COMPARATIVE STUDY AND DESIGN OF PRESTRESSED CONCRETE SOLID AND VOIDED SLAB BRIDGES

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ABSTRACT: While designing prestressed slab bridges the common difficulties arising are – choice of economical span and depth, type of cross-section and choice of method of construction. The superstructure of a bridge shall be designed in such a way that it satisfies load carrying requirements along with necessary geometry. Till date a very limited data are available for the comparison between types of prestressed solid slabs. In the present study a comparison of superstructures of two types of prestressed slabs, that is prestressed solid slab and prestressed voided slab is done. The study is carried out with alternative spans of bridge slab. For that purpose models with different span length but same width will be prepared and analysis is done using SAP2000. A comparison for the bending moments and shear forces for different spans in both types of slabs is done. From the results of analysis for both solid and voided slabs, a slab design for suitable span is done.

I. INTRODUCTION

Bridge construction plays a vital role in development of cities and thus, has achieved great significance these days. It facilitates a free and undisturbed movement for traffic. It also plays an important role in development of trade and industries, enhancing progress of the nation.

A prestressed concrete slab constitutes a great portion of bridges all around the world. Prestressed concrete was introduced into bridge construction since very early period of time. In past decades wide varieties of new techniques have been developed. Along with new developments in technologies spans became longer and aesthetics and appearance of bridge became more important. Prestressed concrete bridges include a wide variety of different forms like cast-in-situ or precast concrete; continuous or cable-stayed; simply supported; box-girders,slabs or beams.

Among wide variety of prestressed concrete bridges, a study on solid and voided slabs has been carried out. A comparison regarding forces and moment in both cases for different spans and sections is done; thus, analyzing both cases for a better section to be used.

II. PRESTRESS CONCRETE BRIDGES

High-strength concrete and high-tensile steel, besides being economical, make for slender sections, which are aesthetically superior. Prestressed concrete bridges can be designed as class I type structures without any tensile stresses under service loads, thus resulting in a crack-free structure. In comparison with steel bridges, prestressed concrete bridges require very little maintenance. Prestressed concrete is ideally suited for composite bridge construction in which precast prestressed girders support the cast in situ slab deck. This type of construction is very popular since it involves minimum disruption of traffic. Post-tensioned prestressed concrete finds extensive applications in long-span continuous girder bridges of variable cross-section. Not only does it make for sleek. structures, but it also effects considerable saving in the overall cost of construction. In recent years, partially prestressed concrete (type-3 structure) has been preferred for bridge construction, because it offers considerable economy in the use of costly high-tensile steel in the girder.

Slab type superstructure

These types of structures require more steel and concrete compared to that of girder bridges of same span. The overall cost of construction of these bridges is lower and is easier to construct. The limit of span of slab bridges depends on magnitude of load and relative cost of frame work, materials and labour. In slab type superstructure bridges, it is the slabs that are major load carrying elements. The loads are directly transferred to substructure through slabs. Bridges are referred as slab bridges if ratio between $W/D \geq 5$, where W =total width of slab and D= Depth of slab (if $W/D < 5$, then the bridge is referred as beam bridge). Slab bridges can be classified as per their construction: Solid slab bridges, voided slab bridges and ribbed bridges. The study here consists of solid slabs and voided slabs. A comparative analysis is done for both type of slabs.

Solid slab bridges

Solid slab decks comprises of a solid section, without beams or voids. This type of deck is commonly used in the construction of short span bridges and culverts. As the slabs are solid, the cross section from any point is a homogeneous structure. The construction of solid slab bridge decks is straight forward and easier. Also the formwork required is very simple and easy. As the structure is solid and the cross section homogeneous, the layout of reinforcement becomes very easy. There is no congestion of reinforcements created and thus, placing concrete becomes easier.

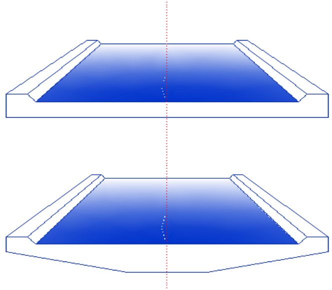

Fig 1 Typical solid slab

The one and major backdrop of solid slabs is a very large volume of concrete. This effects cost and self weight both. Due to high concrete volume, these slabs have a greater self weight. This can be avoided to certain extent by providing suitable variations in thickness of the slab. But this shall be checked properly before commencing. Another method to reduce self weight is by providing voids in the slabs. This is explained in voided slabs.

