate strength are presented. Based on the favourable agreement between the two sets of results, it is concluded that (1) the nonlinear finite
element method is capable of predicting the full response of single- and two-cell prestressed concrete box girder bridges over the complete loading range, and (2) the flexural strength of
the bridge models can be predicted with reasonable accuracy using the conventional rectangular stress block and straincompatability procedure; this method cannot, however, predict the full response of the structure.

10.E.SAUMYA [2017]This study focussed on the parametric variations such as radius of curvature of the deck,span lengths, and span/depth ratio. Girder was subjected to IRC classA loading and the reponses of the structure were obtained using the response spectrum analysis. The study was conducted on the software of ANSYS.The frequency of vibration,Bending moment and reactions and the deflection in the longitudinal direction is obtained.

The following results are obtained for response spectrum analysis. The results which were attained were analysed.Those were the longitudinal deflection, the bending moments,shape of the girder, stresses maxima,and their suitability was evaluated and compared in this study as mentioned.
1. The trapezoidal shape was considered most effiecient rom the deflection and maximum bending moment,streses point of view

2.It is found out that the radius of curvature enhances,moment and the stresses reduces as the variation is made in radius of curvature.

3. The deflection increases with the span length,the bending moment and reaction also increases for the variations in the length ,span.

4. It has been identified that the deflection, stresses and the bending moment is lesser for the trapezoid shape.So, it can be concluded that trapezoidal shape is the most effiecient.

11. MISHRA MONG, SINGH .R [2018]-In this study High strength concrete is used for the optimization of the span depth ratio of the prestresses box girder bridges.They have performes analysis for varying cases of the span lengths and the span depth ratio varying from 10 to 35.In this study they have studed that the end spans shall be of lesser length as compared to other spans so as to balance the moments of the complete structure .It is observed that if the length of the end spans is similar as that of other spans moments increases for such case.

In this study it optimum slenderness ratio for the PSC girder bridges is conductes which have high strength concrete,for the case of cas-in-situ girder and the solid slabs.It has been observed that the slenderness ratio for the cast in situ girder have not been varied since past years.

12. ASHPQAHAMAD NMORB [2018] The pre stressed concrete is used in case of prestressed concrete bridge structures. So,in the present study Prestressed concrete box girder of span40m is used in study . The form of single-cell, multiple-spine, and multicell cross sections is highlighted with references affecting the straight and the curved box girder bridges. The literature survey presented herein deals with: elastic analysis, and experimental studies on the elastic response of box girder bridge. For the optimization of box girder genetic algorithm can be satisfactorily implemeted.I t is observed from the parametric study of the grade of concrete shows with increase in the grade of concrete the total cost of structure increases. From the Parametric study on the span of the bridge it is indicated that with increase in the span for the optimum section the weight increases. The force of pre-stressing is reduced for optimized section as compared to the section considered initially.

2.2 OBJECTIVE AND NEED OF THE PRESENT STUDY

2.2.1 NEED OF THE STUDY

The transportation system of the country is a major guiding wheel for the development of the country .the transportation system affects the ecommerce,freight and the economy of a country. Bridges are one of the most important part of the transport infrastructure of a country.Cost of unit length of a bridge is several times the cost of a unit length of a highway. In India,due to their lesser cost, lower maintenance, smooth and fast maintainance and minimum traffic disruption, precast pre-stressed concrete bridges are popularly used for short and medium spans (5-50 m span). The box girder bridges doesn’t have a complex design ,their span depth ratio can be controlled reasonable, good aesthetics and high durability are the main factors for their wide acceptance in the infrastructure development projects.In India, Most of the bridges constructions irrespective of their use such as rail transiet, vehicles flyovers ,metros etc widely use PSC box girder bridges which can be of steel,concrete or composite.Nowadays the designing of the box girders is still done by trail and error procedure,empirical method ,past experiences and judgment of the designer.There is an urgent need to apply computational technologies and other modern means of the designing ,construction and optimization to achieve the better and most importantly cost efficient designs.The cost optimization is necessary to provide a economic and safe design of the infrastructural projects.

Among all the designs ,for a particular design problem there are many acceptable solutions, one which is economical will pertain to both engineering and structural standards as well as economical urgency. The criterion of finding the best and cost efficient results with maximum possible advantage at minimum cost is called optimization. As a result of past and present advancements in structural designing field it is easier to adopt a safe design but it is certainly difficult to find the economical design, hence optimization technique is necessary to get most cost efficient design. Which is beneficial in many ways such as in terms of saving the material and decreasing the usage of concrete. Hence cost efficiency has gained good scope in structural engineering. In this paper the parametric study and cost optimization of box-girder bridge is carried out.

we should strive to use our natural resources optimally as they are limited,. Adopting the optimization techniques in structural design is a step in that direction. Infact, optimization provides the chance of automation in the design process, which together leads to the following benefits:

- The environmental affect and the cost of it can be reduced.
- A feasible design can be concluded in lesser time.
- The chances of errors in the design process can be reduced.
- The chances that the designs are efficient can be higher.

The selection of the span/depth ratio or as we call it the slenderness ratio is a typical process. Selecting the right ratios can help to achieve the better economy and satisfactory design results. The slenderness ratio is generally being selected by the desginers by the past experiences or from the construction been made in the past,but there is a need to identify the most optimum values so as to control the economy of the structure.

The span/depth ratio is not only dependent on the deflection but is also affected by section properties of the bridge.The aspects such as the number of cells in the box girder bridge changes the inertial properties of the structure which further changes the deflection .The variation in the area and the span length of the bridge affects the stresses generated in the structure. The ratio can be selected by optimization of the span length and depth of box girder to achieve efficiency and aesthetically-decent structure.

2.2.2 OBJECTIVES

The following objectives are mentioned for this study:

i)To identify the effects of the major parameters of such as span/depth ratio,length of span,Number. of cells on the major design parameter of a Reinforced concrete box girder bridge.

ii)To evaluate the cost for the each case of span length,span/depth ratio and no. of cells with respect to material quantity.

iii)To obtain the optimum value of span/depth ratio for the each case of span length and the number of cells of the box girder bridge for which the minimum depth would be required and which would give maximum permissible deflection .

iv)To identify the maximum possible value of slenderness ratio for RCC Box Girder section.

CHAPTER 3

METHODOLOGY ADOPTED IN THE PROJECT

3.1 GENERAL

Significant improvements has been seen the field of structural engineering from the past decades.From the design point of view,drastic improvements has been made which can help to reduce the cost of the structure without compromising with the servicibility limits,infact it has been enhanced proportionally.Developing countries like India,has been spending a lot to improve the infrastructure of the country,and reduction in the expenses by providing a safe and economical design helps in the reduction of fiscal burden.Improvements in the field of structural design,construction techniques,material helps in this feat. Bridge engineering being an important part of the structural engineering,in this chapter various design parameters has been mentioned which are taken in the analysis of the deck of the bridge and different loading conditions are mentioned to which the bridge is subjected.

There are a lot of parameters which controls the design of a bridge structure,such as the span to depth ratio of the bridge,span length,crosssection,prestressing cables,material properties,location etc.

The major components that affect the cost of the bridge were selected on the basis of parametric study performed on all variables. The major variables were selected for their effect on cost and performance of reinforced concrete box girder bridges for parametric study.

This thesis considers the important aspects related to cost optimization of box girder bridge structure.In here,a box girder of different spans such as 30m,40m,and 50m is considered.In general a box girder which has span of more than 50m ,prestressing is used.Box girder can be inconsiderably used to various types of loading,any type of bending moment whether positive or negative,and it has high stiffness in terms of torsion and provides a very economic structure. It has been concluded from the previous studies that the most economical structure is in which the cost of the foundations and the sub structure are equivalent to the cost of the superstructure that has been provided.

In this study dead load and the live load effects have been taken into the consideration according to latest IRC6:2016 recommendation.

- Distribution of the shear stress,and the bending moments have been analysed with the help of CAD software.
- Design and analyses of the box girder.
- The quantity of concrete in every section is to be estimated such as deck slab, web,soffit and diaphragms, as well as quantities of the steel reinforcement.
- A spreadsheet is then prepared which calculates performance in terms of the deflection. This sheet was then used to perform parametric study by varying each parameters and calculating the performance indices and cost of the bridge superstructure.

3.2 SPAN LENGTH

The span length is termed as the distance between the two Consecutive supports of the bridge structure.The bridge are generally categoried on the basis of span length.Span Length is one of the most important and deciding criterion for the selction of the bridge design. spans are sometimes preffered because they have the tendency to reduce the disruption in the flow of the traffic as the number of piers reduces.Different spans length use the different type of the selection of the bridge and the type of the construction methology.

For the bridges with the smaller spans with are less than 60 feet,concrete with the timber reinforcement, or the prestressed concrete or steel girder bridges are generally used.

For the medium span bridges which has span length more than 60 feet but less than 120 feet,steel or prestressed bridges are used.

For the bridges with larger spans i.e which has span length more than 120 feet and lesser than 300 feet, Higher performance steel,composite girders and steel trusses can be used.

Very large span bridges which are greater than 300 feet and lesser than 600 feet, segment bridges,extradosed bridges and cable stayed bridges could be used.

The span length is governing factor for the expenses to be attained in the construction of bridge,therefore in the designing process ,various spans are considered and the feasible outcome is often selected.The various factors which affect the span length are the site conditions,navigation ,Pier height,geotechnical conditions and economy.The other important factor now a days are the aesthetic requirements. The bridges with long spans provides good visual apperances and the obstacles are somehow reduced.The box girder bridge is economical for the bridges with have span length between 30metres to 50 metres above that balanced cantilever or trusses are oftenly used.

From the past studies it has been established that the economical structure comes out to be in which the expenses involved in superstructure is equal to the cost of the substructure.The design and the functioning of a structure mainly depends upon the site locations,topography and the substructure.

As if the span length of the bridges increases,the number of intermediate piers decreases and therefore the cost per unit length reduces.All though the span legth of a bridge structure depends upon other factors such as the foundation depth,soffit level from ground.Therefore the cost of the superstructure is variable depending upon the such factors.Box girder bridges are widely used for the medium span bridges because of the ease of construction and economy.There fore in this study different spans are taken into consideration such as 30m,40,and 50m to evaluate the structural behaviour and optimization of the cost.

With the increase in span length,the dead load also increases,therefore therefore it is needed to reduce the dead load of the structure.To do so,The excess material which is redundant should be removed,when it is done a box girder or hollow section is formed.

The span length of a bridge is also dependent on the other factors such a the launching cost and the expenses incurred on the erection of the superstructure.Therefore the site conditions and the topographgy is also to be kept in mind based upon the complications which can occur in the launching process.It is however possible that the higher span can reduce the cost of the structure but with larger span the erection can be tough resulting in higher erection cost.So, it is evident that the span length is selected by considering all the factors and then choosing a optimum result.

Here in this study different span lengths are taken into the consideration which are used in practical purposes and they are mentioned here below.

Span of 30m

Span of 40m

Span of 50m

3.3 SPAN TO DEPTH RATIO

The designing of a box girder is a very complicated design and there a various paraeters which affects the design process of which span to depth ratio is one of the most important parameter.Span depth ratio which is termed as the selenderness ratio is one of the important and deciding parameter of the behaviour of the bridge.This ratio is used to calculate therequired depth of the superstructure and there plays a crucial part.It is selected during the preliminary or conceptual designing process.Span to depth ratio is genrally selected from the previous experiences or the values used in the bridges constructed in the past .Therefore there has been a case of possiblility of the erroniuos part and hence this study is being conducted to provide a more effifient solution.

It has been observed from previous studies that the ratios of span to depth have not changes since last many decades. The recent developments in terms of material and the introduction of high strength concrete has allowed to better structural behaviour even with more slender components.

The optimization of span to depth can be done by selecting some values and making the suitable combinations and plotting them against the different spans by the process of an iteration.By this process it is beneficial as it can provide a cost efficient solution.The other benefit that can be obtained is the good aesthetics,as it is always preffered to select a slender component as possible.The slection of a optimium span depth ratio is always a critical and important part as it can help to save a lot of expenses involved in the project because the quantity of materials which are to be mobilised and the cost of construction of the superstructure are directly affected the span depth ratio.For instance if the higher span to depth ratio is used,it will require high amount of prestressing,the superstructure would be light,and as the cost of the bridges is generally determined the proportion of the superstructure ,in this the with lesser volume the cost would come out be lesser.

Based on the structurior in terms of deflection ,different span depth ratios are considered in this study for spans of 30m, 40m and 50m and the material consumption in terms of concrete and steel is evaluated.Results demonstrate the total cost of material for specific span and span depth ratio case and are formulated in the form of an graph.The permissible delfelction and the deflection obtained is evaluated and the percentage variation is observed.

3.4 NUMBER OF CELLS

The box girder can be categorised into single cell or multi cell depending upon the arrangement between the web connenction between the top and the bottom slabs. Generally,in case if the depth is more than the one sixth to one fifth of the width of the deck than the single cell girder is considered whereas if the depth is less than the one sixth to one fifth of the width of the deck then the multi cell or twin cell box girder is preffered.

Single cell box girder segment is a type of bridge segment in which number of cells are only two.Whereas as in double or multi cell box girders the number of webs is more than two,where thickness of inner and outer web can vary.The type of segment depends upon several structural aspects such as economy,structural stability,stiffness and the cost of construction.

