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Comparative Analysis and Design of Voided Slab and RCC I Girder with Solid Slab in Bridge Structure

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ABSTRACT
This thesis is basically based on the comparison of the use of voided slab, RCC Solid slab and RCC Girder. In this study analysis and cost comparison of RCC Solid slab deck, RCC Voided slab deck and RCC Girder is done for superstructure spanning 20 m length. Solid slabs having greater span are uneconomical due to heavy dead load of concrete. To make it economical longitudinal beams are provided for spans greater than 10.0 m. Reinforced Concrete Girder is generally adopted for a fly over or road bridge, but in case of a river bridge with submersible superstructure, the longitudinal beams creates obstruction to the flow of water and results in additional stresses in cross direction on beams. To reduce the self-weight of concrete without sacrificing its flexural strength, in solid slab voids are incorporated in concrete section. This technic offers many advantages over a conventional solid concrete slab like reduced material use, lower total cost of construction, and increased structural efficiency. This report also shows that the dead load of bridge superstructure can be reduced by providing voids in concrete where it is unnecessarily provided. Presence of voids within the concrete structure makes analysis of structure very complicated. The analysis of RCC Solid slab, RCC Girder and RCC voided slab deck for various loads as specified in IRC is done using staad pro software for span length of 20 m and width of 15.10 m. The analysis illustrates the behavior of bending moments, Shear Force, displacements, reactions for various load conditions. It is concluded that use of voided slab is more feasible for 20 m length and 15.10 m width. It is also economical as compared to solid slab and Reinforced concrete Girder.

KEYWORDS: *Voided Slab, RCC Girder, Solid Slab, STAADpro Concrete, Reinforcement, Bridge deck*

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1. INTRODUCTION
The part of the bridge that supports the deck and connects all the substructure parts to another. All the portions of the bridge that are provided on top of the supporting substructure system i.e. above abutment and pier, it covers parts such as slab, girders, deck, and everything placed above the main deck such as Reinforced concrete solid slabs, steel truss system, cable-stayed system, cable suspended systems, reinforced concrete girders, bearings, Railings Crash barriers, etc.

1.1. Types of Super Structure
The part of the bridge that supports the deck and connects all the substructure parts to another. All the portions of the bridge that are provided on top of the supporting substructure system i.e. above abutment and pier, it covers parts such as slab, girders, deck, and everything placed above the main deck such as Reinforced concrete solid slabs, steel truss system, cable-stayed system, cable suspended systems, reinforced concrete girders, bearings, Railings Crash barriers, etc:

A. **Solid Slab-** The Solid slab bridges are made up of concrete in which internal stresses of the appropriate distribution and magnitude are introduced so that resulting stresses from external loads are appropriately balanced to the desired degree. Longitudinally reinforced concrete slab bridges have the easiest configuration in terms of superstructure and the polished appearance. The reinforced solid slabs are generally provided at bridges with a span which are up to 15 m.

B. RCC Girder - Girder is that horizontal member of bridge superstructure which is normally a beam which is subjected to loading due to which straining and shearing forces acts on the axial and lateral cross section. In Reinforced concrete girders the reinforced concrete combines concrete and steel bars by simply putting them together and letting them act together naturally. When the loading conditions are applied on a reinforced concrete girder it changes. Reinforced Concrete Girder Bridge is adopted normally as a superstructure of a bridge in the span range of 10 to 25 m. For the larger spans the dead loads becomes too high. Because of easy geometry, simple erection and casting T beams are very famous and generally provided. To carry the traffic (Vehicles and pedestrians), a reinforced concrete slab is provided above the girders.

C. Voided Slab - Voided Slabs are a precast pre stressed and RCC in situ slab for bridge, building, marine pier and underpass structures. These type of slabs can be utilized where slab depth may be a concern or when less construction time is required. The voided slab is being used in construction field around 100 years. By providing the voids in between the slab, dead load of the slab can be reduced and this helps in reducing the overall quantity of concrete in slab which also helps in the reduction in cost of the slab.

D. PSC Girder- Pre stressed concrete Girder is the most updated major type of construction introduced in the field of bridge engineering because of its major advantages like, the scale or dimension of structural members are decreased, which can enhance the clearances or reduce the height of structures. It also allows the construction and design of huge spans (more than 30 m) with small members, even when a heavy weights are applied.

1.2. Objective

The main objectives of this study are:

A. To compare three different type of superstructures i.e. RCC Solid Slab, RCC Girder and RCC Voided slab in simply supported bridge structure.

B. To select the span length, grade of materials used and make grillage of all three types of superstructures with properties, supports and loads as per IRC 6-2017.

C. To check the results and analyze all three type of superstructures i.e. voided slab, RCC I girder and Solid Slab.

D. To determine the difference in stresses and moments generated in all three types of structures.

E. To determine the quantity of concrete and steel for RCC Solid slab, RCC Girder and RCC Voided slab in simply supported bridge structure.

F. Determination of changes and differences in cost of all three types of superstructures.

2. Literature Review

K. Hemalatha, Chippymol James, L. Natrayan, V. Swamynad (July 2020) analyzed pre stressed concrete box girder bridges and RCC T Beam super structure under various span conditions. The objective of the study was to reduce dead load, extra usage of material, which is not used to its full potential, is removed from this section, which can be in the shape of cellular structures or box girder structures depending on whether the shear deformations are neglected or not. After all the analysis this study shows that the ultimate shear strength is within the limits as per IRC 112:2011. The results of this study concludes that for 16 m length of span, RCC Tee beam girder bridge is safe to adopt and easy to build a cast in-situ type of bridge. Since in the study the deck of the bridge was casted monolithically with slab, the flange of the girder also bears the compressive stresses generated in it that mean it will resist the sagging moment on deck more effectively. Further the results concluded that, the ultimate shear strength, minimum section modulus at service loads, stresses at service loads and ultimate flexural strength are within the limits as per IRC 112:2011 and IS: 1343-2012. This study also proves that 50 m length of span, Pre stressed Concrete Box Girder Bridge can be adopted.

Rahul Gangwar, Ankur Pratap Singh, T.N.Pandey (April 2020) compared RCC and PSC Girder of various spans which includes the design and estimates of both type of structures. The motive of the study was to study RCC as well PSC Girder of different span and find out the difference in design and estimation. In this study while calculating the cost of PSC Girder cost of accessories like spilt cones, bearing plates, sheathing duct and cost of prestressing were also considered and after the quantity calculations it was concluded that from spans 10 m to 18 m, PSC Girder is economical, as the span increases its economic efficiency also increases. The deflection in girder also decreases in the case of pre stressed concrete which satisfies the limit state of serviceability & durability. This study also shows the saving of concrete quantity and reinforcement but as there is a huge saving of material in prestressed concrete structure but on the other hand skilled labor and accessories are required to execute prestressed girder. Further it was concluded that Reinforced concrete beams are generally heavy. They always need shear reinforcements besides the longitudinal reinforcement for flexure. Prestressed concrete beams are lighter. By using the curved tendons and the pre-compression, the most part of the shear is resisted.

High strength concrete is not needed in reinforced concrete beams. But high strength concrete and high strength steel are very important for prestressed concrete beams.

Situations which demands weight more than strength, reinforced concrete beams can be used because reinforced concrete beams are heavy and massive. For heavy load and larger spans prestressed girders can be used because in prestressed beams slender and artistic treatments can be easily provided. The deflection of prestressed beams are small so the cracks do not occur under working loads. If in case even a minute crack is developed, such crack gets closed when the overload is removed.

Singh Shailendr, Jain Utkars, Nimoriya Manish Kumar, Faraz Md. Islamuddinn (June 2015) compared after changing the simply supported bridges into continuous bridges and then analyzed the behavior of continuous bridges with respect to that of simply supported bridges.

For this study six cases of simply supported were considered. For the comparison study the simply supported bridges, the bending moments developed in continuous bridges were considerably very less and therefore smaller sections can be adopted which results in economy of steel and concrete. The ultimate moment carrying capacity of continuous bridge deck was higher than that of simply supported decks due to the fact of redistribution of moments in continuous type of structures. Results of the study shows that for spans up to 6 m the dead load moments obtained were 63% as of live load moments and for span of 8 m length they were approximately equal. At 12 m and 10 m spans the dead load moments calculated were 2.40 times and 1.50 times if compared to that of dead load moments respectively. The study concluded that from slab design point of view it is way better to choose continuous two or three spans in multiple of 4 m, 5 m and 6 m. The study further suggested that use of continuous spans in place of single span reduces dead load, live load and design moments considerably. This study observed that providing two spans instead of one span reduces moments from 80% to 90% and providing three spans instead of one span reduces moments approximately 92%.