Voided slab Bridges

Voided slabs are characterized by presence of voids within the slab. As it was discussed in solid slab section voids in the slab helps reducing the self weight of structure. Thus, the major function of voided slabs is to reduce the concrete volume and thereby decrease the self weight of slab. When the concrete is being cast, the void formers are subjected to large buoyancy forces. These buoyancy forces are resisted by straps tied to bearers below the formwork. If proper care is not taken during this process, it can create major difficulties; sometimes to the extent of demolishing the slab. Hence, it should be properly designed and the formers to be used must be sufficiently rigid, thoroughly sealed and tied before commencement. The voids are usually cylindrical and are constructed using a hollow thin walled steel sections placed in the slab. If designed properly, it can reduce the self weight of slab up to 35% as compared to solid slab for same section and span. The voided slabs can be modelled and designed by the method same as that used for solid slab in case of void diameters less than 60% of the depth of slab. In case of diameters larger than 60% of slab depth the behaviour of the same becomes a cellular behaviour. Apart from reducing the slab weight and concrete volume of the slab, the voided slabs helps providing advantages also like; it provides large open floor areas. Also, large spans are possible to construct without beams by providing voided slabs. The biaxial forces created helps in reduction of deflection. Again by reducing material consumption, it is thus economic compared solid slab or beams.

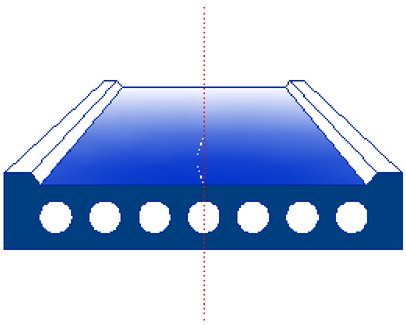

Fig 2 Typical voided slab

III. METHODOLOGY

PRESTRESSING AND ITS TECHNIQUES

Principles of prestrressing

Prestressing of any concrete structure is obtained by transfer of forces between prestressing tendons and concrete. Concrete is strong in compression; but is weak in tension. Concrete experiences prestressing because of the force that is transferred between the prestressed tendon and concrete. The tendons when pulled or stressed are under tension. This tension in tendons is balanced by compression in concrete. Thus, an external compressive force applied to concrete counteracts the tensile stresses generated under shear forces and bending moments caused due applied loading. The tendons can be externally placed or can be internal tendons. Also, it can be bonded tendons or unbounded tendons. Again, they could be pre-tensioned or post tensioned. However, its effect and principles remains the same. The concrete if prestressed fully; that is full prestressed concrete, ensures longitudinal stress in compression always and a partially prestressed concrete allows a part of tension to occur under some specific loading conditions.

Materials and techniques for prestressing

With the continuous development of technologies in the field of construction, there are various different systems allowing to obtain prestressing force in the structural members. Certain popular systems in India are Freyssinet, MagnelBlaton and Gifford Udall systems. Apart from above systems, there many other local systems developed recently in the country.

A method in which the reinforcement bars are tensioned prior to placement of concrete is termed as pretensioning. Similarly, when tendons are stressed and anchored after the process of concrete casting is complete is termed as post tensioning.

BRIDGE LOADING

General perspective on loading

In order to have uniformity over entire country in designing the structure for bridges uniform standards are laid regarding loads to be considered while designing. Detailed guidelines are laid in standard specifications and codes by The Indian Roads Congress (IRC). These specifications are collectively called Bridge Codes. The bridge codes are now consisting of eight sections; with general features of design in section 1 like specifications for primary data collection, clearances and foundations; loads and stresses in section 2. Rest of sections provides guidance for designing bridge super structure; section 3 comprises cement concrete; Bricks stone and masonry in section 4; Steel road bridges are included in section 5 and composite structures in section 6; whereas sections 7 and 8 includes foundations, substructures and bearings respectively.

IRC standard live loads

Live loads are caused by vehicles that pass over the bridge. Live loads are very difficult to estimate precisely. There are certain standard loads determined for which the road bridges are designed. These are of four different types.

(a). IRC CLASS AA LOADING: Two different types of vehicles are specified under this category grouped as tracked and wheeled vehicles. The IRC Class AA tracked vehicle (simulating an army tank) of 700 KN and a wheeled vehicle (heavy duty army truck) of 400 KN as shown in following figure. The track vehicle considered here is similar to a combat army tank. The length of track in contact with ground is 3600mm and nose to tail length of vehicle is 7200mm. The minimum spacing between noses to tail of two successive vehicles shall be 900mm. For a multilane bridge, among a train of class AA tracked vehicle or a wheeled vehicle the one which creates a severe condition shall be considered while deciding a two lane width. When class AA train is considered on bridge, no other live load shall be included. All bridges on national and state highways shall be designed for this class AA heavy loading only. These loadings are also considered for the bridges accommodated within certain municipal localities and also along certain specific highways.