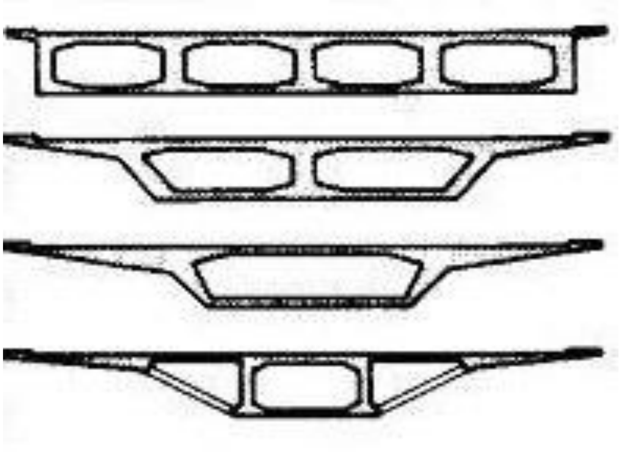

Figure 3.1 Depicting Sections with Different Number of Cells

Multi cell box girder is preffered for very wide segments in which the carraige way width requirements is more such as three lane or more lane bridges.Box girder segments either single cell or multi cell can be either prestressed or poststressed.this type of box girder segments are usually preferred for span of the range 30 metres to 70 metres. Box girder bridges are commonly used for flyovers and advanced light mode of rail transportation system.This segments can be a part of any type of bridge structure such as arch bridges,portal frame bridges,suspension bridges and cable stayed of all kinds.This box girder decks can be either cast insitu units or can be precated in the cast yard.A box girder structure is preffered due to its high torsional rigitidy which is particular required for bridges with certain curvature or skew angle.

Box girder bridges have smaller economical girder depth as compared to plate girder.Box girder segment is also aesthetically appealing in nature.

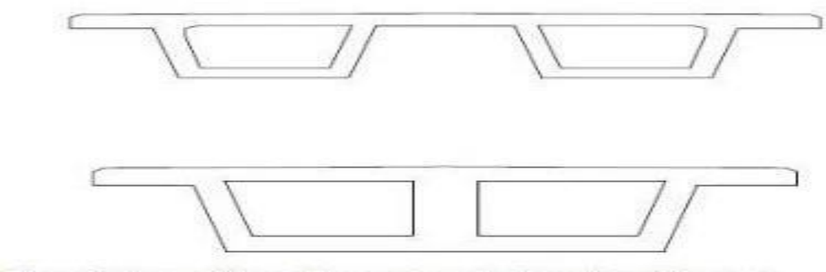

Figure 3.2 Twin Cell Box Girder

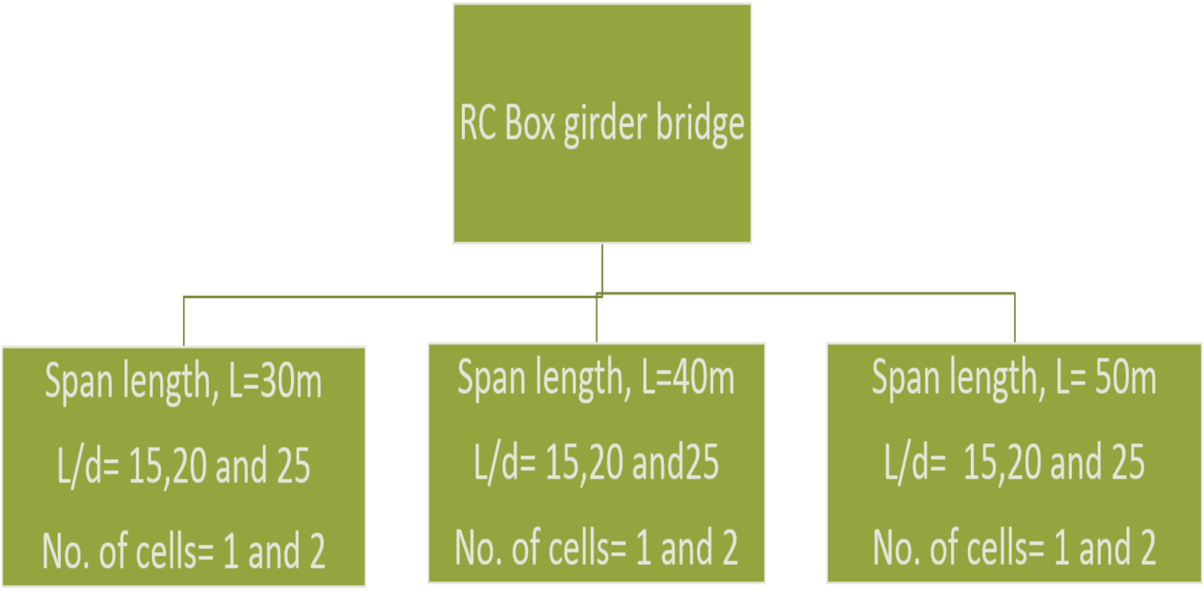

Figure 3.3 Cases Undertaken in the Thesis

3.5 LOADING

3.5.1 DEAD LOAD

The dead weight of the structure is the total weight of the components in a bridge.It included the weight of the superstructure plus the weight of the substructure components.The dead load of a structure can be calculated to the precise and accurate level and it plays an important role in the design of the structure and selection of the bridge type as it can be controlled in the process of construction.The dead load can be calculated by the material properties enables in a structure.

3.5.2 IRC STANDARD LIVE LOADS

In a structure,Live loads are the vehicular loads that travel on the bridge and are moving loads.A designer don’t have much control over them and are very dynamic in nature .These loads are very hard to estimate accurately.Live loads are those caused by vehicles which pass over the bridge and are transient in nature.There has been efforts to estimate and consider the live loads reasonably so that they can give true picture of the behaviour of the structure that are occurring over them.

In the designing of the bridges, the live loads which are considered shall consists of vehicles which are wheeled or tracked and are classifies in the clause of 201.1 of IRC 6:2016 and the other special vehicle loading for other purposes such as military or transient purposes is as per the clause 204.5 if needed.It is to be notes that the trailers which are attached are not detachable.

There are four types of standard loadings for which are road bridges are designed.

a)IRC class AA Loading: This loading consists of either a tracked vehicle of 700KN or a wheeled vehicle of 400KN with dimensions as shown below.The tarcked vehicle simulates a combat tank used by the army.The groung contact length of the track is 3.6m and the nose to tail length of the vehicle is 7.2m.The nose to tail spacing between two successive vehicles shallnot be less than 90m.For two lane bridges and culverts one lane of class AA tracked or wheeled vehicle whichever creates severer conditions shall be considered for every two lane width.No other live load shall be considered on any part of the above two lane carriageway when the class AA train of vehicles is on the bridge.The class AA loading is to be adopted for bridges located within certain specified municipal localities and along specified highways.Normally,structures on National highways are provided for these loadings.

b) IRC class 70R loading: This loading type has been included in the appendix part which has been used for the pointing of the already constructed bridges.In place of class AA loading,there has been planning to replace it with this loading from the past few years. In this loading type,there is a wheeled loading of the total load amounting to 1000KN and the tracked vehicle of the load of 700KN. The maximum amount of loading fot the vehicle of wheeled type for a single axle on the bridge shall be of 20 tonnes or 40 tonnes for train of vehicles of two axles and shall not be spaced more than the 1.22 metres centre to centre. .

The total wheeled loading with the total axle loads is one thousand KN and the total length of the vehicle is 4.57 metres.The tracked vehicle i.e a tank in this case is almost similar to Class AA loading provided in the the code except for the case that the nose is of the length of 4.57metres, and the nose to tail length of the traked vehicle is 7.92 metres and the minimum spacing between the consecutive vehicles is 30 metres. Also the boggie loading of 4000Kn is also checked on the bridge components in addition to this.The dimensions of the class 70R loading vehicles are shown in fig.below.The specified spacing between the vehicles is measured from the rear most point of the ground contact of the leading vehicle of the forward most point of ground contact of the following vehicle in case of the tracked vehicle;for wheeled vehicle it is measured from the centre of the rear most wheel of the leading vehicle to the centre of the first axle of the following vehicle.

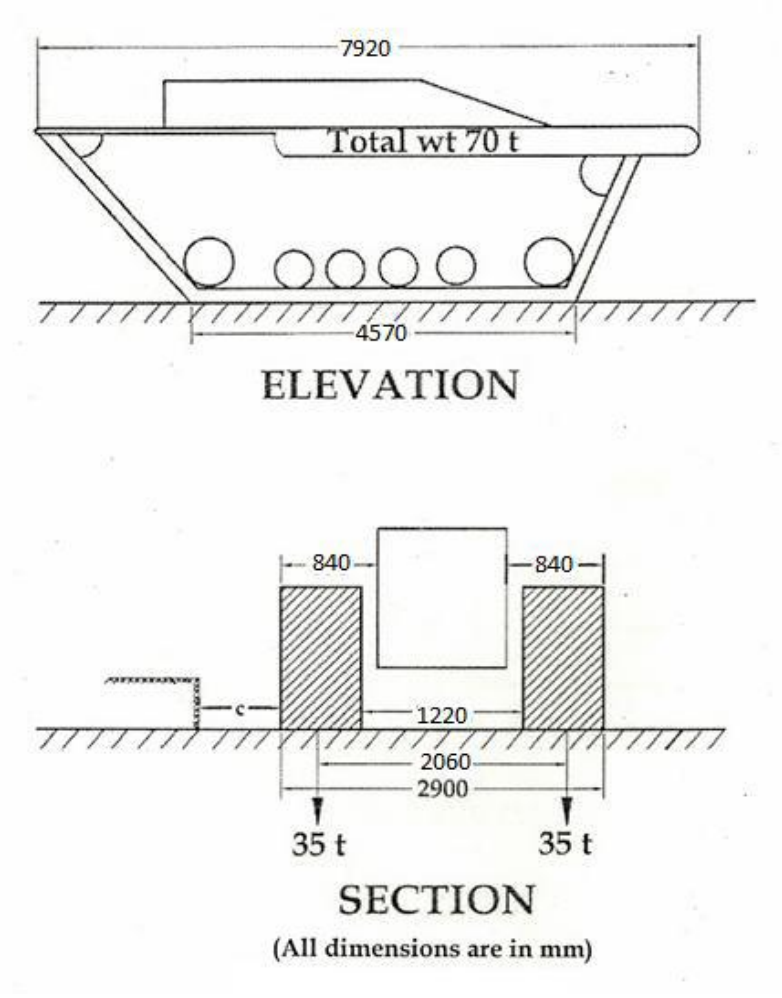

Figure 3.4 IRC Class 70R Tracked Vehicle

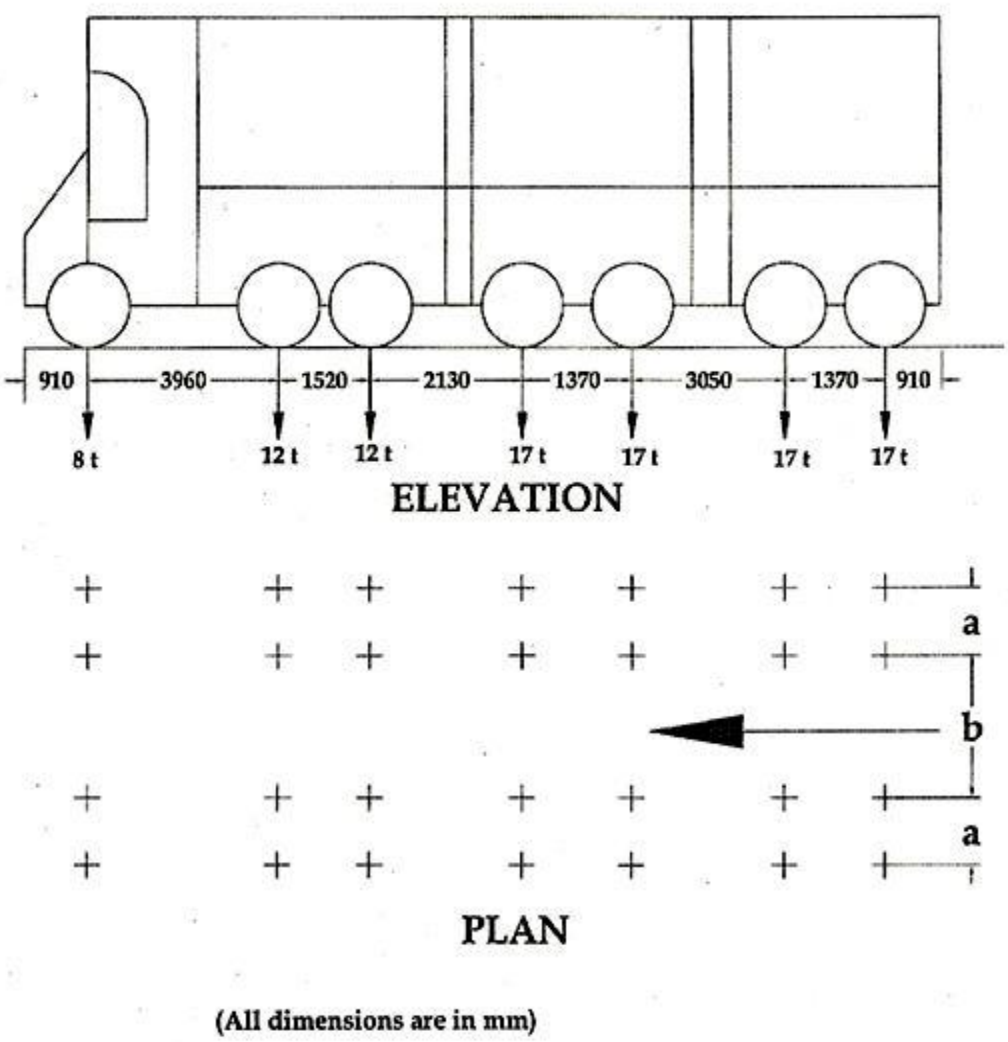

Figure 3.5 IRC Class A Wheeled Loading

c) IRC Class A Loading: The IRC Class AA loading is composed of wheel train loading which consists of number of wheels loads that has a a vehicle for driving number of trailers of particular axles with a specified spacing and different loads which is also depicted in the figure below.The spacing between the nose of the vehicle to the back of the vehicle should not be less than the length of 18.5 metres. It has been specified that no other live loading shall be applied on the carriageway when the vehicle train loading is applied on the bridge it is also applicable for the wheel loading tarin of vehicle for the multi lane bridgesThese loading is applicable and being used for all types of bridges which are permanent in nature and culverts on all type of roads.It is also depicted in the figure below that what shol]ouls be the contact area of the ground and the least specified clearance.