Rajesh F. Kale, N.G.Gore, P.J.Salunke (January 2014) in this study, cost optimization approach of R.C.C. T-beam girder was discussed. The main aim of the study was to minimize the total cost in the design process of the bridge structure considering the cost of materials. For a specific span of girder and width of bridge, the design variables considered for the minimization of cost of the bridge system, are deck slab depth, width of web of girder and, depth of girder, (i.e. X1, X2, X3 resp.) Design constraints for the development are considered according to Standard Specifications from IRC-21:2000 (Indian road congress). The development process was done for different grade of concrete and steel. The results for different grade of steel and concrete were compared was presented in tabulated form. The optimization problem is classified by having a combination of continuous, discrete and integer sets of design variables. The structure was modeled and calculated using the direct design method. Optimization problem is formulated is in nonlinear programming problem (NLPP) by SUMT. In this study the optimization for reinforced concrete R.C.C. T type beam girder system was explained and the results of the optimum and old design procedures are compared. The results of the study also suggests that it is possible to formulate and to obtain solution for the minimum cost design for R.C.C. T-beam girder, Interior penalty function method can be used for solving resulting non-linear optimization problems. The study showed that it is possible to obtain the global minimum for the optimization problem by starting from different starting points with the interior penalty function method. The minimum cost design of R.C.C. T-beam girder is fully constrained design which is defined as the design bounded by at least as many constraints as there are the design variables in the problems. Actual percentage of the saving obtained for optimum design for R.C.C. T-beam girder depend upon the deck slab thickness, depth of girder, grade of steel and grade of concrete. The optimum cost for a R.C.C. T-beam girder is achieved in M25 grade of concrete and fe415 grade of steel. The cost of R.C.C. T-beam girder unit increased rapidly with respect grade of concrete increases and grade of steel increases whereas cost of R.C.C. T-beam girder decreases as the span of bridge reduces, also the cost of girder decreases with the increase in the girder depth. Noticeable savings in cost over the normal design can be achieved by the optimization. However the study showed that the actual percentage.

3. Methodology and Problem Formulation

3.1. Problem Formulation

In the present study the analysis and design of three different types of bridge deck is considered which are

Solid Slab, Voided slab and RCC I Girder for earthquake zone II where we have assumed that type of substructure is same for all three deck system, there foundation is assumed to rest on soil having SBC of 30 t/m^2 and analysis of bridge deck is to be done in STAAD PRO V8i software. The result is compare on basis of quantity of concrete and steel is used in bridge deck, depth of bridge deck, cost, maximum stresses, maximum displacement, maximum force, and maximum bending moment. Here three different model is prepared for consider three bridge deck for having a same span of 20m and width of structure is 15.1m and load is applied as per IRC 6-2017 where Live load is to consider for 4 lane Class A Loading, 2 lane of Class A and One

Lane of Class 70R and also 2 Lane of Class 70 R.

3.2. Loading Combination

Various Load Considered for design of Super-Structure which are as follows:

1. **Dead Load**: It includes weight of Superstructure itself.

A. In case Solid Slab: It includes the weight of solid Slab

B. In case of Voided Slab: It includes weight of Voided Slab Excluding the weight of Voids.

C. In case of RCC I Girder: It includes weight of girder, diaphragms and deck slab.

2. **Super-Imposed Load:** It is generally imposed dead load on bridge deck i.e. Crash Barrier load and Wearing Coat load.
3. **Live Load:** Live Load is consider as per IRC 6-2017, as in our case we have consider width of structure is 15.1 m, so as per IRC the above three structure should be design vehicular load as per follow:

A. 4 Lane For Class A Vehicle

B. 2 Lane for Class A Vehicle + 1 lane for Class 70 R

C. 2 Lane for Class 70 R

The live load cases shown above are for a 4 lane carriage way. The live load combination decided on basis of carriage way width of bridge which is as per IRC 6-2017, table -6.

The shear force and bending moment for every load case is decided at distance d from the support and at mid of the span of a bridge. The bending obtained at mid of span is used to calculate area of reinforcement, hence longitudinal reinforcement is obtained. The curtailment to be provided at distance from 0.25 effective length of span based of moment at that section.

3.3. Methodology

The process of analysis and design of Super structure performed on STAAD–Pro V8i in accordance with IRC 6-2017, IRC SP 64-2016 and IRC 112-2020 is shown through Flow Chart below.

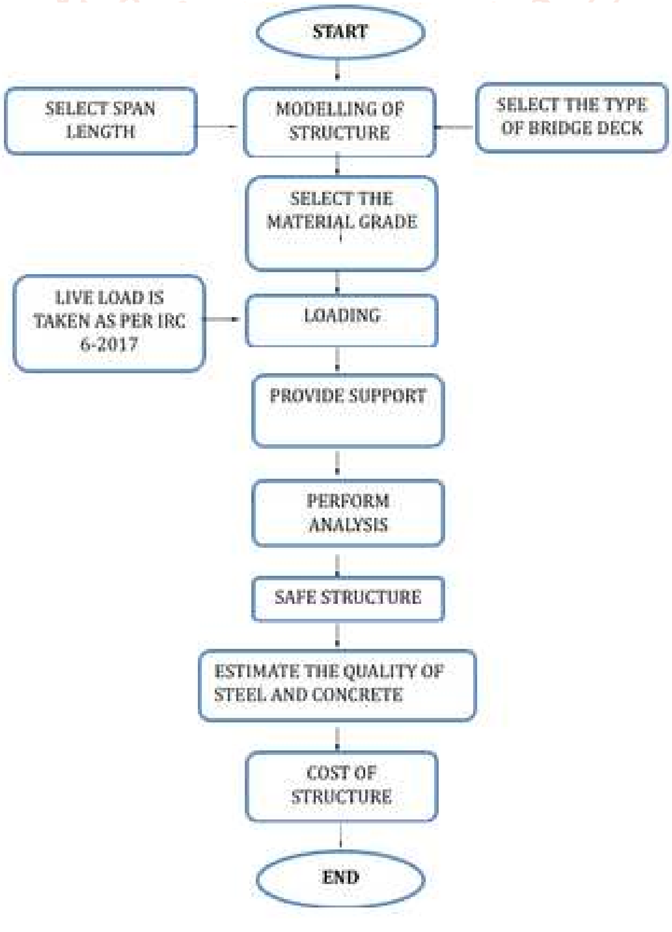


Table 1: Material Specification

S. No	MATERIAL SPECIFICATION	
1	Grade of Concrete, M-35	Fck = 35 N/mm2
2	Grade of Steel, Fe-500	Fy = 500 N/mm2
3	Density of Concrete	ϒ’c = 25KN/m3
4	Cost of Steel bars	Rs 70/Kg
5	Cost of Concrete	Rs 7000/m3

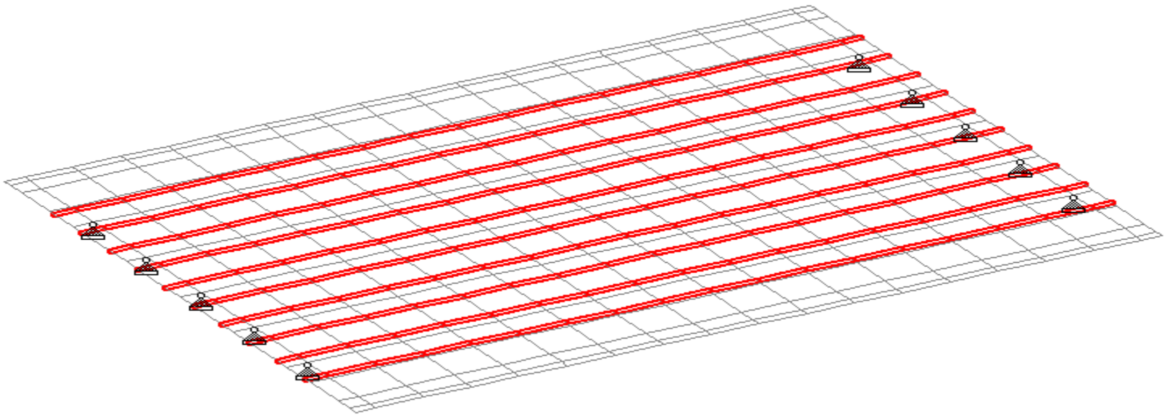
Step -1 Modelling of Bridge Decks:

A bridge deck is assume to be beam when its length is more than its width that load act on it tends to bend and twist along its length of cross section within the elastic limit. So in order to analyze bridge deck in computer software in grillage analysis method is used in order to get proper result. Therefore in Grillage analysis designer should kept in mind following points in order to develop proper grillage mesh are as follows:

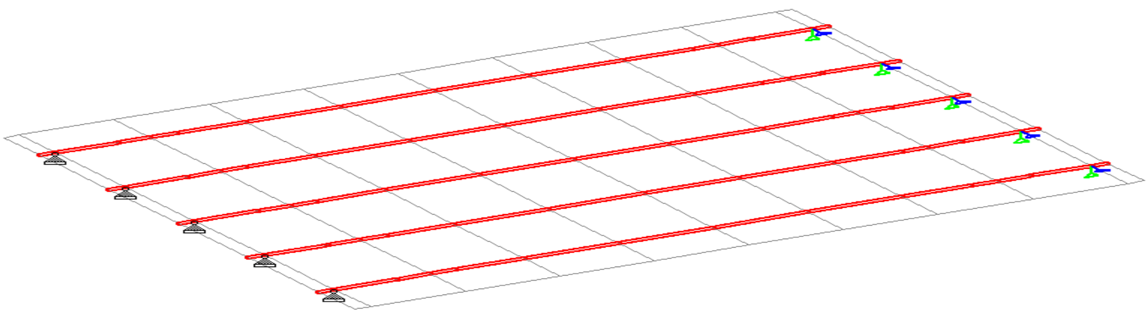
1. Designer should know how the structure will behave and placing of grillage beam coincide with lines of desired strength.
2. Designer also consider how forces will be distributed within the prototype i.e. torsion shear flow, vertical shear flow within cross section of beam.
3. Number of Longitudinal member can be any number and should be selected throughout the width of bridge in such a way that local dispersion with grillage mesh is neglected.
4. The spacing within transverse member should be less so that fully load is taken by longitudinal member and should be kept less one-fourth of effective span.
5. Transverse member should be orthogonal to longitudinal member unless it is skew in nature, but in our case it is not skew.
6. In Grillage analysis the point load represent loads distributed over the width represented by the member.

Step -2 Assigning Section Properties and support:

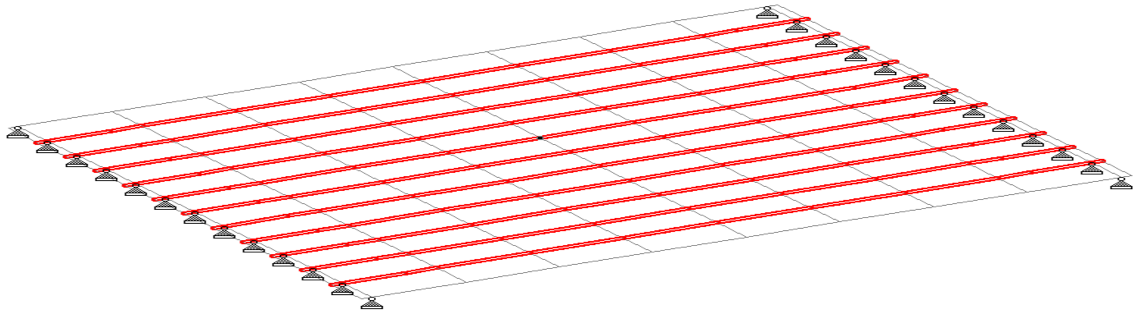
After preparing grillage model for each consider bridge deck slab, section properties need to assign for each longitudinal member and transverse member in prepared Staad model for designing bridge deck. These properties assign on basis of criteria discuss above or grillage mesh prepared, which will fit in grillage modelling. So that bending moment, shear force develop in these member is used for designing them. The support condition is defined for the model assuming that end bearing is Elastomeric in nature i.e. Elastomeric Bearing hence it is defined accordingly.



1. Stadd Pro Model for Voided Slab



2. Stadd Pro Model for RCC I Girder



3. Stadd Pro Model for Solid Slab

Figure 1: Prepared Stadd Pro Model for Solid Slab, Voided Slab and RCC I Girder with their Longitudinal Member.

Step 3: Application of load

Next Step is to Consider Load on above consider Bridge Deck i.e. Voided Slab, RCC I Girder and Solid Slab. Various kind of load need to be consider on Bridge Deck like Dead Load, SIDL which includes Wearing Coat and Crash Barrier Load, Live Load as per IRC 6-2017, Temperature Strain Etc. All these load are taken as per standard provision which are according to IRC 6-2017. These above mention load is applied in Stadd Pro.

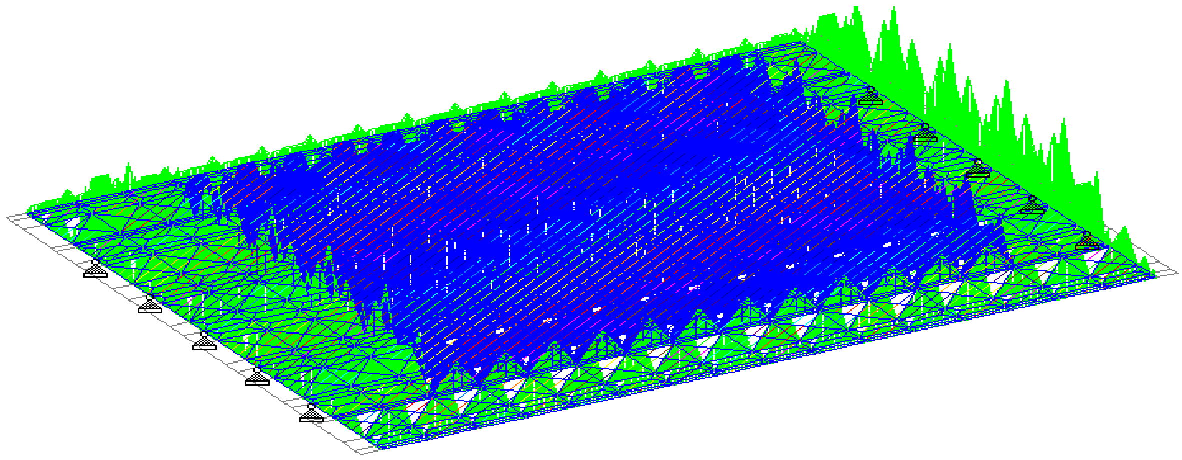
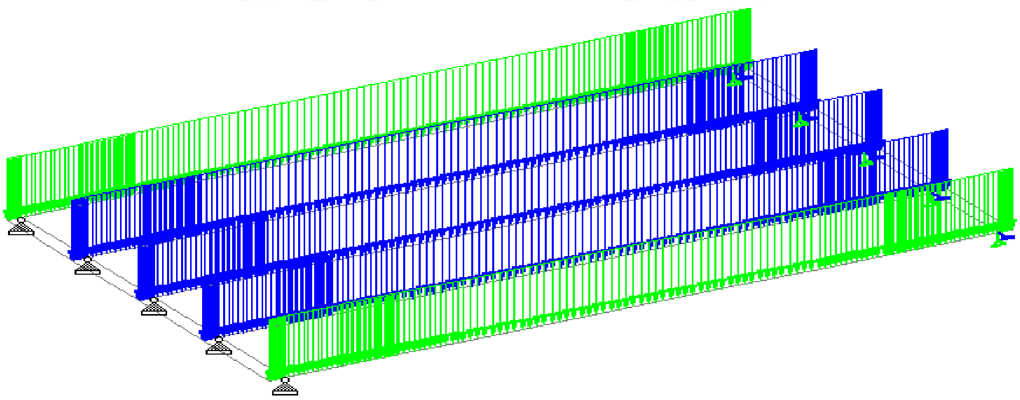
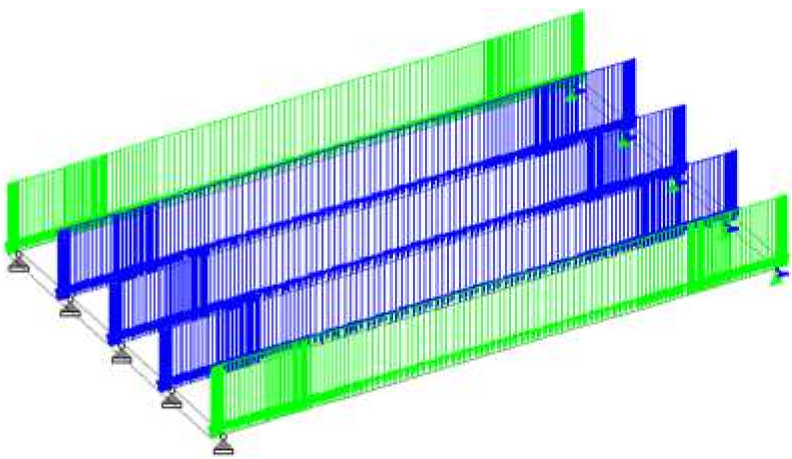


Figure 2: Dead Load on Voided Slab.