(b). IRC CLASS 70R LOADING: This loading was included originally to rate existing bridges. But later and specially in recent years there is an increasing demand of specifying IRC class 70R instead of class AA loading. IRC class 70R consists of three types of loading.
1. Tracked vehicle of 700 KN with two tracks. It is similar to class AA loading except that the contact length of tracks with ground is 4.57m; nose to tail length of vehicle is 7.92m and minimum specified spacing between successive vehicles is 30m.
2. The wheeled vehicle is 15.22m in length with seven axles weighing 1000KN in total.
3. The wheeled vehicle comprising of four wheels each with a load of 100KN.
In case of tracked vehicles, the spacing between vehicles is measured from rear most point of contact with ground of the leading vehicle to the forward most point of ground contact of the following vehicle. For wheeled vehicles the same is measured from centre of rear most wheel of the leading vehicle to the centre of the first axle of following vehicle.

(c). IRC CLASS A LOADING: Class A loading comprises of a wheel loaf train with a driving vehicle as well as trailers. These are of a specific axle spacing and loads. The spacing nose to tail between two consecutive trains shall be a minimum of 18.5m. No other live load is considered to cover any part of carriage way while the train is on the bridge.

(d). IRC CLASS B LOADING: Class B loading has a train similar to that of class A but the axle loads are lesser. This type of loading is usually adopted for timber made bridges, temporary These loads specified by IRC shall be arranged in a way as to produce the severe effect of bending moment or shear at any given cross section of the bridge.

Dead loads
For majority of bridges, the dominant loading is the self weight of bridge itself. The dead loads to be considered for any bridge consists of its own weight and any fixed weight supported by its members. Dead loads can be estimated during its designing and can alsobe controlled accordingly. Usually it is initially assumed approximately and later checked after designing process is complete.

Impact Effect
Usually the live load trains considered while designing causes more stresses than the same caused if vehicles were stationary. An impact allowance is considered in order to get simpler statical analysis with the differential increase in stresses caused due to dynamic action. Hence, impact factors are generally applied to a moving vehicle or distributed loads to enhance their magnitude inorder to include their dynamic effects on the bridge deck. The impact allowance to be considered is expressed as a fraction of applied live load which can be computed for different load cases:
I = (A)/(B+L) where,
I = Impact factor fraction
A = Constant of a value 4.5 for reinforced concrete bridges.
B = Constant of value 6.0 for reinforced concrete bridges.
L = Span in meters.

Summary of Bridge loading
While the main purpose of any bridge is to support the traffic passing over the bridge in a safest possible manner, the dominant loading for almost all bridges is the self weight of the bridge. Along with the dead and traffic loads, the bridge must also be capable enough to withstand safely the environmental effects like wind pressure, water pressure if any, thermal variations and also seismic effects. The design of bridge must investigate safety of bridge in its different construction stages as well as in its final configuration.
Usually analysis of any bridge is done separately for the transverse direction and longitudinal direction of the bridge. Like, moments and axial loads are checked in a transverse direction and then in a separate analysis response in longitudinal direction is then checked assuming that the cross section is rigid. The design in transverse direction is typically dominated either by moment due to dead loads or moment due to uniform live loads. The moment caused by the concentrated wheel loads usually spread out along a considerable length of the bridge. This reduces the demand of considering these loads over the section. In certain cases, a dispersion angle of 45° is assumed to estimate the moments due to concentrated loads

IV. MODELLING ANALYSIS AND DESIGN

MODELS FOR ANALYSIS:
DATA FOR MODEL

Table 1. Data For Modelling of Slab Bridge

Description	Solid Slab			Voided Slab		
Span (m)	20 m	25 m	30 m	20 m	25 m	30 m
Depth (m)	0.8	1.0	1.2	0.8	1.0	1.2
Width (m)	8.4					
No. of Void	-	-	-	6	6	6
Area (m^2)	6.72	8.4	10.08	5.25	6.44	8.12
Section Modulus (Z)	0.896	1.4	2.016	0.868	1.347	1.972
Cable	19 T 15.2					
Concrete Grade	M45					
Description	Solid Slab			Voided Slab		
Steel Grade	Fe415					
Vehicular Loading	Class A					
	Class 70 R					

Based on above data models were prepared and analysis is performed in SAP 2000.