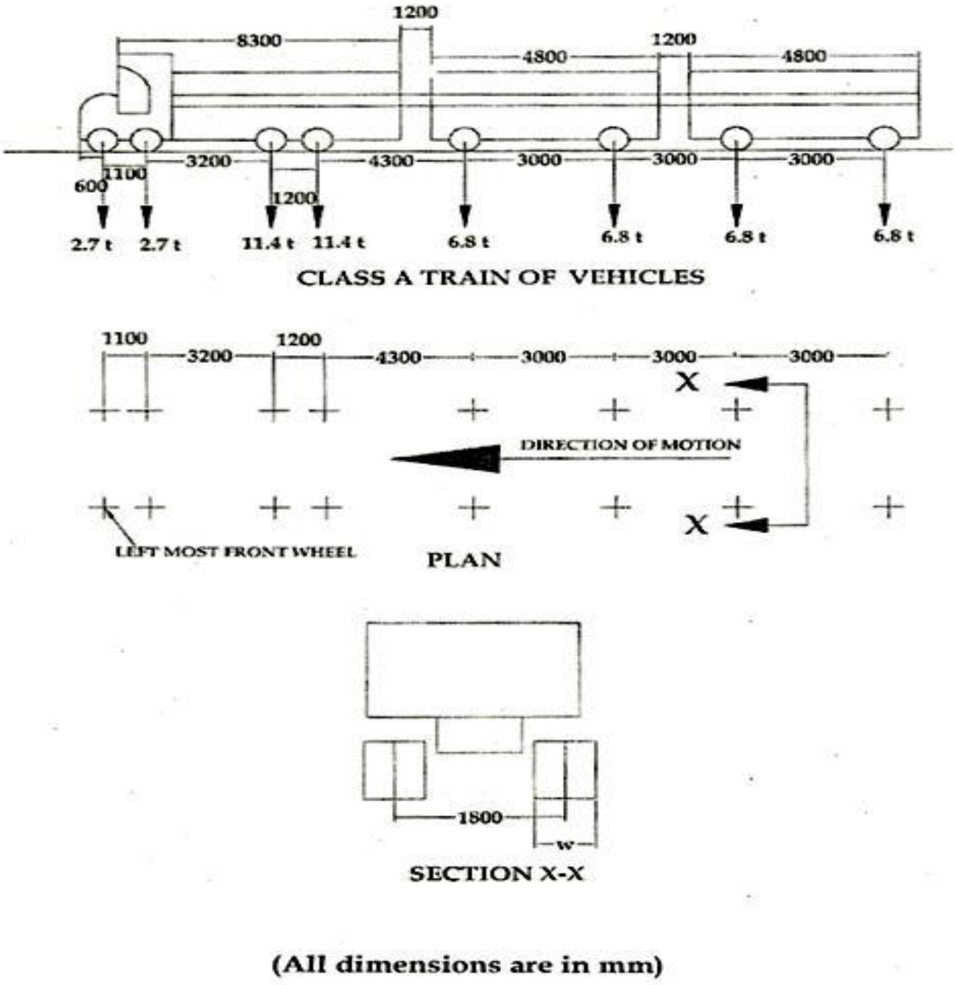

Figure 3.6 IRC Class A wheeled loading

d) IRC Class B loading: Class B loading of IRC is almost as same as class A wheel loading but the axle loads are smaller in comparision as shown in the figures below. This loading is mailnly used for the structures such as the bridges of timber, structures for temporary purposes and the other tyoe of bridge structures in particular areas.

The standard loads are to be organized in such a way, that as to create the severest twisting ,bending moment or shear at any area considered.The combination of the Loading of the vehicles which are to be aligned are generally put together parallel to the direction of the travelling of the vehicles and the combination is such as which is considered for multi lane bridges and single lane bridges and it has been specifies in the clause 207.4 of IRC6:2016.

3.6 IMPACT EFFECT

The live loads on the bridge generally have higher affects than that if they would have been in stationary position.The action that they apply on the bridge structure is generally dynamic in nature and is taken into the account by the static methods therefore on allowance for the impact is required.The impact factore for different type of structure is mentioned as here in:

The impact allowance is taken into account by the percentage of the live loads and is shown as below:

The impact allowance is expressed as a fraction or percentage of the applied live load and is computed as below:

a) For loading of IRC class A or

$$I=A/(B+L)$$

Where I=impact factor fraction
A= Constant of value 4.5 for reinforced concrete bridges and 9.0 for steel bridges
B=constant of value 6.0 for reinforced concrete bridges and 13.5 for steel bridges
L= span in metres

For spans less than 3metres, the impact fator is 0.5 for reinforced concrete bridges and 0.545 for steel bridges.When the span exceeds 45 metres, the impact factor is taken as 0.154 for steel bridges and 0.088 for reinforced concrete bridges.Alternatively,the impact factor fraction may be determined from the curve given in figure.

b) For IRC Class AA or 70R loading

i)For spans less than 9m

a)For tracked vehicle..25% for spans up to 5m linearly reducing to 10% for spans of 9m.

b)For wheeled vehicle..25%

ii) For spans of 9m and more.

a)For tracked vehicle.. For R.C bridges,10% up to span of 40m and in according with fig. for spans exceeding 40m,

For steel bridges,10% for all spans.

b)For wheeled vehicle.. For R.C 25% for spans up to 12m and in accordance with fig for spans exceeding 12m

For steel bridges,25% for spans up to 23m,and as in fig. for span exceeding 23m.

The span length to be considered in the above computations is determined as below:

i)Simply supported,continuous or arch spans-the effective span on which the load is placed.

ii)Bridges having cantilever arm without suspended span-0.75 of effectice cantilever arm for loads on the cantilever arm and the effective span between supports for loads on the main span.

When there is a filling of not less than 0.6m including the rod crust as in spandrel filled arches, the impact allowance may be taken as half that computed by the above procedure.

Full impact allowance should be made for design of bearings.But for computing the pressure at different levels of the substructure,a reduced impacr allowance is made by multiplying the appropriate impact fraction by a factor as below:

i)At the bottom of bed block0.5

ii)For the top 3m of the sub-structure below the bed block 0.5 decreasing uniformly to zero.

iii)For portion of sub-structure more than 3m below the bed block 0.0.

Table 3.1 Impact Factor

Highway bridges according to IRC regulations	IRC class 70R	(i) Spans less than 9 m. a) Tracked Vehicle	25 per cent for spans up to 5 m linearly reducing to 10 per cent for spans of 9m
		b) Wheeled Vehicle	25 per cent
		(ii) Spans of 9 m or more A. Reinforced concrete bridges a) Tracked Vehicle	10 per cent up to a span of 40 m and in accordance with the curve in Fig.3.8 for spans in excess of 40 m
		b) Wheeled Vehicle	25 per cent for spans up to 12 m and in accordance with the curve in Fig.3.8 for spans in excess of 12 m
		B. Steel bridges a) Tracked Vehicle	10 per cent for all spans
		b) Wheeled Vehicles	25 per cent for spans up to 23 m and in accordance with the curve indicated in Fig. 3.8 for spans in excess of 23 m.
	IRC class A loading and IRC class B loading	Spans in the range of 3m to 45 m	The impact per cent shall be determined from Fig.3.8

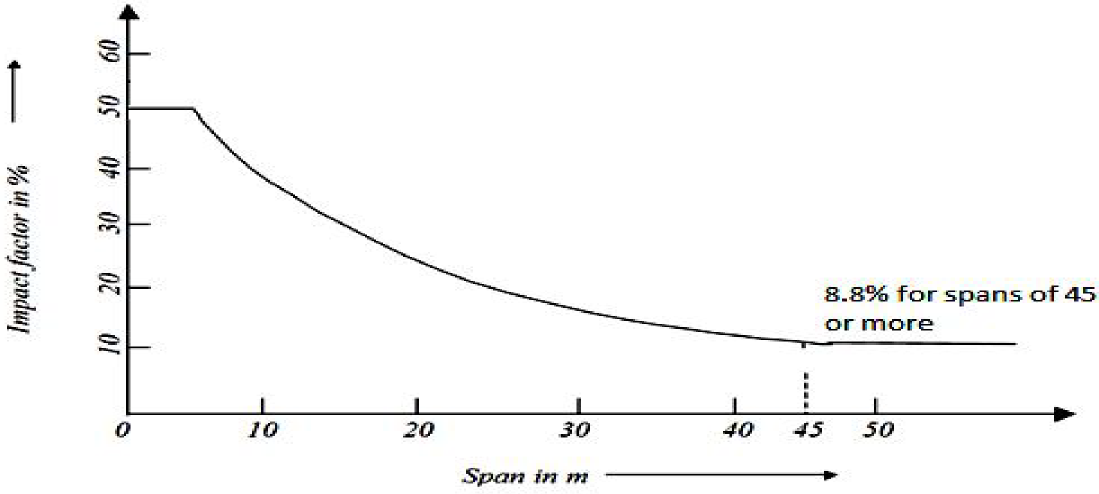

Figure 3.7 Impact Factor

3.7 REVIEW OF THE IRC LOADINGS

In this study a review has also been conducted to compare the IRC loading with the standard loading of other countries.The reason being,this IRC loading is used in this study and it will provide a picture of the IRC loading with respect to the loading of other countries.In this comparative study ,IRC Loading is compared with the othe seven countries's loading. It is observed that the IRC loading is the most extreme for the bridges of single lane,but for the two lane bridges it is less as compared with the loadings of countries of Gremany,France, Britain and Japan.

3.8 GEOMETRY OF THE BOX GIRDER

In this study the variables are span and the depth of the single cell and double cell box girder bridge.The variables depth as per the selected span to depth ratio has been calculated and the modelling has been done accordingly.The different depths of the box girder pertaining to particular span length is mentioned in the table below.The other cross sectional properties such as the thickness and the spacing between the outer webs is 5.6 metres.The other portion is cantilever part and the length of the cantilever is 3.25 metres on each side. The cantilever portion has footpath over it which is of 1.5 metres on each side.The thickness of outer web is 200mm.