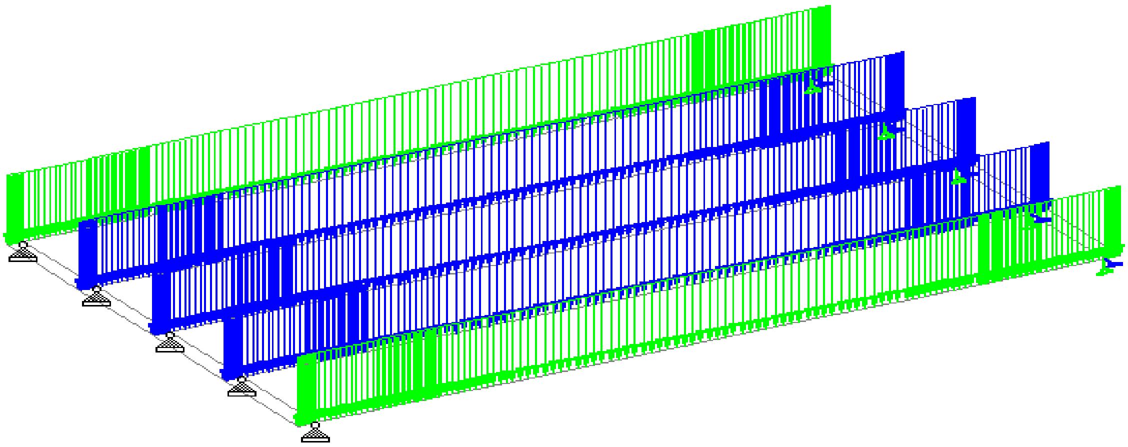


Figure 3: Dead Load on RCC Girder from Deck Slab above the Girder.

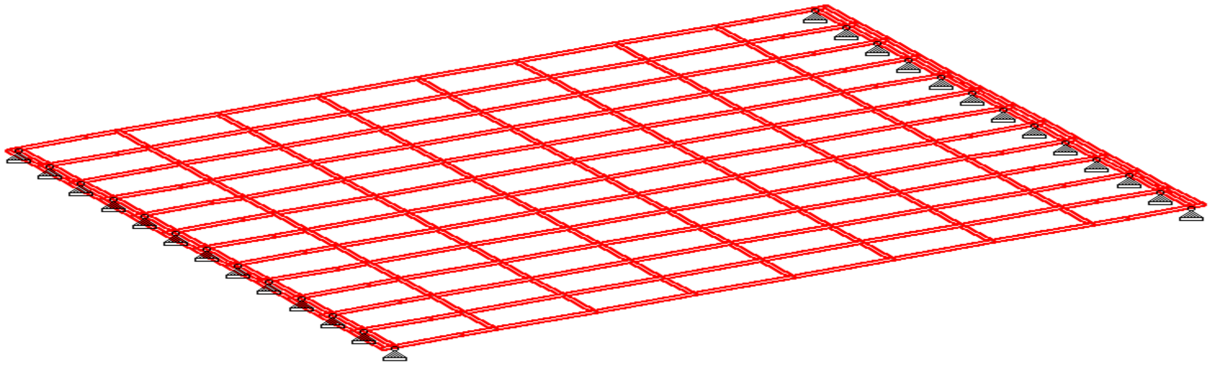


Figure 4: Self Weight on Solid Slab.

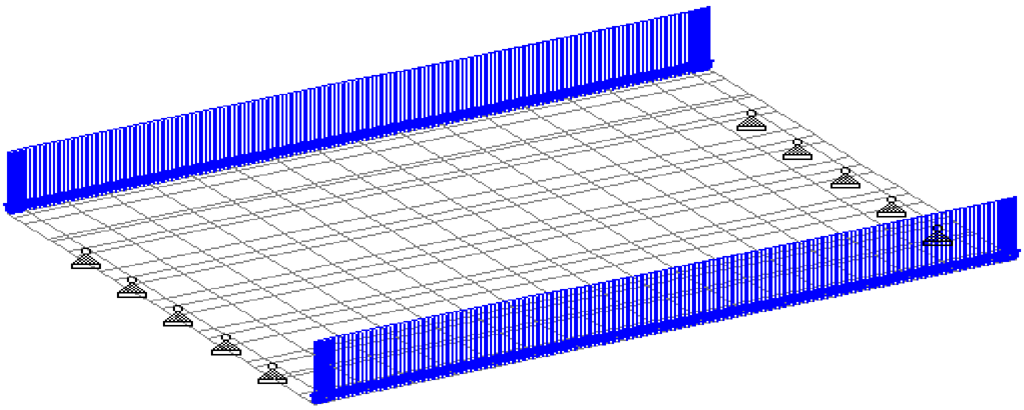


Figure 5: Crash Barrier Load on Voided Slab.

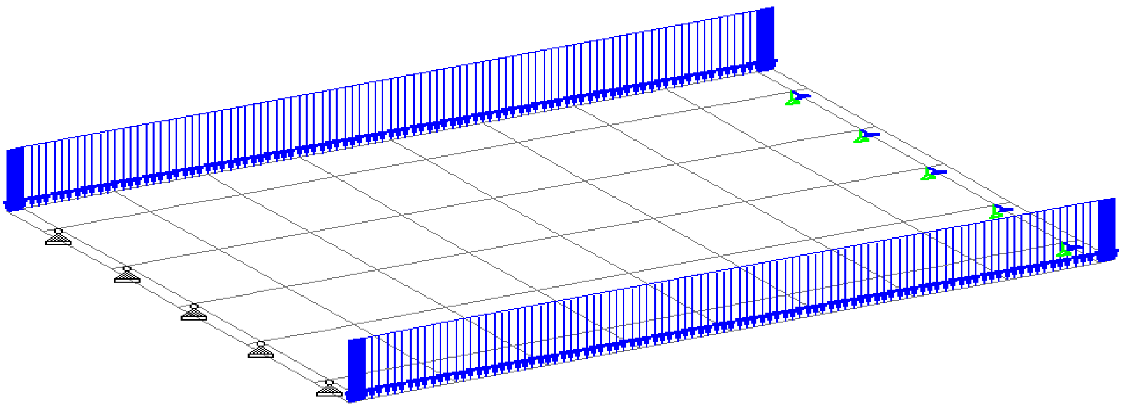


Figure 6: Crash Barrier Load on RCC I Girder.

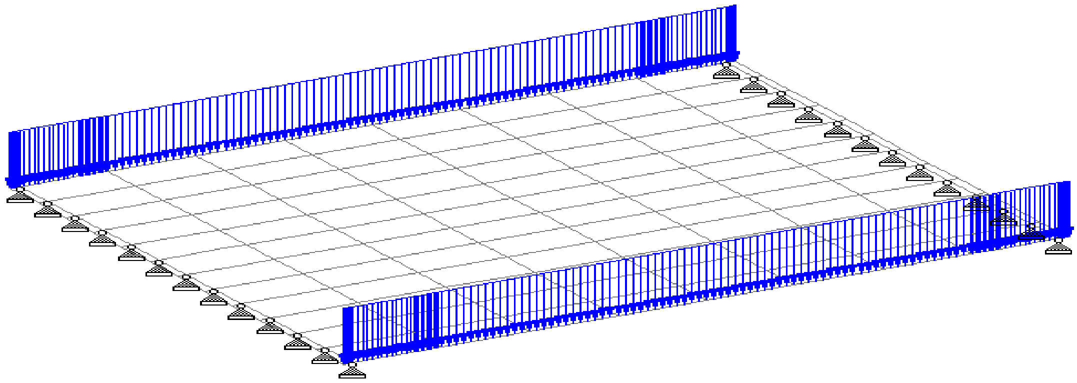


Figure 7: Crash Barrier Load on Solid Slab.