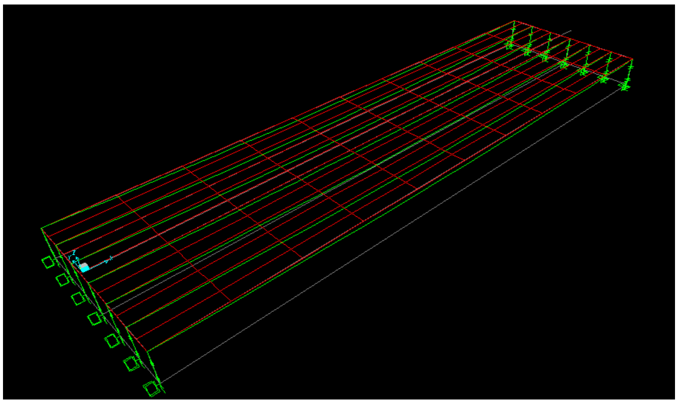

Figure 3: Model Of Solid Slab Bridge In SAP 2000.

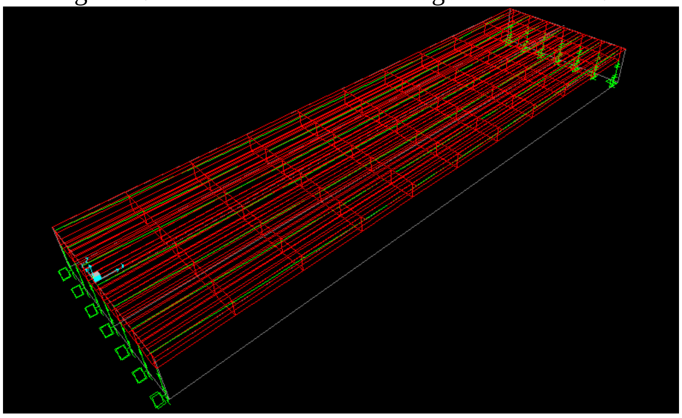

Figure 4: Model Of Voided Slab Bridge In SAP 2000.

V. ANALYSIS RESULTS

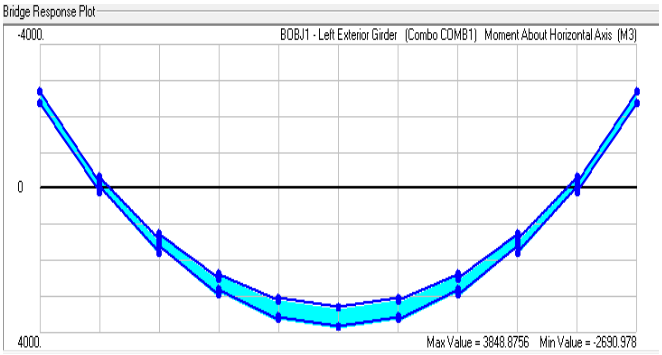

Figure 5: Response Plot ForExteriorPoint (Distance Vs Bending Moment)

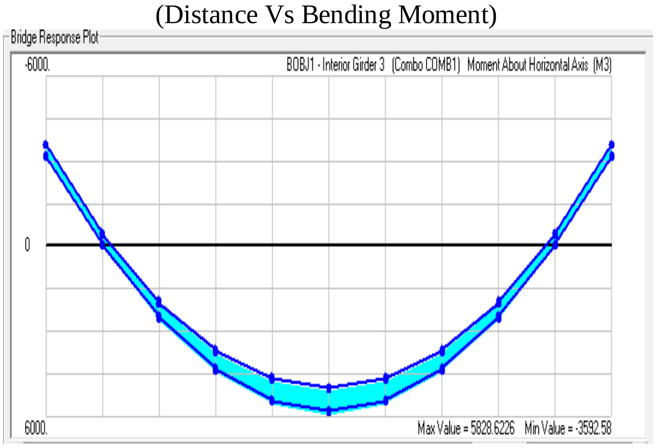

Figure 6: Response Plot ForInterior Point (Distance Vs Bending Moment)

Table 2 B.M. at Exterior Point Due to DL+LL+MOV

Span	Solid Slab (kN m)	Voided Slab (kN m)	Diff (%)
20	1961.558	1536.807	21.65
25	2666.5	2230.995	16.33
30	4448.058	3898.27	12.36