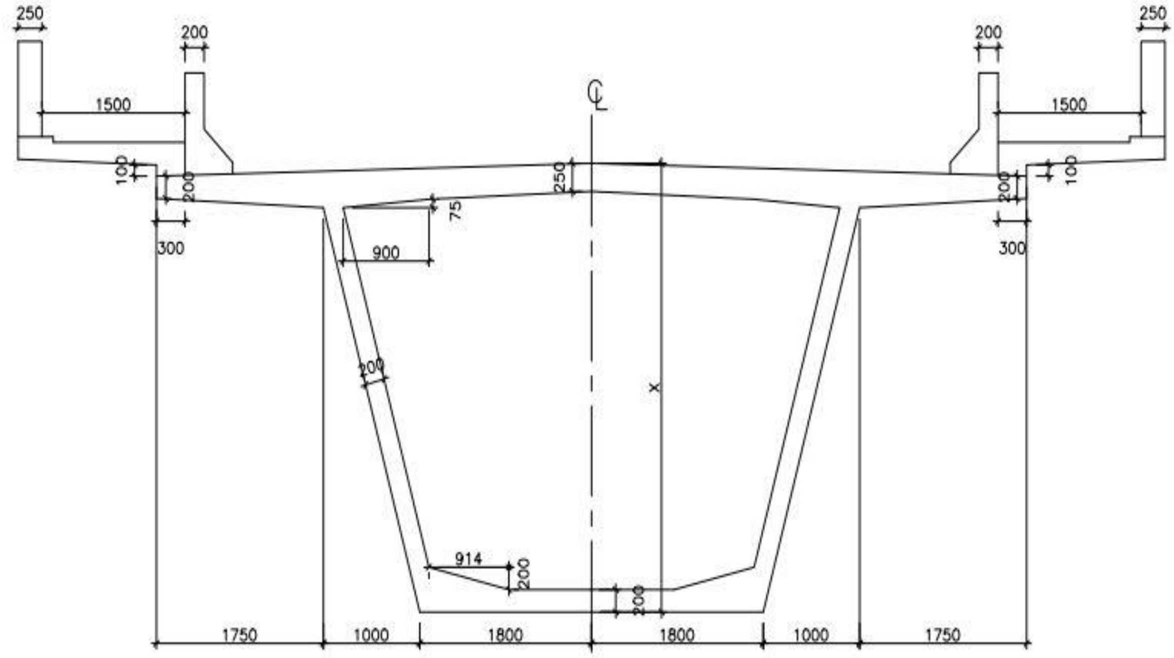

Figure 2.8 CROSS SECTION OF SINGLE CELL BOX GIRDER

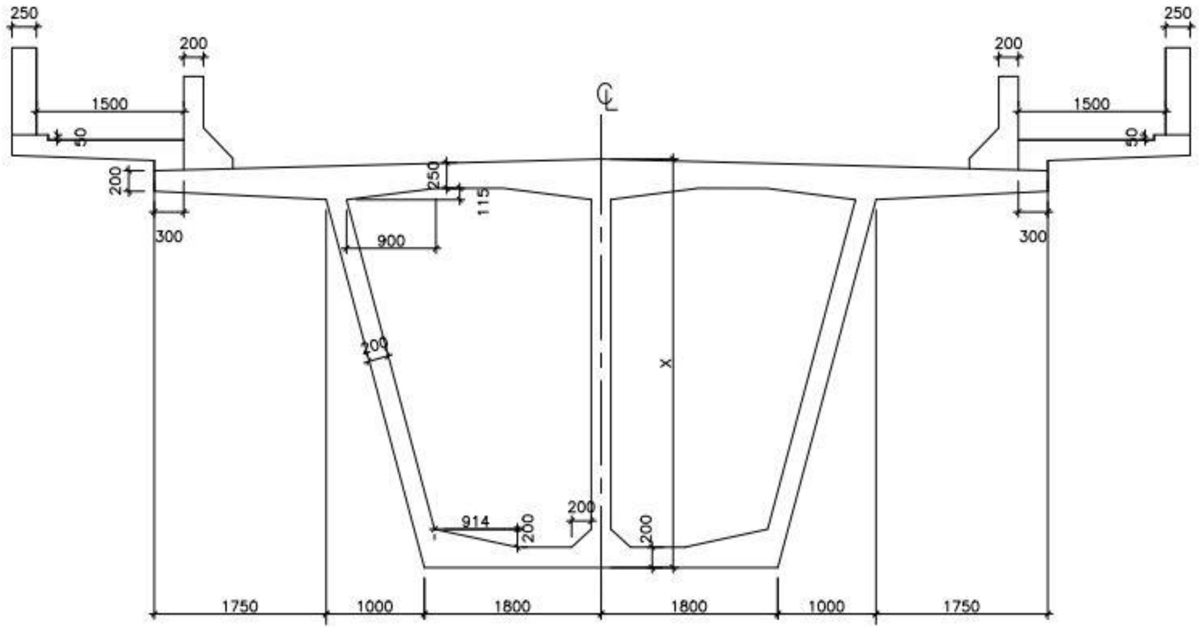

Figure 3.9 CROSS SECTION OF MULTI CELL BOX GIRDER

Table 3.2 The Depth Pertaining to each case of span length and the span/depth

Span (m)	Span to depth ratio	Depth 'x' (m)
30	15	2.00
	20	1.50
	25	1.20
40	15	2.67
	20	2.00
	25	1.60
50	15	3.33
	20	2.50
	25	2.00

3.9 MATERIAL AND SECTIONAL PROPERTIES

From the section selected for the study,sectional properties for each varying span and span depth ratio and for the number of cells are calculated.The calculations for the same has been shown in the appendix ii.The properties which are calculated are the area and the moment of inertia of the section.These properties are very vital for the calculation of the deflection and the maximum bending moment and the maximum shear force induces into the section.The moment of inertia plays an important role as it is the property of the material to resist the deformations due to the loads applied.

The material properties are also inputed to files during analyses and these are the grade of the concrete and the steel.The grade of concrete used is M40 and the grade of the steel is Fe 415 HYSD.

3.10 DESIGN ANALYSIS

The software used for dissertation work is staad pro.All the analysis of bridge supersturcutre is done using this software by taking account of effect of earlier mentioned vehicle on bridge superstructure by generating influence surface.Structural behaviour in terms of deflection in both the directions that is longitudinal as well as transeverse is obtained using this procedure.

The sectional properties have been calculated manually using excel spreadsheet,and are inputed in the staad to calculate the required factors.From the staad analysis the bending moments and the shear forces which are occurring in the transverse and the longitudinal direction are observed and taken into the account.

After Staad analysis, the desgining of box girder bridge deck is carried out manually and the excel spreadsheet is prepared for the purpose.

A spreadsheet for the design of 50m span box girder bridge deck is attached in the appendix.In the design ,required area of the steel for each individual span and corresponding span depth ratio is calculated.From the area,requisite quantity of steel is taken out and the cost estimation is perfomed. The quantity of steel for each individual case is represented in the units of metric tonnes.Then from the sectional properties of the box girder ,volume of concrete to be used is find out from which the cost analysis of concrete is performed.From this cost analysis of the material quantity detailed study is performed and the optimum values are identified for each case of span depth ratio and the number of cells.

Deflection is an important criterion which not only monitors the bridge behaviour due to various forces but also plays an important role in the overall cost of the bridge structure.Due to emergence of new construction materials and other construction techniques, deflection of the structure can be controlled to an extent.Now a days there is an urget need to reduce the costing of the structure than the same bridges constructed in past decades.Therefore, efforts are made to make the box girder as slender as possible.But this possibility is available only upto an extent as the deflection cannot be more than an certain permissible value.

In this analysis,for various spans,and span depth ratios, induced deflection due to vehicle loads,super imposed dead loads,foot path live loads has been considered and accordingly the variation in the costs has been evaluated.The concerning factor in the design of RCC box girder bridge is the induced deflection in both longitudinal and the transeverse directions.

It is therefore this parameter is selected for the study.In this study deflection due to vehicles loads, SIDL and the dead weight of the superstructure is calculated.The bridge is subjected to three different types of vehicle loads as per IRC 6:2016, and the case in which maximum moments occur is considered further for the analysis. The cases which are considered were IRC class 70 R tracked vehicle,IRC class 70R tracked vehicle and IRC class A loading.The maximum moments were reorded in IRC class 70R wheeled loading.hence the deflection for such case is considered.The total deflection is the sum of the deflection due to vehicle loads,SIDL,and dead load of the box girder.It is then compared with the maximum permissible deflection according to IRC which is mentioned as maximum upto (span length/220). There is also an theoretical expression for the deflection which is:

Deflection, $\delta = 5\ W\ L^4 / 384\ EI$

Where ‘L’ is the span legth,’W’ is the total load on the structure, ‘E’ is the young’s modulus of elasticity and ‘I’ is the maximum moment of inertial

3.11 COST ANALYSIS

Cost analysis has been performed of the structural element to analyse the variation in the costs for different selections of span depth ratios and number of cell and to study the trend of the cost vis a vis changes in span length. Cost analysis is conducted after detailed analysis and the design of the box girder of particular parameters.

It is done by calculating the exact quantities of steel and concrete which is required in the structure.The quantites are calclutated from the designs performed.The rates of the quantities are as per Current schedule of rates.The rate specied are Rs 4699 for the concrete of grade M40. The rate of steel is Rs 51,600 Per metric tonnes of quantity and also the binding cost of steel of Rs 4000 per metric tonn is also added as specifies in the book.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

In this study ,detailed analysis is carried out for different span length of a box girder bridge with respect to selected span to depth ratios.The two lane carriageway is analysed,and the appropriate dimensions were considered. The carriageway width of the box girder is kept to be 7.8metres and the toatal width of 8.2 metres including the width of the kerbs. The bridge deck is analysed for various type of live loads as per IRC 6:2016.The live loads taken into consideration are IRC Class 70R wheeled load,IRC Class 70R Tracked vehicle,IRC Class A vehicle.The load combinations are then applied as per table 6A of IRC 6:2016.The other loads considered were dead load , superimposed dead loads and footpath live live.Then the analysis of the structure was carried out.

The spans to depth ratio of 15,20 and 25 is selected for the spans of 30m,40m and 50m and accordingly the section properties were accounted.The box girder considered were single cell and double cell and the results in terms of deflection were analysed.The output in terms of deflection is evaluated in the form of Bar graphs and Curves.After the detailed analyse ,cost estimate for each observed case is carrired out and the cost optimization for the most optimum values in terms of quantity of concrete and steel is done taking the most efficient geometrics of the structure in terms of deflection into consideration.

The results are discussed here below

4.2 RESULT ANALYSIS

4.2.1 VARIATION IN SPAN LENGTH AND ITS EFFECTS

Here the effects of span length in terms of deflection is discussed,also the results are then computed by evaluating the cost of material quantity in box girders.The spans are of 30 metres,40metres and 50 metres analysed for single cell and double cell box girder.

4.2.1.1 DEFLECTION

The observed deflection for the respective span lengths and permissible deflection according to IRC is reported for both single cell and double cell box girder

Table 4.1 Showing The deflection for different values of span length of single cell box girder .

Span (m)	Span to depth ratio	Max. deflection (mm)	Permissible deflection (mm)	% variation of max. deflection w.r.t permissible deflection
30	15	43.3	136	-68
	20	88.8		-35
	25	155.9		15
40	15	67.6	182	-63
	20	129.8		-29
	25	226.3		24
50	15	91.4	227	-60
	20	180.1		-21
	25	305.3		34

Table 4.2 Showing Deflection for different values of span length for double cell box girder.

span (m)	Span/depth ratio	Max Deflection (in mm)	Permissible Deflection (in mm)	% variation of max. deflection w.r.t permissible deflection
30	15	41.5	136	-69
	20	86.5		-36
	25	153.5		13
40	15	64.8	182	-64
	20	121.4		-33
	25	222.7		22
50	15	91.9	227	-60
	20	187		-18
	25	293.7		29

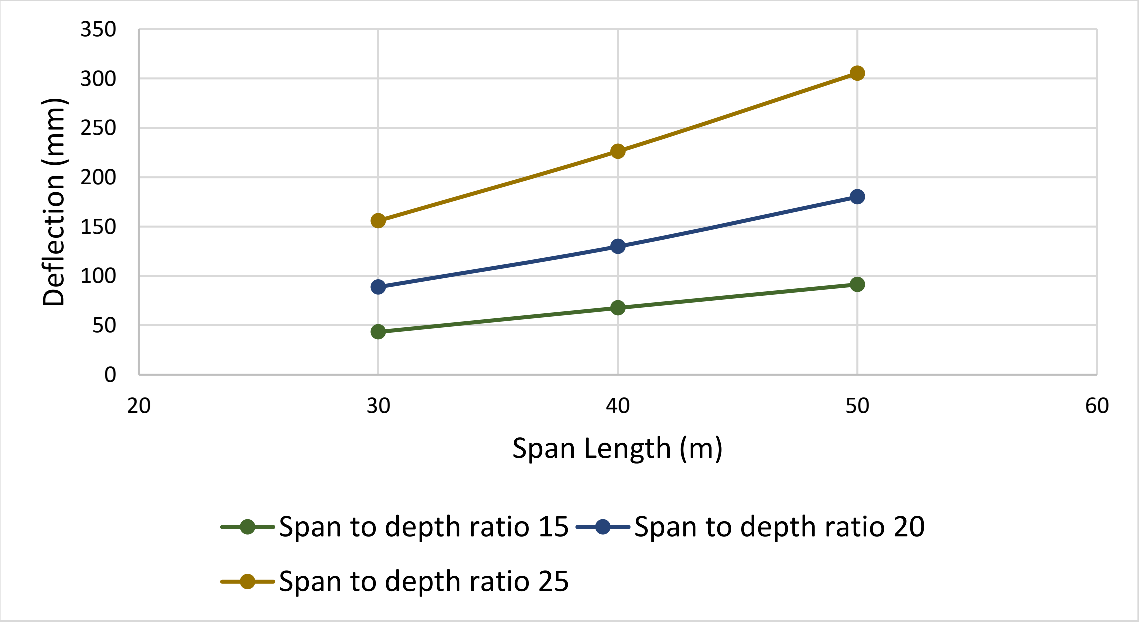

Figure 4.1 Graph depicting the variation of deflection with respect to span length of single cell Box Girder

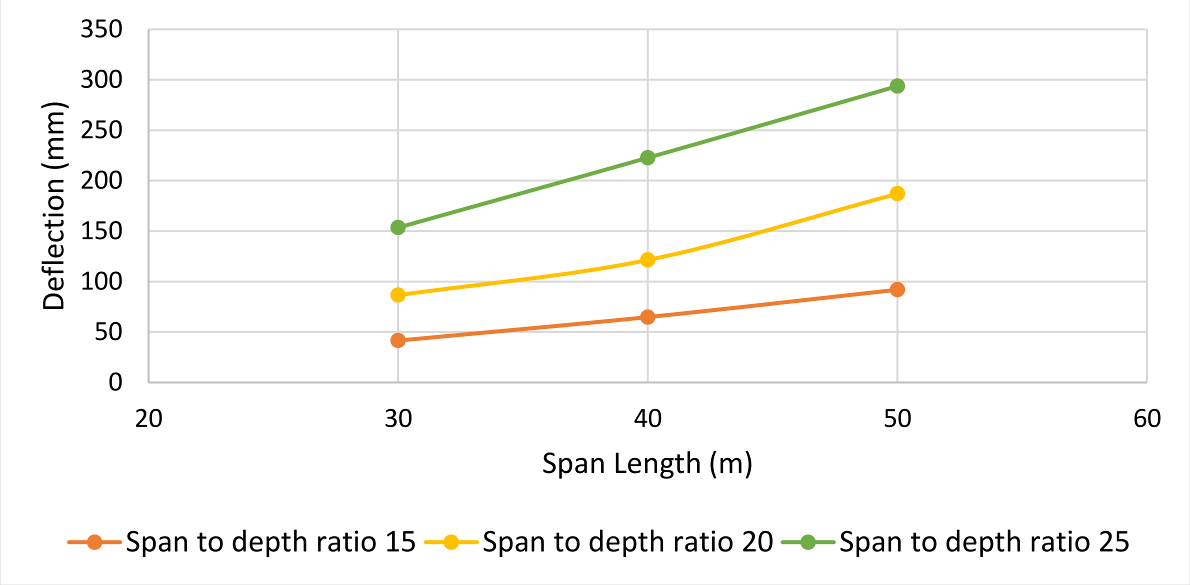

Figure 4.2 Graph depicting the variation of deflection with respect to span length of Double cell Box Girder

The deflection indices for different spans has been calculated and are compared with respect to the allowable deflection in each case.It is then represented in the form of graph.From the graphs plotted and the values mentioned,it can be observed that the deflection in each case of span increases with the increase in span to depth ratio.For the span depth ratio of 25,deflection is maximum in all the cases,but it shall be noted that the deflection in that case is more than the maximum permissible deflection and hence that case is not feasible.