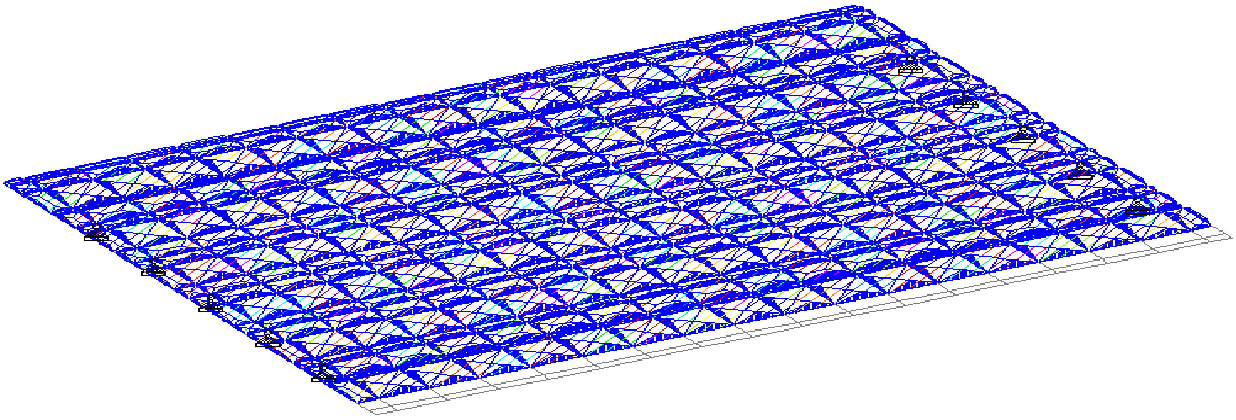


Figure 8: Wearing Coat on Voided Slab.

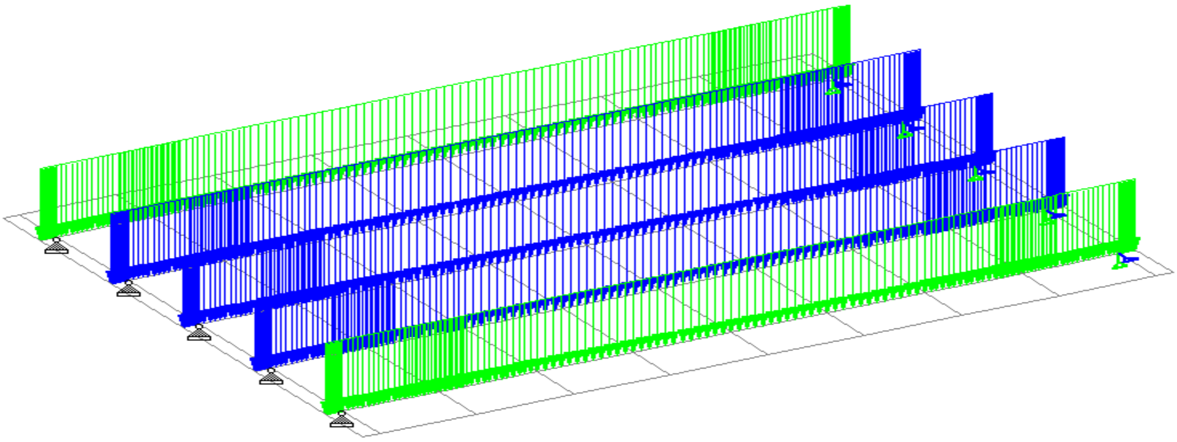


Figure 9: Wearing Coat on RCC I Girder.

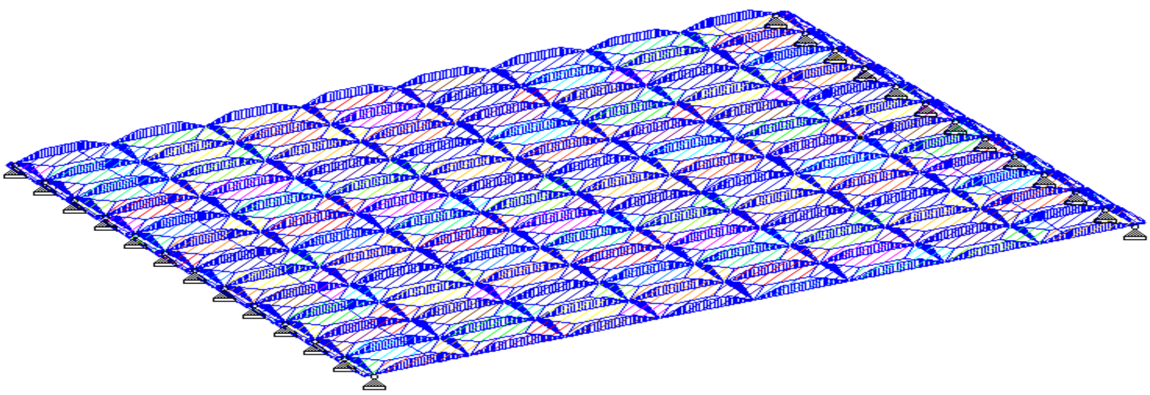


Figure 10: Wearing Coat on Solid Slab.

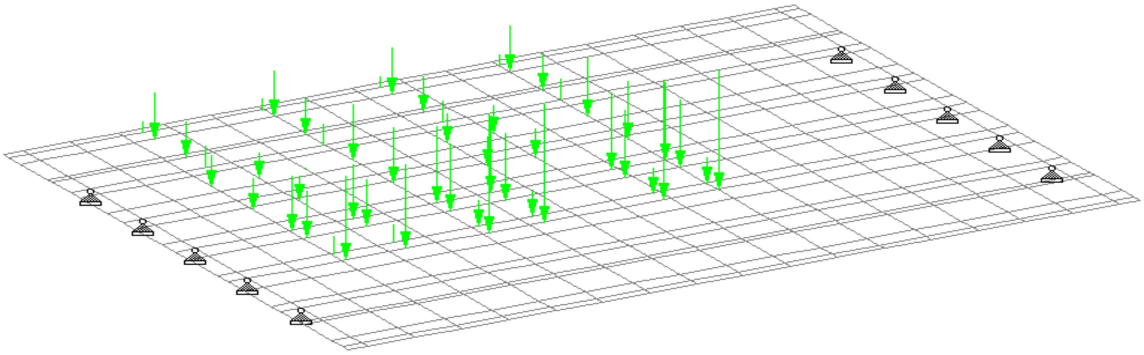


Figure 11: Live Load on Voided Slab.

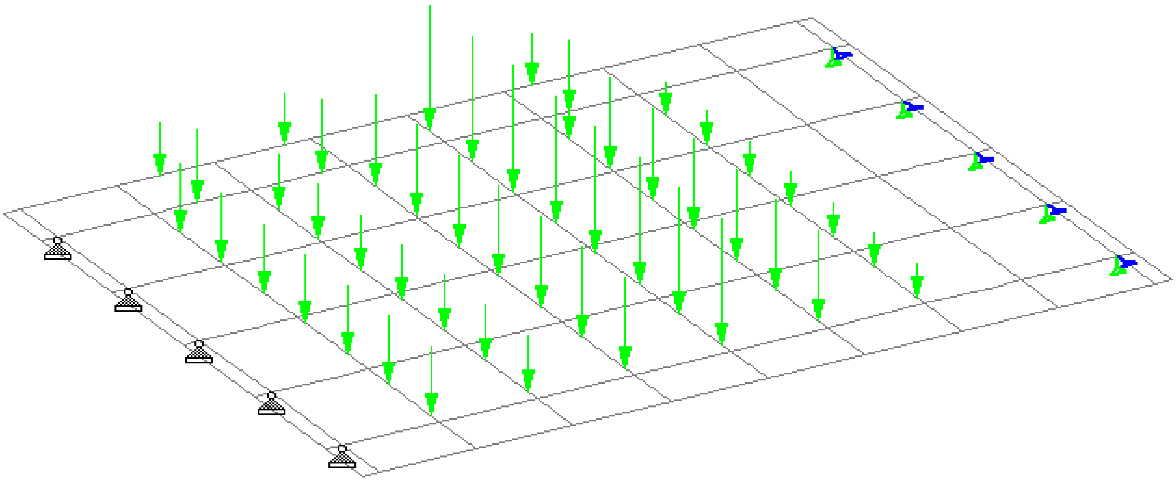


Figure 12: Live Load on RCC I Girder.