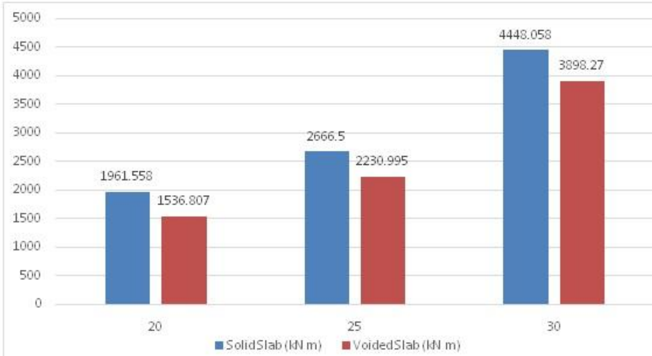

Figure 7: Comparison Graph of B.M. at Exterior Point Due to DL+LL+MOV

Table 3 B.M. at Interior Point Due to DL+LL+MOV

Span	Solid Slab (kN m)	Voided Slab (kN m)	Diff (%)
20	2961.672	2631.4	11.15
25	4517.595	4166.55	7.77
30	6972.024	6591.89	5.45

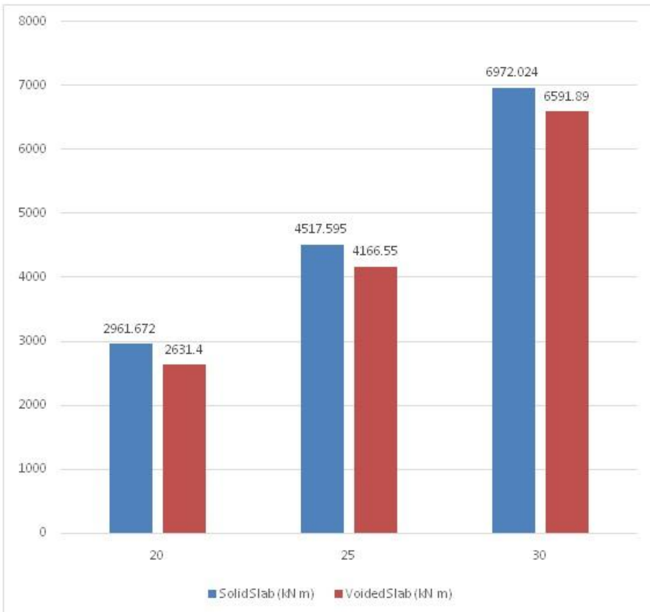

Figure 8: Comparison Graph of B.M. at Interior Point Due to DL+LL+MOV

Table 4 S.F. at Exterior Point Due to DL+LL+MOV

Span	Solid Slab (kN)	Voided Slab (kN)	Diff (%)
20	5846.21	5581.369	4.53
25	7005.084	6350.475	9.34
30	7862.3	7234.91	7.98

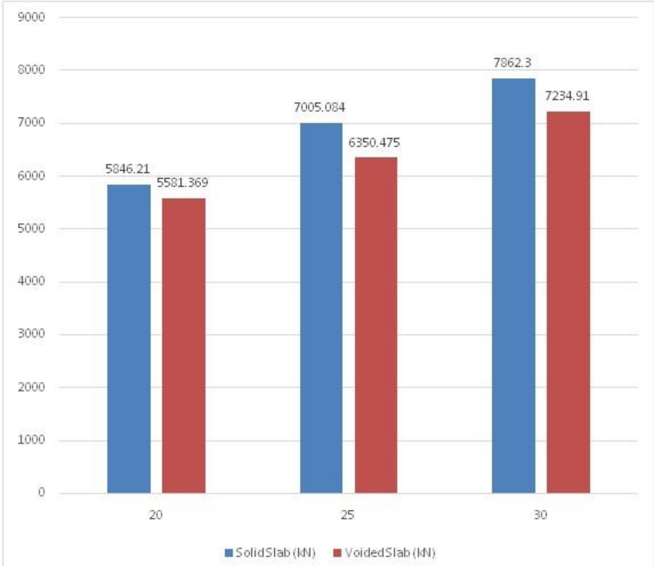

Figure 9: Comparison Graph of S.F. at Exterior Point Due to DL+LL+MOV

Table 5 S.F. at Interior Point Due to DL+LL+MOV

Span	Solid Slab (kN)	Voided Slab (kN)	Diff (%)
20	7629.515	6405.604	16.04
25	8689.318	7687.268	11.53
30	9898.614	9187.733	7.18