It is observed that the percent variation of the deflection that is the difference of the deflection observed to the maximum permissible deflection decreases with the increase of span depth ratio.i.e the variation is more when moved to span depth ratio of 15 to 20 then the 20 to 25.

The deflection for single cell box girder is more than the deflection in double cell box girder while keeping all the other parameters constant.

4.2.1.2 THE COST

Cost of the material for each configuration ,calculated using material quantity and the Schedule rates is mentioned herein.

Table 4.3 Showing the Cost of material with respect to quantity of material for single cell case.

Span (m)	L/d Ratio	Steel Quantity (MT)	Concrete quantity (m^3)	Total Cost for span (Lakh Rs.)	Cost per running meter (Rs.)
30	15	13.01	122	12.96	43,211
	20	12.57	115	12.39	41,298
	25	12.64	111	12.24	40,808
40	15	13.53	174	15.70	39,244
	20	13.92	163	15.38	38,442
	25	12.57	156	14.32	35,808
50	15	13.53	235	18.57	37,140
	20	13.39	214	17.51	35,017
	25	13.9	203	17.28	34,553

Table 4.4 Showing the Cost of material with respect to quantity of material for Double cell case.

Span (m)	L/d Ratio	Steel Quantity (MT)	Concrete quantity (m^3)	Total cost for span (Lakh Rs.)	Cost per running meter (Rs.)
30	15	15.61	134	14.98	49,932
	20	15.41	123	14.35	47,854
	25	16.18	118	14.54	48,460
40	15	14.62	193	17.20	43,000
	20	15.45	179	16.99	42,475
	25	15.41	168	16.44	41,111
50	15	14.61	261	20.39	40,774
	20	14.6	237	19.24	38,487
	25	15.45	222	19.04	38,071

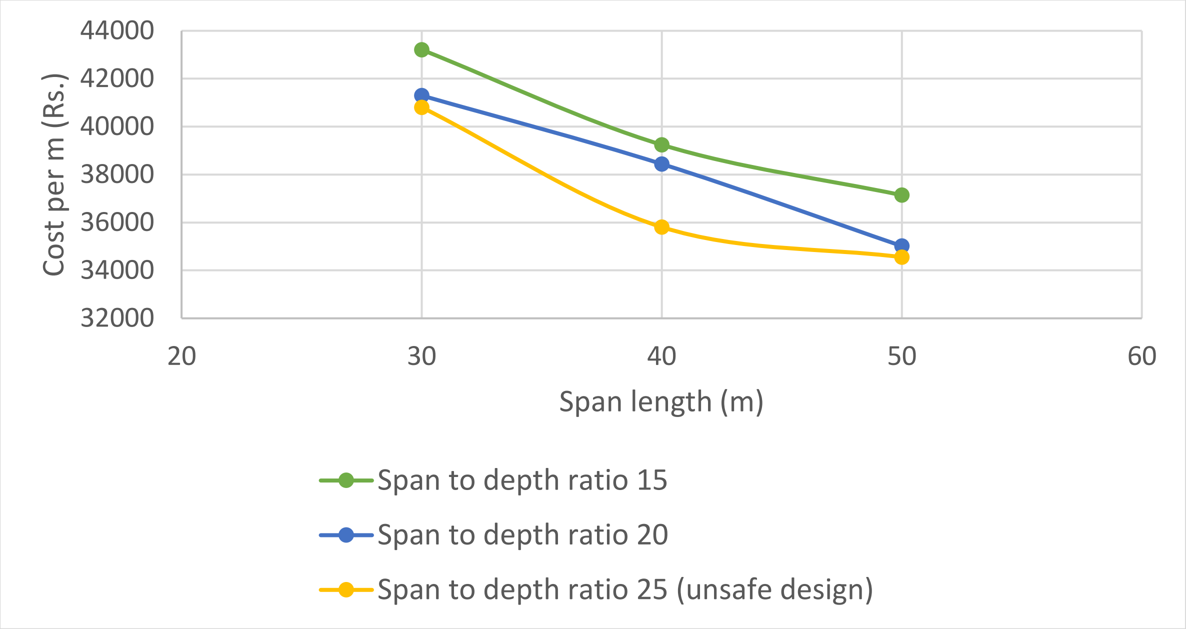

Figure 4.3 Graph depicting the variation of Cost with respect to span length of Single cell Box Girder

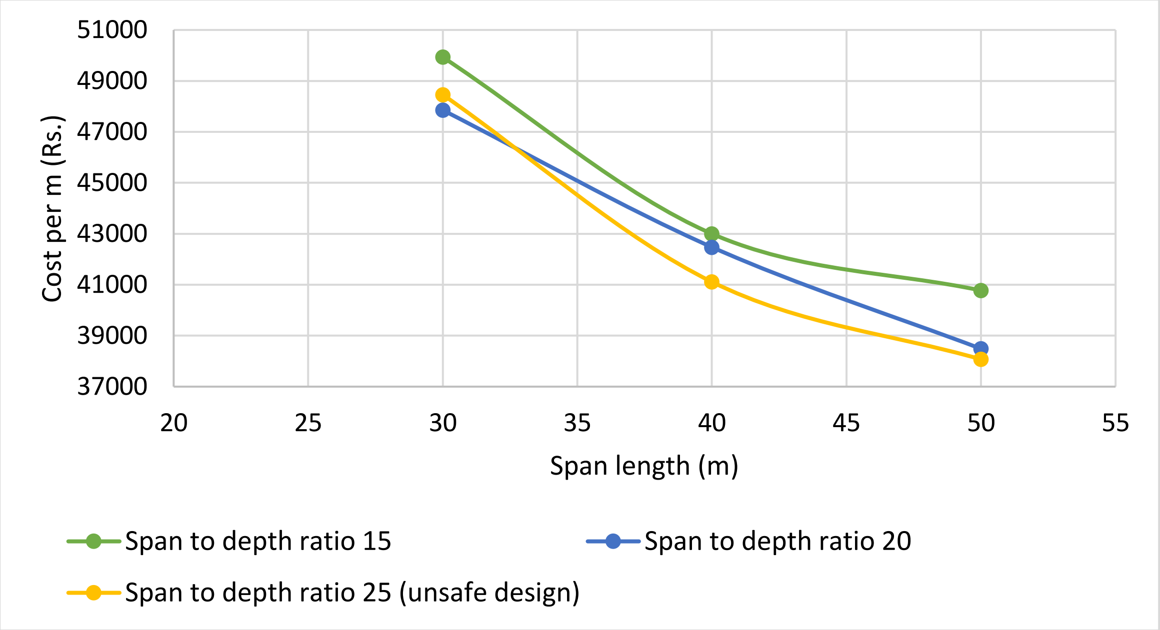

Figure 4.4 Graph depicting the variation of Cost with respect to span length of Double cell Box Girder

As depicted by the graphs represented above, it can be seen that for both single cell RCC Box girder bridge and double cell RCC box girder bridge the cost of the structure decreases with increase in the span length.

4.2.2 SPAN DEPTH RATIO

Here the results are obtained for the different span depth ratios considered and its effects on the bridge in terms of deflection is analysed and costing is done for both single cell and double cell box girder .

4.2.2.1 DEFLECTION

The variation in Deflection obtained with respect to span/depth ratio is mentioned in the tables shown below.

Table 4.5 Showing the Variation in Deflection with Span/Depth for Single Cell Box Girder .

Span to depth ratio	Span (m)	Max. deflection (mm)	Permissible Deflection (in mm)
15	30	43.3	136
	40	67.6	182
	50	91.4	227
20	30	88.8	136
	40	129.8	182
	50	180.1	227
25	30	155.9	136
	40	226.3	182
	50	305.3	227

Table 4.6 Showing the Variation in Deflection with Span/Depth for Double Cell Box Girder

Span to depth ratio	Span (m)	Max. deflection (mm)	Permissible Deflection (in mm)
15	30	41.5	136
	40	64.8	182
	50	91.9	227
20	30	86.5	136
	40	121.4	182
	50	187	227
25	30	153.5	136
	40	222.7	182
	50	293.7	227

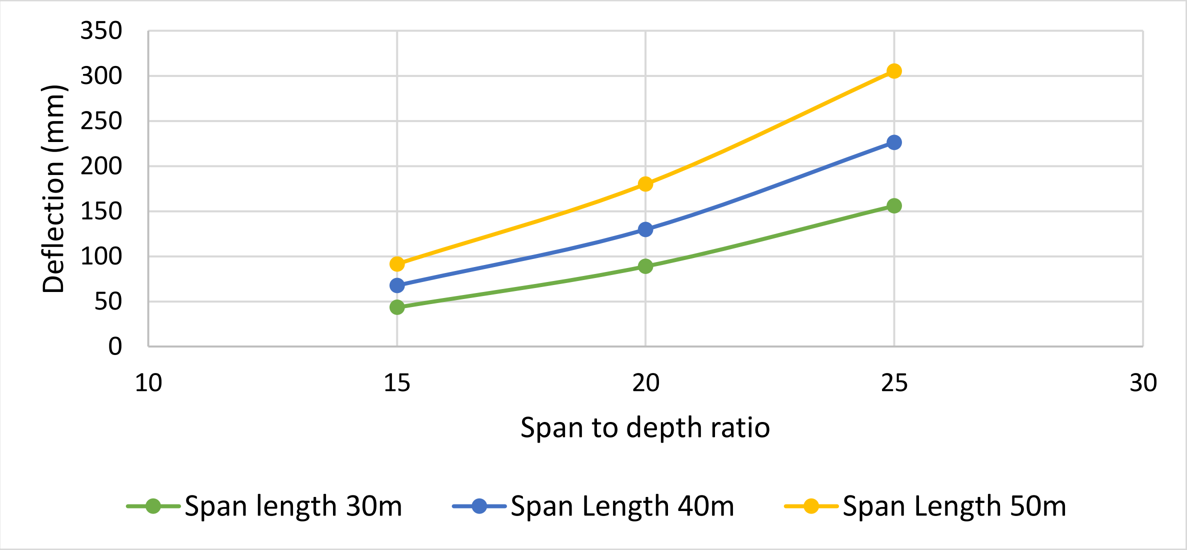

Figure 3.5 Graph Depicting the Variation in Deflection with Span/Depth for Single Cell Box Girder