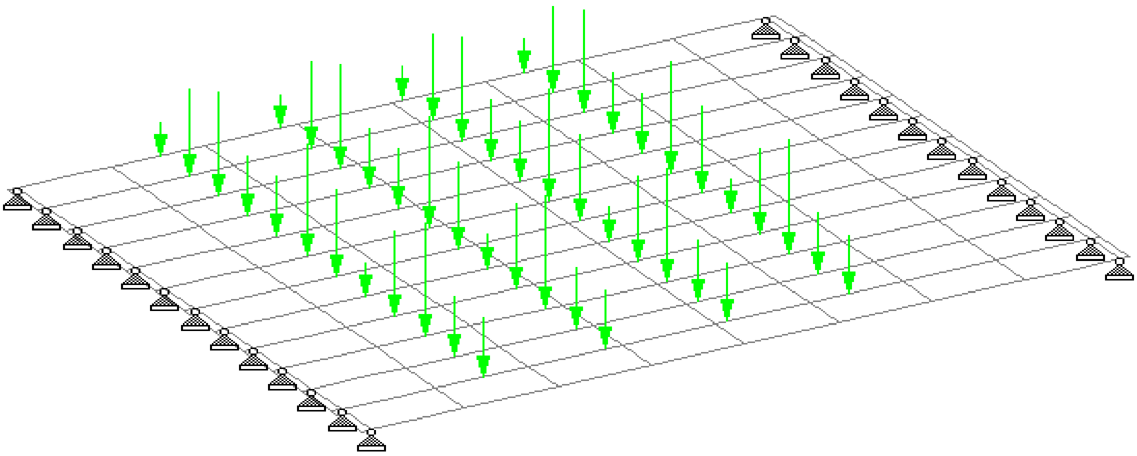


Figure 13: Live Load on Solid Slab.

Step -4 Load Combinations as per IRC 6-2017:

After considering all load on bridge deck load factor needs to be applied on consider load so in order to design bridge deck for ultimate strength limit and these load combination is to be consider as per IRC 6-2017 from Annexure B Table No. B.2. The output file generate from Stadd pro of Live Load is need to be multiply with impact factor so to account dynamic action made by increment of live load. The provision of impact factor is consider as per IRC 6-2017 from clause no. 208.

Table 2 : Load Combination as per IRC 6-2017

S.NO	LOAD COMBIATION	PRIMARY LOAD	FACTOR
1	LOAD COMBINATION	DEAD LOAD	1.35
		CRASH BARRIER	1.35
		WEARING COAT	1.75
		LIVE LOAD	1.5

Step -5 Design of structure

Separate excel sheet is prepared in design of Bridge deck which is enclose in Annexure-C, D, E. The design of bridge deck is done as per IRC 112-2020 and IRC SP 64-2016 and section properties and area of reinforcement required is calculated as per IRC 112-2020 and IRC SP 64-2016. General Design parameter is taken for design as follow and mention below:

Span c/c of Expansion Joint =20m

Total Width of the Structure =15.1m

Density of concrete= 2.5 t/m2

Grade of concrete = M-35

Young Modulus of Elasticity for Concrete Ecm= 32000 MPa

Grade of main steel = Fe-500

Young Modulus of Elasticity for Concrete Es=200000 MPa

Grade of secondary steel = Fe-500

The result like Bending Moment, Shear force, Displacement etc. obtain from Staad Pro for three different bridge deck which are Voided Slab, RCC I Girder and Solid Slab is put in excel sheet and where need to find which type of section properties like depth of slab/girder, amount to steel is required to section is remain under-reinforced, shear force is within permissible limit, deflection and stresses is within permissible limit in order to satisfy serviceability criteria. As a whole just want to know structure is safe and constructible, designed is to serve purpose for design period.

Step-6 Following above design criteria designing of bridge deck is performed.

Design of Bridge deck is done for Voided Slab, RCC I Girder and Solid Slab as per above mention criteria until opted depth of section is safe and full filling design criteria.

3.1. Result and Inferences

3.2. Results

3.2.1. Depth of Bridge Deck:

The depth of bridge deck decided on basis of length of span and type of bridge deck provided, and also it depend upon design criteria ultimate limit state and serviceability limit state so that it can fulfil purpose:

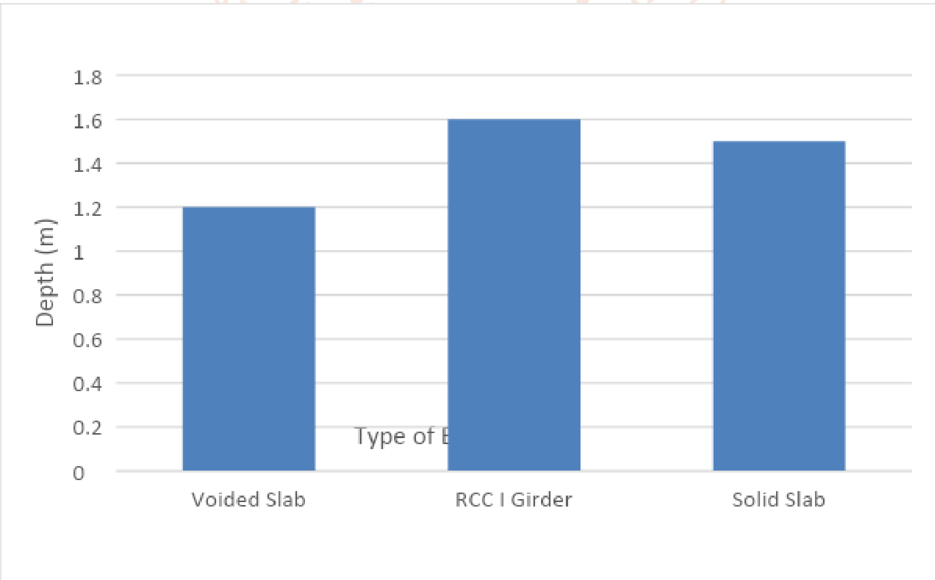


Figure 14: Depth of Bridge deck for Voided Slab, RCC I Girder and Solid Slab

3.2.2. Quantity of steel:

Quantity of steel required for different type of deck is different and which mainly depend upon cross section of bridge deck is selected in order to satisfy the ultimate limit state as per IRC 112-2020:

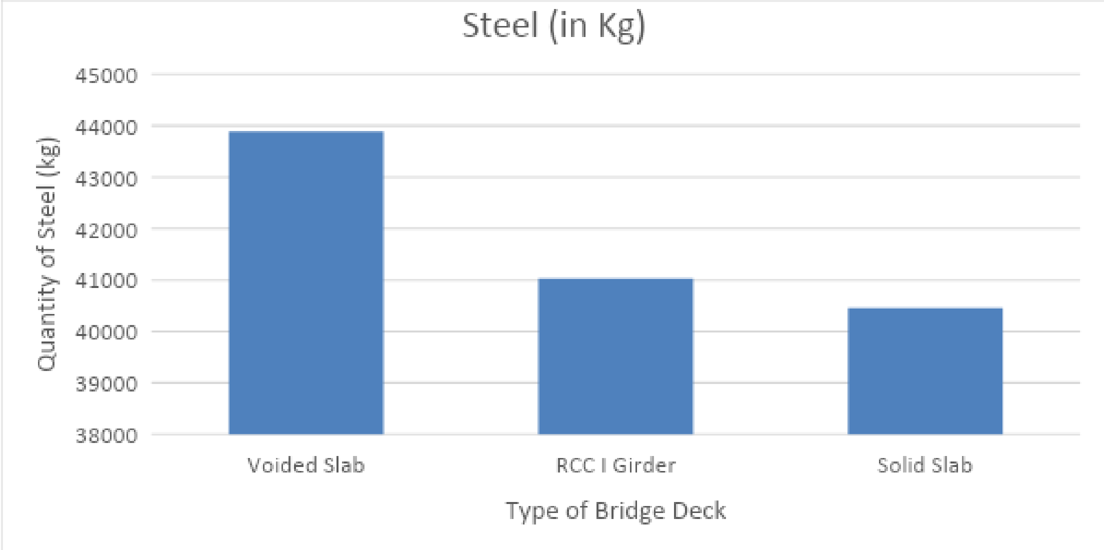


Figure 15: Quantity of Steel for Voided Slab, RCC I Girder and Solid Slab

3.2.3. Quantity of Concrete:

Quantity of concrete which mainly depend upon depth and cross section of bridge deck is selected. The quantity of concrete required for different type of bridge deck is represented in chart below:

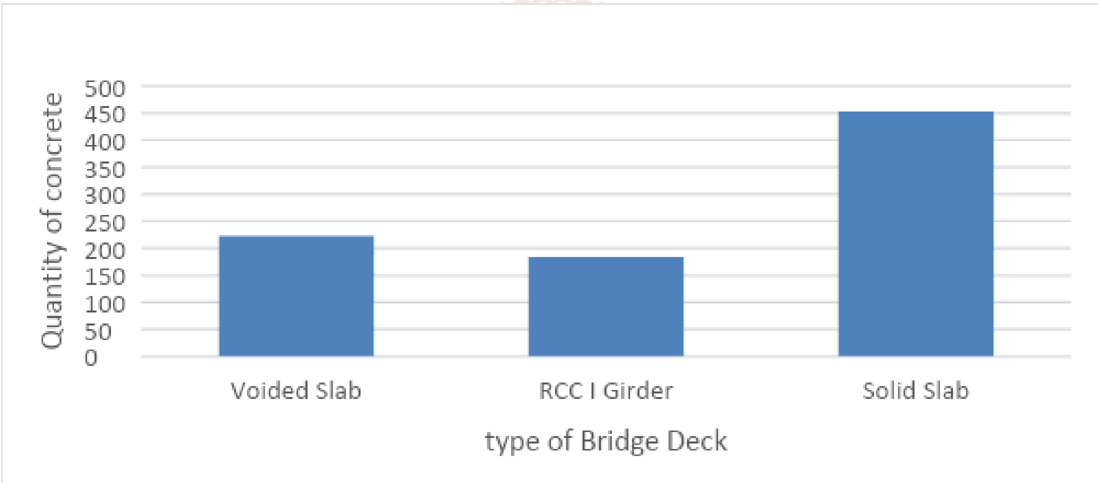


Figure 16: Quantity of Concrete for Voided Slab, RCC I Girder and Solid Slab

3.2.4. Cost of structure:

The cost of structure is purely dependent on the quantity of concrete and steel. If the quantity of concrete and steel is changing then the cost of bridge deck is affected. Total cost and cost per running meter for three different bridge deck is represented in chart below:

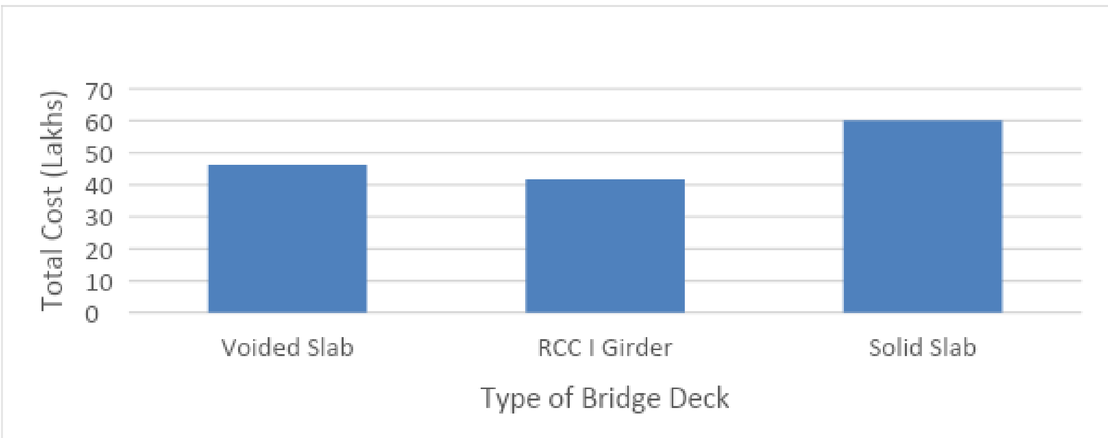


Figure 17: Cost of Structure for Voided Slab, RCC I Girder and Solid Slab

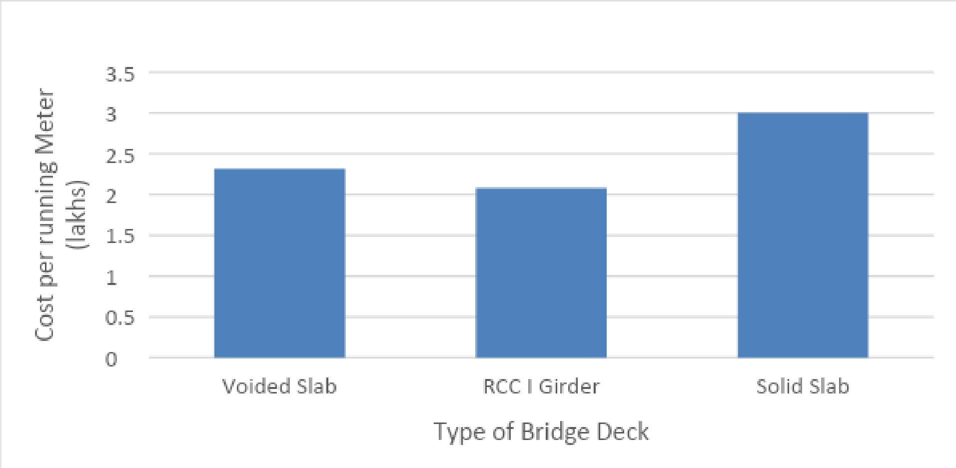


Figure 18: Cost per running meter for Voided Slab, RCC I Girder and Solid Slab

3.2.5. Maximum Displacement:

It is observed that maximum displacement occur in mid of the span of simply supported bridge deck structure in vertical downward y direction. It is also observed that for every load case deflection occur in vertical downward y direction for all bridge deck i.e. voided slab, RCC I Girder and Solid slab.

Table 3 : Maximum Displacement (mm) in Y-Direction

Maximum Displacement (mm) in Y-Direction			
Type of Load	Voided Slab	RCC I Girder	Solid Slab
Dead Load	14.943	8.849	19.218
Crash Barrier	1.763	3.338	0.806
Wearing Coat	2.152	0.427	1.023
Live Load	14.416	3.513	6.716
Total Displacement	33.274	16.127	27.763