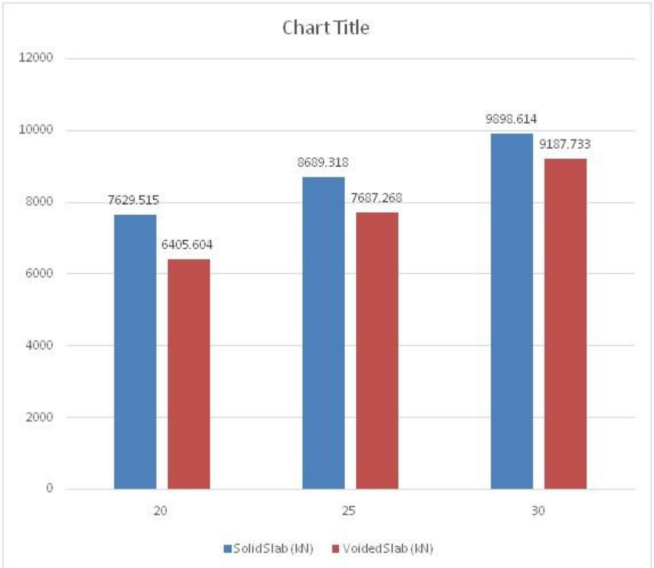

Figure 10: Comparison Graph of S.F. at Interior Point Due to DL+LL+MOV

Design Of Deck Slab

Table 6 Prestress Forces

Span	Solid Slab (kN)	Voided Slab (kN)
20	6266.527	4894.158
25	6924.34	5333.64
30	7615.37	6226.71

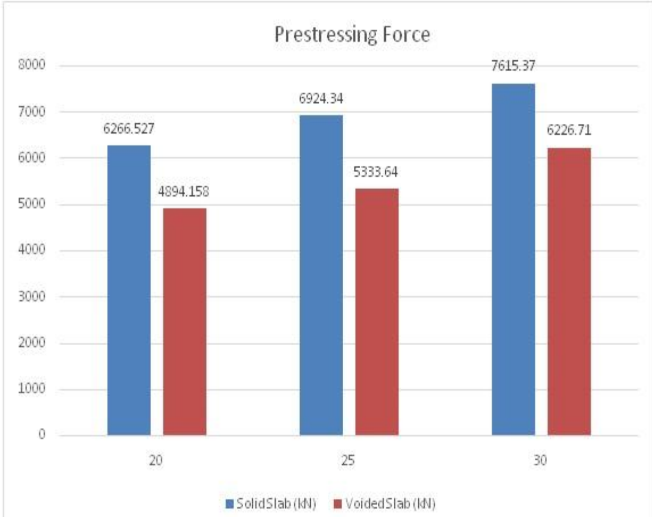

Figure 11: Comparison Graph of Prestress Forces

Table 7 Number of tendon Required

Span	Solid Slab	Voided Slab
20	08	05
25	10	08
30	13	11

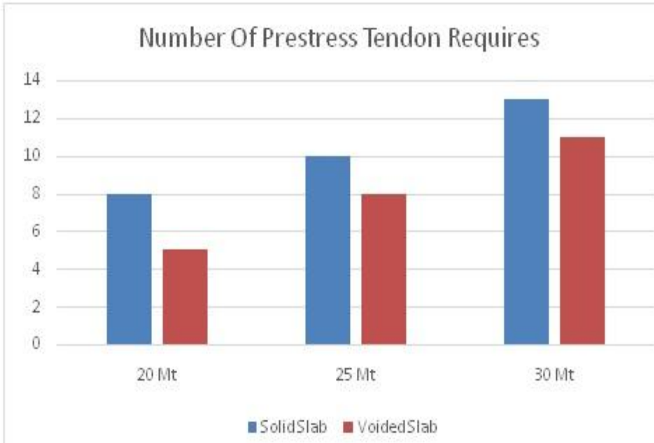

Figure 12: Comparison Graph of required number of tendons

VI. CONCLUSION

The following conclusions can be drawn from the present study.

Comparatively the shear force and bending moment are higher in solid slabs with a maximum for 40 m span.

Based on bending moments and shear forces obtained through analysis, it be said that the voided slabs are more convenient and efficient as compared to solid slab for bridge design.

From Comparative study it is clear that decrease in moments for solid slabs to voided slabs are 11.15% , 7.77% and 5.45% respectively for 20m , 30m and 40m spans.

Similarly, the decrease in shear force for solid slabs to voided slabs are 16,04%, 11.53% and 7.18% respectively for 20m , 30m and 40m spans.

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