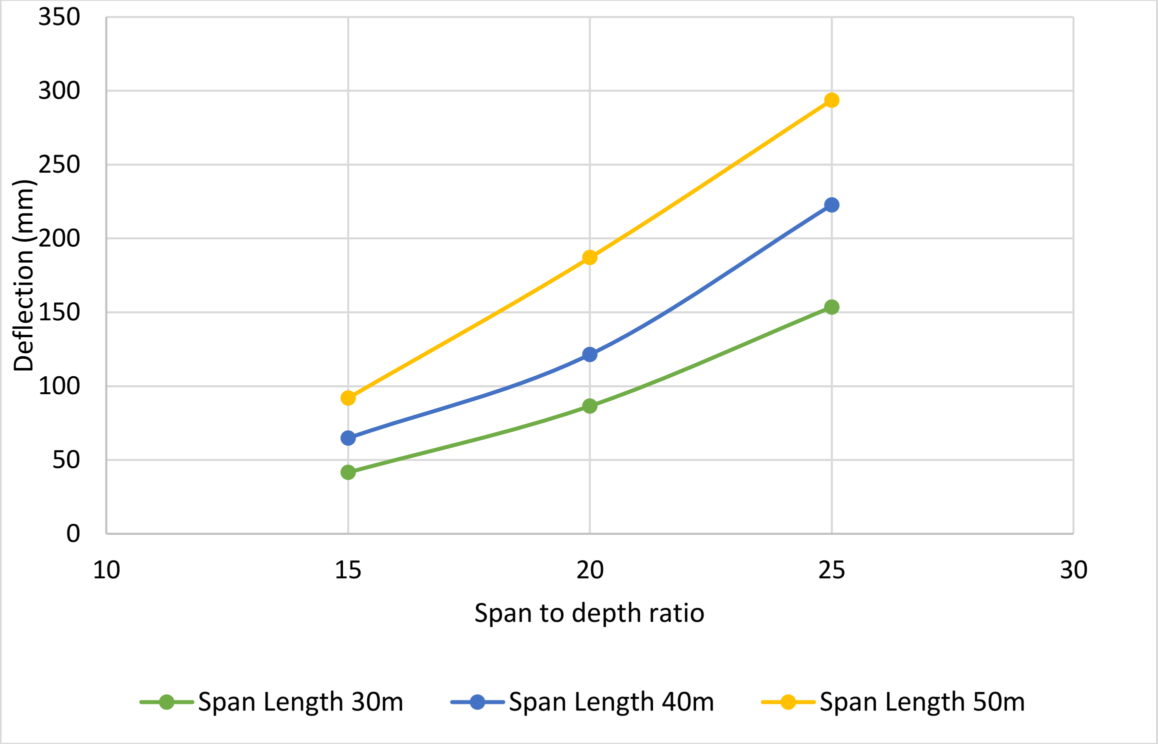

Figure 4.6 Graph Depicting the Variation in Deflection with Span/Depth for Double Cell Box Girder

It is observed that with the increase in the ratio of span depth the deflection decreases.It is similar for all the cases of span lengths and for both single cell and double cell box girder bridge. But from the graph it is noted that the slope of the curve is note same for the increase from span/depth of 15 to 20 to that of span/depth 20 to 25.Therefore it can be concluded that the rate of change of deflection with span/depth is not constant and it increases with the increase in the ratio.

For the span/depth ratio of 25 the obtained deflection is more than the maximum permissible deflection. Hence the case of span/depth of 25 is not feasible.

4.2.2.2 COST

Cost incurring for the span variation with respect to material quantity for both single cell box girder and double cell box girder is mentioned here below.

Table 4.7 Showing the Variation in cost with respect to Span /Depth for Single Cell Box Girder

Span to Depth Ratio	Span (m)	Steel Quantity (MT)	Concrete quantity (m^3)	Total Cost for span (Lakh Rs.)	Cost per running meter (Rs.)
15	30	13.01	122	12.96	43,211
	40	13.53	174	15.7	39,244
	50	13.53	235	18.57	37,140
20	30	12.57	115	12.39	41,298
	40	13.92	163	15.38	38,442
	50	13.39	214	17.51	35,017
25	30	12.64	111	12.24	40,808
	40	12.57	156	14.32	35,808
	50	13.9	203	17.28	34,553

Table 4.8 Showing the Variation in cost with respect to Span /Depth for Double Cell Box Girder

Span to Depth Ratio	Span (m)	Steel Quantity (MT)	Concrete quantity (m^3)	Total Cost for span (Lakh Rs.)	Cost per running meter (Rs.)
15	30	15.61	134	1497969	49932
	40	14.62	193	1720012	43000
	50	14.61	261	2038715	40774
20	30	15.41	123	1435618	47854
	40	15.45	179	1698991	42475
	50	14.6	237	1924367	38487
25	30	16.18	118	1453800	48460
	40	15.41	168	1644457	41111
	50	15.45	222	1903546	38071

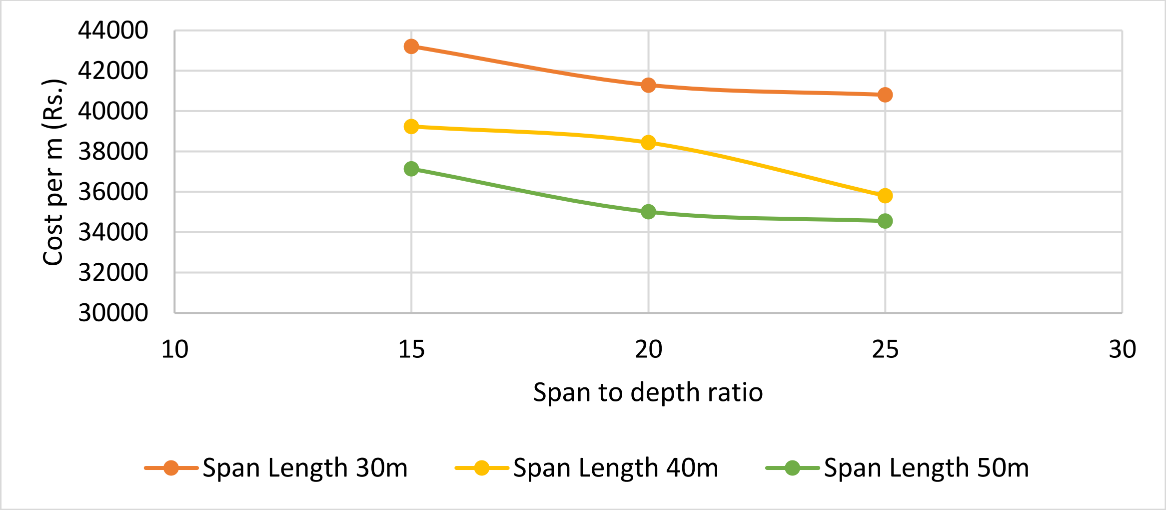

Figure 4.7 Graph Depicting the Trend in Cost with Span/Depth for Single Cell Box Girder

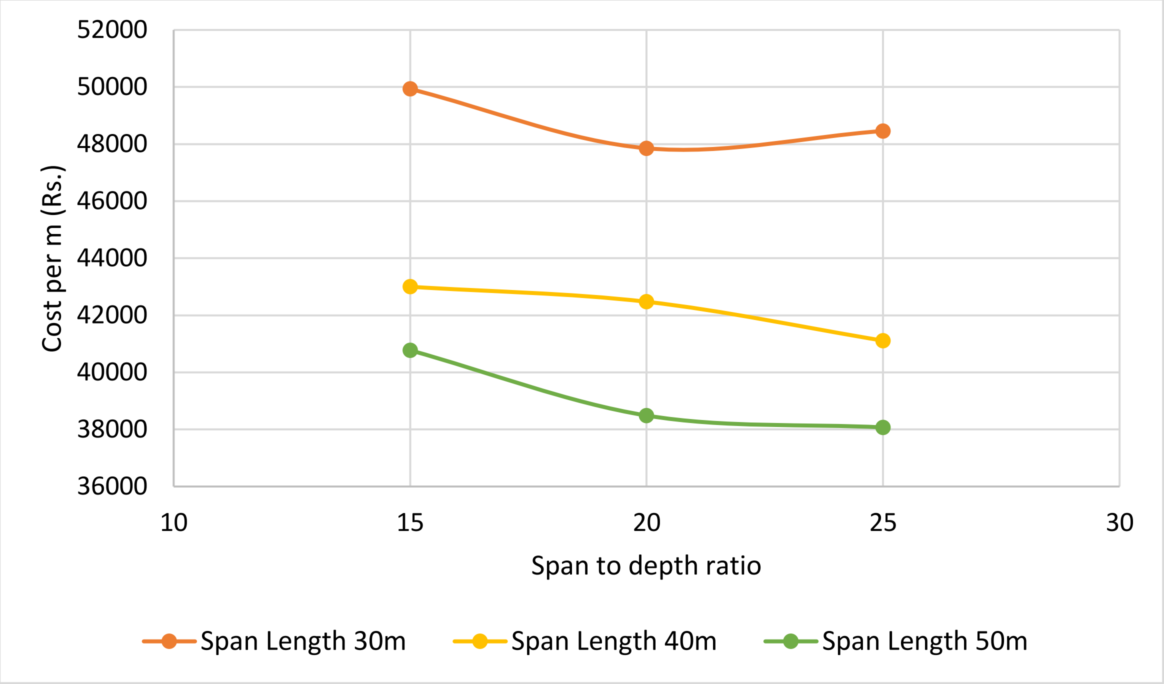

Figure 4.8 Graph Depicting the Trend in Cost with Span/Depth for Double Cell Box Girder

From the values and the graph shown above it is obtained that the unit cost of of the box girder bridge whether it is single cell or double cell ,decreases with the increase in the span/depth ratio. It is because the material quantity consumed in for the bridges with higher span depth raito is lesser than the ones with lesser ratio.The conclusion for it is the reason that the with the increase in span/depth the depth decreases hence the quantity of steel and the concrete decreases.The values of variation in quantities is exactly depicted in the tabular form above.

The span/depth of 25 is however least costly to construct but from deflection criterio is can be seen that it fails in that aspect therefore it is not feasible.The optimum values of span depth ratio is also calculated and is shown further.

4.2.3 NO. OF CELLS

4.2.3.1 DEFLECTION

The variation in the deflection with respect to the no. of cells i.e single and the double cells for a box girder bridge is mentioned as below:

Table 4.9 Showing the Variation in deflection with respect to No. of cells for a box girder bridge

Span length (m)	No. of cells	Span/depth ratio	Max Overall bridge deflection (in mm)	Allowable total deflection (in mm)
30m	1	15	43.3	136
		20	88.8	
		25	155.9	
	2	15	41.5	136
		20	86.5	
		25	153.5	
40m	1	15	67.6	182
		20	129.8	
		25	226.3	
	2	15	64.8	182
		20	121.4	
		25	222.7	
50m	1	15	91.4	227
		20	180.1	
		25	305.3	
	2	15	91.9	227
		20	187	
		25	293.7	

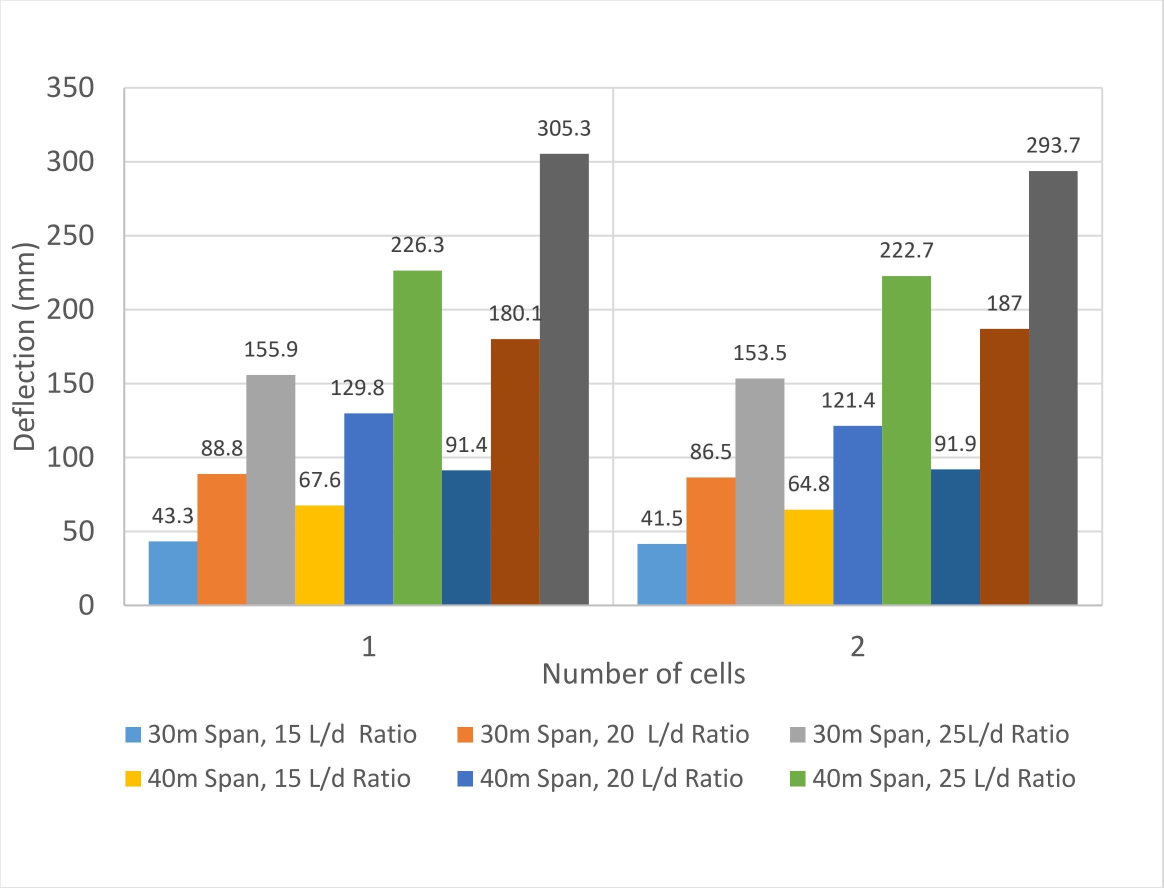

Figure 4.9 Bar graph showing the Deflection trend with respect to no. of cells

From the effect of cells of box girder bridge superstructure and it co relation with the deflection,It is observed that whether for single cell or double cell, the deflection increases with the increase in the span/depth ratio. The deflection is maximum for span/depth ratio of 25 for both single cell and double cell however the important point which is observed is deflection for the same ratios of span depth is lesser in double cell box girder than the single cell box girder bridge. The variation is however small but significant. For instance for 40m span and span depth ratio of 20 the deflection for single cell box grider is 129.8mm while for double cell box girder it is 121.4mm. The reason being while the deflection is inversely proportional to the stiffness of the element. The deflection for double cell box girder is lesser due to fact that the stiffness in that case is higher.