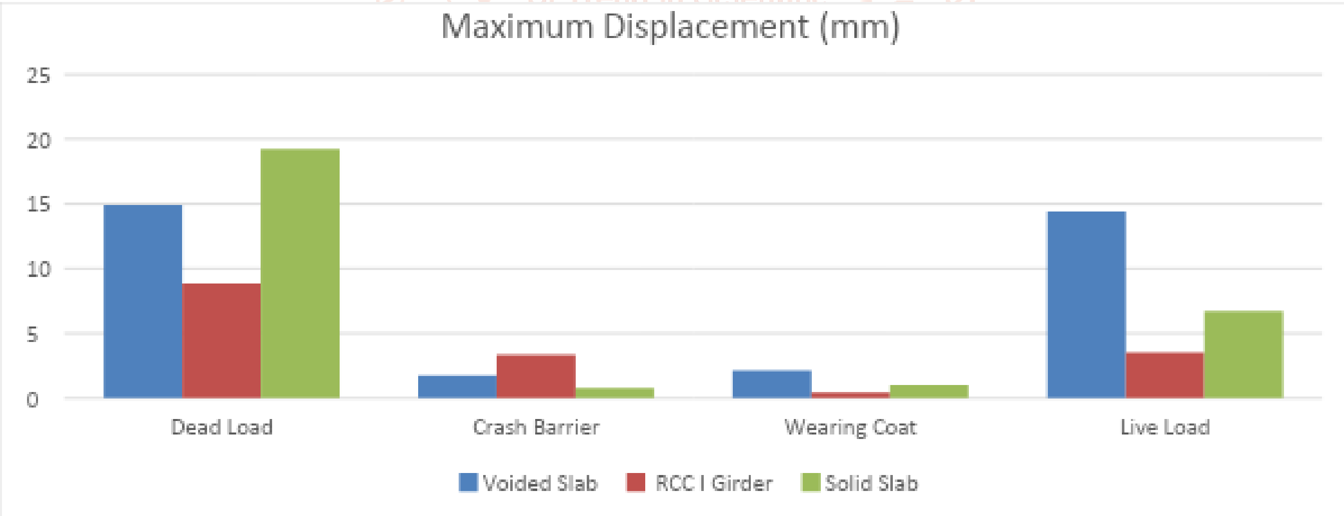


Figure 19: Maximum displacement (mm) in Y-Direction

3.2.6. Maximum Force:

It is observed that maximum shear force occur at support of the span of simply supported bridge deck structure. It is also observed that for every load case shear force occur maximum at support of bridge deck.

Table 4: Maximum Force (KN) in Y-Direction

Maximum Shear Force (kN) in Y-Direction			
Type of Load	Voided Slab	RCC I Girder	Solid Slab
Dead Load	232.034	347.29	356.7
Crash Barrier	21.205	120.128	20.174
Wearing Coat	25.616	41.123	19.027
Live Load	152.599	293.983	275.411
Total Shear Force	431.454	802.524	671.312

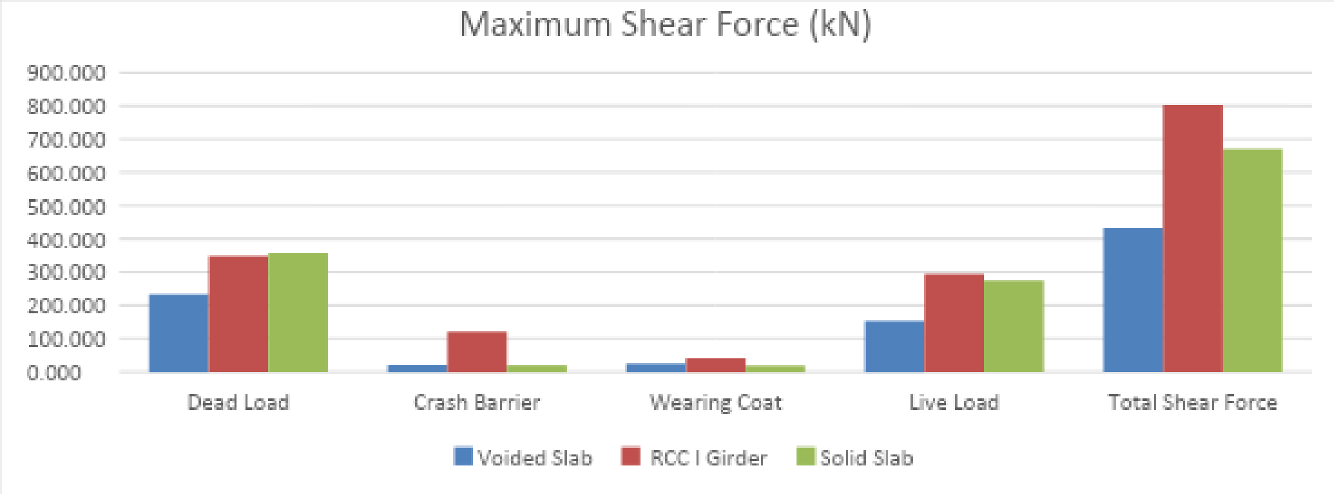


Figure 20: Maximum Force (KN) in Y-Direction

3.2.7. Maximum Bending Moment:

In case of simply supported span maximum bending moment is found to be maximum at the mid of the span of bridge deck. For designing a bridge deck maximum bending moment is taken.

Table 5 : Maximum Bending Moment (KN-M) in Y-Direction

Maximum Bending Moment (kN-m)			
Type of Load	Voided Slab	RCC I Girder	Solid Slab
Dead Load	1026.387	1527.168	1970.498
Crash Barrier	100.725	586.179	75.988
Wearing Coat	121.676	193.234	105.046
Live Load	803.259	1410.126	891.048
Total Shear Force	2052.047	3716.707	3042.58

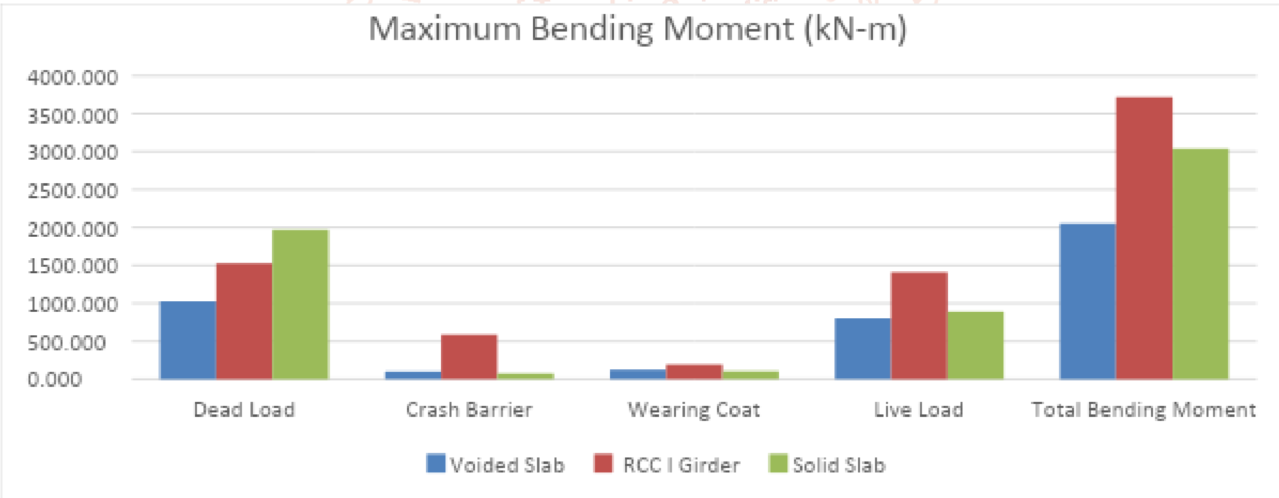


Figure 21: Maximum Bending Moment (KN-M) in Y-Direction

3.3. Discussion and Inferences

The analysis and designing of Bridge Deck shows the following inferences:

1. The depth of bridge deck for RCC I girder comes out to be more than voided slab and solid slab.
2. The quantity of concrete required for solid slab is maximum and for RCC I Girder is minimum for the span 20 m having a width of 15.1 m.
3. The quantity of steel required for voided slab is maximum and for solid slab is minimum for the span 20 m having a width of 15.1 m.
4. The cost of structure for RCC I girder is found to be least and for the solid slab is found to be high.
5. The cost per meter for RCC I girder is also found to be minimum. Hence we can say that for constructing 20 m span among these bridge deck, RCC I girder will be economical.
6. The maximum deflection and total deflection is found to be more for voided slab and hence it can be say that voided slab is a bridge deck which is least satisfying the serviceability criteria.
7. The maximum force is found to be maximum for RCC I girder and followed by solid slab and least

for voided slab for same span of the bridge having same width of the structure.

8. The maximum bending moment is also found to be most for RCC I girder and followed by Solid slab and least for voided slab for same span of the bridge having same width of the structure.

4. Conclusion

1. Considering all the above inference made on analysis and designing of all bridge deck, we finally conclude that the RCC I girder is most economical bridge deck for 20 m span having a width of 15.1 m width of structure.
2. In RCC I Girder it is also seen in from the study that maximum displacement comes out to be lowest and maximum shear force and maximum bending moment comes out to be highest.
3. The quantity of concrete is found to be lowest among rest of other bridge deck and quantity of steel is found to be second lowest among rest of other bridge deck but at last overall economy of bridge is seen, it found that total cost and cost per running meter is lowest for RCC I Girder.

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