So, it can be concluded that in cases where there is limitation the depth of the girder,to control deflection more cellular box girders can be taken into consideration.

4.2.3.2 COST

The variation in cost of the box girder with respect to the no.of cells is as:

Table 4.10 Showing the Variation in cost with respect to No. of cells for a box girder bridge

Span length	No. of cells	Span/depth ratio	Cost per m (in Rs.)
30m	1	15	43,211
		20	41,298
		25	40,808
	2	15	49,932
		20	47,854
		25	48,460
40m	1	15	39,244
		20	38,442
		25	35,808
	2	15	43,000
		20	42,475
		25	41,111
50m	1	15	37,140
		20	35,017
		25	34,553
	2	15	40,774
		20	38,487
		25	38,071

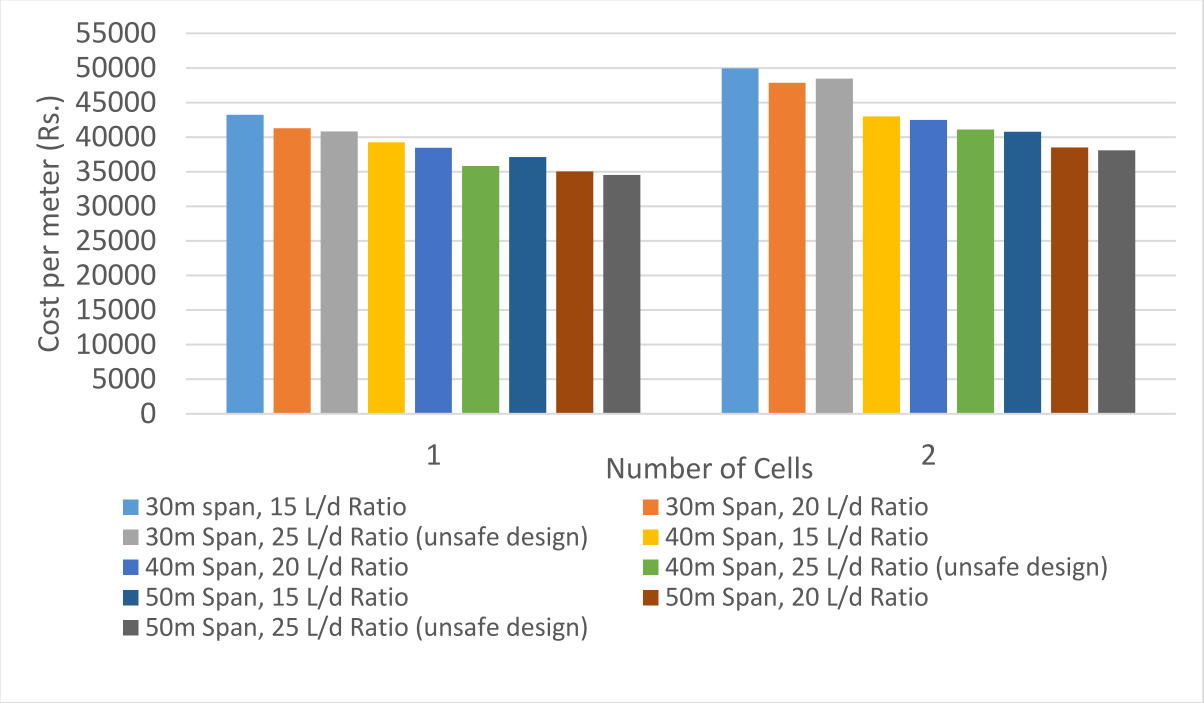

Figure 4.10 Bar graph showing the Cost trend with respect to no. of cells

It has been observed from the graphs and the tables shown above that the cost of the bridge deck reduces with the increase in the span depth ratio.The cost for the double cell box girder is more than the cost for the single cell box girder bridge. Also,it can be seen that for the same span depth ratio,the unit cost for 30 metre span is more than the cost for 50 m span .The cost for 30m span for the span depth ratio of 20 m is Rs 41,298 whereas for the 50 m span for span depth ratio of 20m is Rs 35,057.Therefore it can be concluded that the cost is higher for the shorter spans. Also in circumstances where single cell box girder is capable of servicibility ,it will provide more economical solution to bridges as compared to double cell box girder.Although it can be observed that the difference between per unit cost of the single cell and double cell box girder is relatively smaller,but it can result in higher saving when comes to the bridges with longer overall lengths.The cost for 25 span depth ratio is minimum but that is not a feasible design and therefore the most feasible values are identified here further.

The optimum values for the deflection for all the cases and minimum cost for those cases has been inferred further.

4.2.4 THE OPTIMIUM VALUES

4.2.4.1 OPTIMUM SPAN DEPTH RATIOS

The optimum values of the span/depth ratios were calculated from the analysis and are mentioned here below:

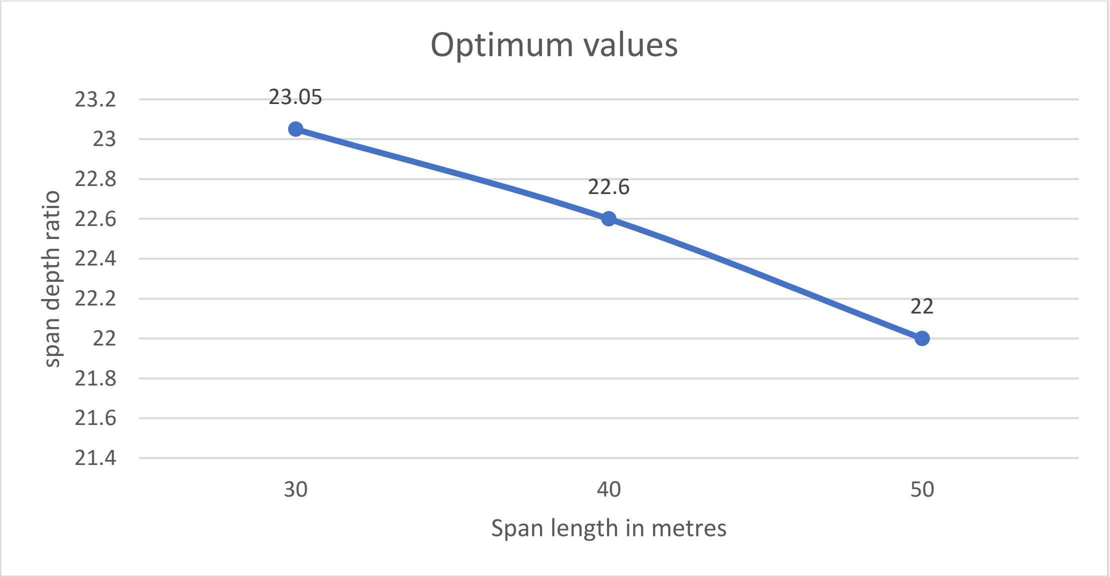

Figure 4.11 The graph Depicting the values and the trend of optimum span/depth ratio with respect to span lengths for a single cell Box girder

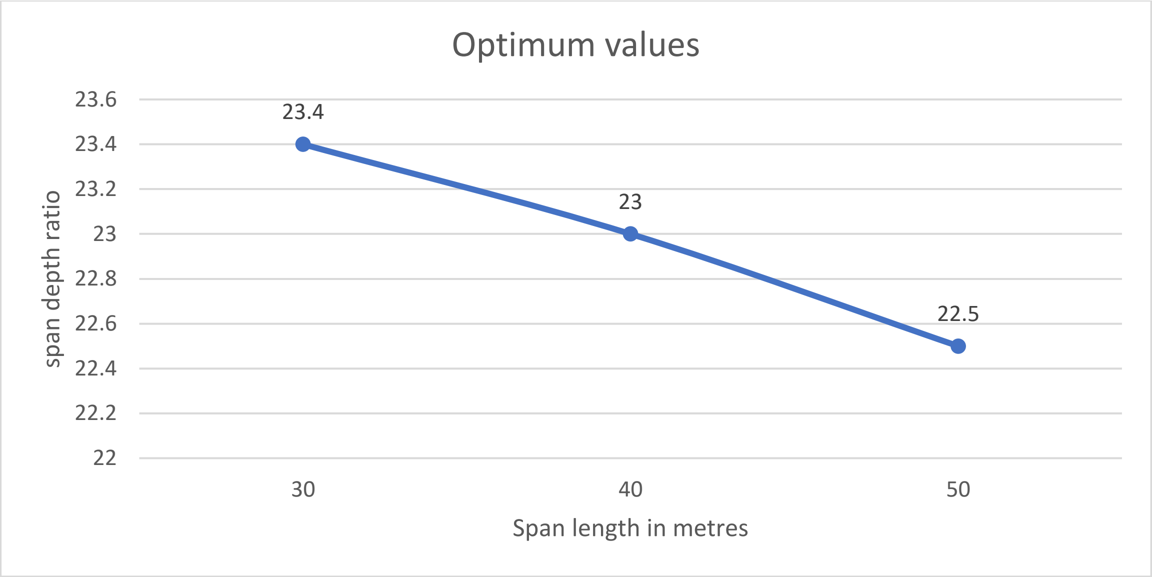

Figure 4.12 The graph Depicting the values and the trend of optimum span/depth ratio with respect to span lengths for a Double cell Box girder.

From the results stated above it was observed that the span depth ratio of 25 is not feasible as the deflection in that case exceeds the maximum permissible deflection and the cost decreases with increase in span depth ratio.However as we moved further the variation /difference between the maximum deflection and the permissible deflection tends to decrease and also the variation in cost decreased but there is as need to obtain the exact optimum value under which the cost is minimum.therefore,from the iterations the exact values on which the maximum deflection becomes equivalent to the maximum permissible deflection.From the graph shown it can be observed that the optimum value of span depth ratio for 30m span for single cell box girder is 23.05 while for 50m span it is 22. Hence it can said that the limit for span depth ratio decreases with increases in span lengths. The trend is similar for the case of double cell box girder bridge too.Also, it has to be noted that the slopes of the curve is not same,it rather increase from the 40m span to 50m span.Hence it is inferred that the percentage decrease in maximum limit of span depth is more significant for higher spans.

4.2.4.2 OPTIMUM COST

The optimum value of the cost with respect to the material quantity and the maximum values of span depth ratio is mentioned herein:

Table 4.11 showing the values of the optimum cost for the both case of single and double cell Box Girder Bridge.

Box girder type	Span (m)	L/d Ratio	Steel Quantity (MT)	Concrete quantity (m^3)	Total cost for span (Lakh Rs.)	Cost per running meter (Rs.)
Single cell	30	23.05	12.6	112.5	12.41573	41,386
	40	22.6	13.1	159	14.88283	37,207
	50	22	13.61	209	17.51999	35,040
Double cell	30	23.4	15.9	120	14.6358	48,786
	40	23	15.43	172	16.81222	42,031
	50	22.5	15.1	229	19.30273	38,605

In the table shown above , the span depth ratios are mentioned,which shows the maximum permissible deflection corresponding to the the optimum values of cost of each span per running meter. This is the minimum possible cost of the RCC box girder bridge.From the results it is inferred that the from all the optimum ranges,the minimum cost that can be incurred is by the 50 m span single cell box girder bridge with the maximum span depth ratio of 22 with the cost of Rs 35,040.

CHAPTER 5

CONCLUSION

5.1 GENERAL

Bridges are the one of the most important part of the transport infrastructure of the country.With the advent of infrastructure sector,the construction of bridge structures have been increased drastically in the past few decades .So,there is a need to develop efficient solutions which can help in providing sturctures which can give better performance with lesser consumption of resources and economically effective.To achieve this,immense efforts have been put in the research and analysis for the cost optimisation in the designing and construction of bridges.Box girder section for the superstructure is one of the most preffered section in the bridge engineering because of its geometrics.Structural behaviour of a box girder section depends upon the various parameters .In this dissertion ,several parameters such as span lengths, span depth ratio,number of cells of reinforced concrete box girder bridge bridge, have been taken into account to study their effects on the most important design aspect of deflection.The superstructure is subjected to IRC loading pertaining to standard codes of practice.The steps followed for the analysis is mentioned in the chapter and the other data which was formulated for the same is presented in the appendices. The results were then analysed and compared in chapter 4 on the basis of the deflection criterion,percentage variation from the permissible limits and the cost analysis to obtain an optimum range of results for the cases considered.The optimum span depth ratios identified in this thesis for various spans can be used in design and analysis of bridges which would provide a more effiecient and economic solution.

5.2 CONCLUSION

The following conclusions can be made from the resuts investigated in the previous chapter:

i)The deflection is observed to be on the safer side as compared to the permissible limits in the span depth ratio of 15 to 22-23(Depending upon the span length selected),However it exceeded the maximum permissible level for the ratio of 25 subjecting to the live loading according to IRC-6:2016.So,it can be concluded that the span depth ratio of 25 is not feasible for the both single cell and double cell reinforced concrete box girder bridge.

ii) The variation in the produced deflection in the single cell box girder and double cell box girder is less.However,it is observed that the deflection for same span length and the depth for double cell box girder is less than that of double cell box girder.

iii) With the increase in the span depth ratio,the unit cost RCC box girder decreases,the trend is same for the increase in span lengths with same depth.

iv)It is evident that the optimum value for the RCC box girder bridge is of length 50m with the span depth ratio of 22,at unit cost of Rs35,040.It is also concluded that the double cell box girder with similar span depth ratio doesnot help much in reduction in deflection but only results in increase in cost of structure .Hence it is inferred that single cell box girder with 50m span and span depth ratio of 22 is the most economical and efficient configuration.

5.3 FUTURE SCOPE

In this study vast parameters have been studied and analysed,and a broad conclusions have been drawn from the results obtained.But, there are still many other areas which are not explored and can been undertaken into the scope in the future.Those parameters could be:

i)The study here was confined between the span length ranges between 30m to 50m,studies with span length more than that can be perfomed.

ii) In this study static analysis has only been studied.Dynamic analysis and its effects can be considered further.

iii) The similar study for skewed bridges can be carried out .

PUBLICATIONS

1) The paper entitled “Cost Optimization Aspects of RCC Box Girder Bridge” has been communicated to International Journal of Advanced Production and Industrial Engineering, for Publication.

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APPENDIX-II

DESIGN SPREADSHEET FOR SINGLE CELL CONCRETE BOX GIRDER BRIDGE WITH SPAN 50M AND SPAN TO DEPTH RATIO 20.

LOAD CALCULATIONS **Span(L) = 50.00 m L/d=20 Single Cell**

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Wt of box girder (w1) = 42853.4 x 10^-4 x 2.50 = 10.71 t/m

Superimposed dead loads -

Footpath & road kerbs = 2 x 1.850 x 0.200 x 2.50 = 1.85 t/m

Wearing coat = 7.50 x 0.065 x 2.50 = 1.22 t/m

Railing + Crash barriers = 2 [0.80 + 0.25] = 2.10 t/m

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w2 = 5.17 t/m

Due to FPLL -

Intensity as per IRC Cl 209.4 (c) = 500 Kg/m^2

a) **Due to two lanes of IRC class A** I.F. = 1.0804

consider axle load = 11.4 t

wheel spacing = 1.8 x 1.2 m

Tyre dimensions = 0.5 x 0.25 m

effective width of dispersion = 0.5 + 2 x 0.315 = 1.13 m

effective width of slab for outer wheel = 1.2 x 0.7 + 0.38 = 1.22 m

effective width of slab for inner wheel = 2.6 x 1.1 x 0.792 + 0.38 = 2.64512 m

UDL for outer wheel = 1.080 x 0.5 x 11.4 / 1.13 / 1.22

= 4.47

UDL for inner wheel = 1.080 x 0.5 x 11.4 / 1.13 / 2.645

= 2.060

b) **due to IRC Class 70R Wheeled** I.F = 1.088

Consider two wheel loads = 10 t

wheel spacing = 1.93 x 1.2 m

tyre dimensions = 0.81 x 0.234 m

effective width of dispersion = 0.81 + 2.0 x 0.315 = 1.44 m

effective width of slab for outer wheel = 2.6 x 0.530 x 0.9 + 0.364 = 1.6042 m

effective width of slab for inner wheel = 2.6 x 2.460 x 0.536 + 0.364 = 3.792256

3.792256 > 1.2 m Hence 2.496 m

UDL for outer wheel = 1.088 X 10 / 1.44 / 1.6042 = 4.7098588 t/m^2

UDL for inner wheel = 1.088 x 10 / 1.44 / 2.496 = 3.0270655 t/m2

=

Consider four wheel loads = 5 t

wheel spacing = 0.33 x 1.2 m

tyre dimensions = 0.36 x 0.263 m

effective width of dispersion = 0.36 + 2.0 x 0.315 = 0.99 m

effective width of slab for outer wheel = 2.6 x 1.460 x 0.725 + 0.393 = 3.1451 m

3.1451 m > 1.20 Hence 2 m

effective width of slab for inner wheel = 2.6 x 2.255 x 0.575 + 0.393 = 3.764225

3.764225 > 1.2 m Hence 2 m

UDL for outer wheel = 1.088 X 5 / 0.99 / 2.172 = 2.5299031 t/m^2

UDL for inner wheel = 1.088 x 5 / 0.99 / 2.481 = 2.2148124 t/m2

c) **For 70R Tracked in span**

Consider tracked load of 35t for local flexure

Track dimensions = 0.84 x 4.57 I.F = 1.088

Effective width of dispersion = 0.84 + 2 x 0.315 = 1.47

effective width of slab for each track = 2.6 x 1.62 x 0.694 + 4.7 = 7.62

UDL for track load = 1.088 x 35 / 1.47 / 7.62 = 3.3981801 t/m^2

Design of sections-

Transverse analysis is done by STAAD and moments are picked from output.

Design Constants-

Permissible stress of concrete in compression (σ) = 13.3 (IRC: 21-2000, table 9) for M40

lever arm constant (j) = 0.867

Resisting moment factor (Q) = 2.31

permissible stress of steel in tension ($\sigma_{st)}$) = 200 N/mm^2 (IRC: 21-2000, table 10) for Fe415

Recaptulation of Moments and Shear-

Loading

At cantilever face

Moment = 8.933 tm/m as staad

Shear = 8.299 mt as staad

Depth provided, D = 262.5 mm

depth required d √M/Q.b = 148.653 mm REF.BOOK

ok

Ast= BM/σ_{st}.j.d = 3465.569 mm^2
~~~~~~~~~~~~~~~~~~~~~~~~~

Minimum tenion R/f (0.18%bD) = 874.125
Governing Ast (mm^2) = 3465.569
dia of bar provided (mm) = 16
Ast Provided (mm^2) = 3619.584
spacing provided (mm) = 55.55556
ok

Distribution steel:
Dead load Bending Moment (tm/m) = 3.365
Live load bending moment (tm/m) = 5.298
moment (tm/m) = 2.2624
depth available (mm) = 979
Ast required (mm^2) = 133.2716
dia of bar (mm) = 8
Ast provided (mm^2) = 402.176
spacing (mm) = 231.25

Check for shear stress
Nominal Shear stress, τ_v SF/bd = 0.055828
As per IRC 21 (2000), permissible shear in concrete shall be $k\tau_c$, where
k is a factor that depends on concrete grade
ρ is % of steel = $100A_s/bd$ = 2.434922
for given ρ and M40 Grade concrete, τ_c = 0.49 table 12B of IRC 21(2000)
$\tau_c > \tau_v$
Hence OK

At midpsan of deck slab
Moment = 7.319 tm/m as staad
Shear = 7.631 mt as staad
depth provided, D = 250 mm
depth required √M/Q.b = 76.59898 mm
= ok
Ast= BM/σ_{st}.j.d = 5510.356 mm^2
Minimum tenion R/f (0.18%bD) = 2430
Governing Ast (mm^2) = 5510.356
dia of bar provided (mm) = 20
Ast Provided (mm^2) = 5652
spacing provided (mm) = 55.55556
ok

Distribution steel:
Dead load Bending Moment (tm/m) = 3.145
Live load bending moment (tm/m) = 5.842
moment (tm/m) = 2.3816
depth available (mm) = 974
Ast required (mm^2) = 141.0135
dia of bar (mm) = 8
Ast provided (mm^2) = 1005.44
spacing (mm) = 300

Check for shear stress
Nominal Shear stress, τ_v SF/bd = 0.099623
As per IRC 21 (2000), permissible shear in concrete shall be $k\tau_c$, where
k is a factor that depends on concrete grade
ρ is % of steel = $100A_s/bd$ = 7.378688
for given ρ and M40 Grade concrete, τ_c = 0.63 Table 12B of IRC 21(2000)
$\tau_c > \tau_v$
HENCE OK

At web
Moment = 2.817 tm/m as staad
Shear = 1.74 mt as staad
depth provided, D = 200 mm
depth required √M/Q.b = 68.71084 mm
= ok
Ast= BM/σ_{st}.j.d = 2364.354 mm^2
Minimum tenion R/f (0.18%bD) = 929.88
Governing Ast (mm^2) = 2364.354
dia of bar provided (mm) = 16
Ast Provided (mm^2) = 2411.52
spacing provided (mm) = 83.33333
ok

Distribution steel:
Dead load Bending Moment (tm/m) = 0.556
Live load bending moment (tm/m) = 5.526
moment (tm/m) = 1.769
depth available (mm) = 980

Ast required (mm^2) = 104.1005
dia of bar (mm) = 8
Ast provided (mm^2) = 402.176
spacing (mm) = 245.625

Check for ultimate shear srength
Acc. To IRC 18:2000, the ultimate shear resistance of the support section uncracked in flexure is given by

v = .67bd(f+.8f)^1/2
here, f = .24(fck)^(1/2)
f = 1.517893277
v = 7.60951372
sf = 1.74
ok

In Soffit Slab
Moment = 1.807 tm/m as staad
Shear = 1.592 mt as staad
depth provided, D = 200 mm
depth required √M/Q.b = 46.61459 mm
ok
Ast= BM/σ_{st}.j.d = 2235.565 mm^2
Minimum tenion R/f (0.18%bD) = 1296
Governing Ast (mm^2) = 2235.565
dia of bar provided (mm) = 16
Ast Provided (mm^2) = 2411.52
spacing provided (mm) = 83.33333
ok

Distribution steel:
Dead load Bending Moment (tm/m) = 0.556
Live load bending moment (tm/m) = 2.142
moment (tm/m) = 0.7538
depth available (mm) = 980
Ast required (mm^2) = 44.35892
dia of bar (mm) = 8
Ast provided (mm^2) = 603.264
spacing (mm) = 300

Check for shear stress
Nominal Shear stress, τ_v SF/bd = 0.034152
As per IRC 21 (2000), permissible shear in concrete shall be kτ_c , where
k is a factor that depends on concrete grade
ρ is % of steel = 100A_s/bd = 5.173316
for given ρ and M40 Grade concrete, τ_c = 0.626 Table 12B of IRC 21(2000)
τ_c > τ_v
Hence OK

Footpath Slab
Moment = 0.981 tm/m as staad
Shear = 0.35 as staad
depth provided, D = 200 mm
depth required √M/Q.b = 49.26171 mm
ok
Ast= BM/σ_{st}.j.d = 1148.446 mm^2
Minimum tenion R/f (0.18%bD) = 630 as per clause 15.4, IRC 18:2000
Governing Ast (mm^2) = 1148.446
dia of bar provided (mm) = 16
Ast Provided (mm^2) = 1205.76
spacing provided (mm) = 166.6667
ok

Distribution steel:
Dead load Bending Moment (tm/m) = 0.455
Live load bending moment (tm/m) = 0.526
moment (tm/m) = 0.2488
depth available (mm) = 980
Ast required (mm^2) = 14.64115
dia of bar (mm) = 8
Ast provided (mm^2) = 301.632
spacing (mm) = 291.6667

Check for shear stress
Nominal Shear stress, τ_v SF/bd = 0.071049
As per IRC 21 (2000), permissible shear in concrete shall be kτ_c , where
k is a factor that depends on concrete grade
ρ is % of steel = 100A_s/bd = 2.447662

for given ρ and M40 Grade concrete, τ_c = 0.518 Table 12B of IRC 21(2000)

τ_c > τ_v

OK

Haunch portion at bottom

Maximum bending moment (tm/m) = 0.468
depth ,d = 266
Ast= BM/σst.j.d = 101.4647 mm2
dia of bar = 8
Ast provided = 150.816 mm2
ok

SECTION PROPERTIES OF BOX GIRDER

Overall depth	D	=	250.0	cn
Top slab between webs	560.0	x	25.0	cn
Side cantilever	175.0	x	32.5	cn
Thickness at tip of cantilever			20.0	cn
Web	205.0	x	20.0	cn
Soffit slab	360.0	x	20.0	cn
Haunch at top	90.0	x	7.5	cn
Haunch at bottom	90.0	x	26.6	cn

S. No	b or d (cm)	t (cm)	Area of element A (cm^2)	CG dist. from top Yt (cm)	A.Yt (A x Yt) (cm^3)	A.Yt^2 (cm^4)	Self moment of inertia I_{xx} (cm^4)
1	560.0	25.0	14000	12.5	175000	2187500	729167
2	350.0	20.0	7000	10.0	70000	700000	233333
3	350.0	12.5	2188	24.2	52865	1277561	18989
4	205.0	40.0	8200	127.5	1045500	133301250	28717083
5	360.0	20.0	7200	240.0	1728000	414720000	240000
6	180.0	7.5	675	27.5	18563	510469	2109
7	180.0	26.6	2394	221.1	529393	117066483	94105
		Sum	41657		3619320	669763262	30034787

CG distance of box girder

a) from top (Ytg = A.Yt/A) = 86.9 cm

b) from bottom (Ybg = D - Ytg) = 163.1 cm

M.I of box girder

I_{xx} = Io + A.Yt^2 - A.Ytg^2 = 385333817 cm^4

Section moduli of box girder

a) about top (Zt = I/Ytg) = 4434992 cm^3

b) about bottom (Zb = I/Ybg) = 2362343 cr