Analysis of Voided Deck Slab and Cellular Deck Slab using Midas Civil

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***Abstract*:-The paper deals with analysis of the voided deck slab and cellular deck slab for medium bridge span ranging from 7.0 m to 15.0 m. The analysis presented illustrates the behavior of bending moments, Shear Force, displacements, reactions due to change in Span for various load conditions of voided and cellular decks. Generally for construction of a medium bridge idea for selection depends upon various factors. When Solid slab becomes uneconomical we have to go for the next alternative to make our deck economical as well as safe. However, Deciding of deck may become difficult unless we have an idea on its model and shape. As we know we use voided slab for a void depth upto 60% and cellular deck slab if the void depth is more than 60%.As in any text book it is not clear about the behavior of using various shapes as voids. In this project an experiment has been done using Midas civil software by taking void as 60% of total deck depth and analyzed under various Indian code loading conditions as per IRC and results has been compared to know the behavior of the shape constraint for deciding a bridge deck. A real voided slab model is taken for deciding dimensions and changed in line with IRCS SP 64-2005. From that model keeping width of the deck slab as constant (i.e 11.05m) by using shape of void as circular and rectangular analysis has been done in Midas civil for various spans ranging from 7.00m to 15.00m for an interval of 0.2m so total (41+41) models analyzed and their Beam forces, Reactions and Displacements in x,y and z directions have been compared interms of span wise.**

Keywords -Voided Slab deck, Cellular Slab deck, MIDAS-CIVIL

I. INTRODUCTION

One of the most important factors affecting the design of the structures is the shape of the structure. The analysis presented illustrates the behavior of bending moments, Shear Force, displacements, reactions due to change in Span for various load conditions and vehicles. Generally for construction of a medium bridge idea for selection depends upon various factors. When Solid slab becomes uneconomical we have to go for the next alternative to make our deck economical as well as safe. However, Deciding of deck may become difficult unless we have an idea on its model and shape. As we know we use voided slab for a void depth upto 60% and cellular deck slab if the void depth is more than 60%.As in any text book it is not clear about the behavior of using various shapes as void. So by using shape of void as circular and rectangular.

There are several methods available for the analysis of bridges. In each analysis methods, the three dimensional bridge structures are usually simplified by means of assumptions in the Materials, geometry and relationship between components. The accuracy of the structural analysis is dependent upon the choice of a particular method and its assumptions. Available research works on some methods are grillage analogy method, orthotropic plate theory method, folded plate method, finite strip method, finite element method, computer programming and experimental studies.E.C Hambly et al. applied grillage analogy method to the multi-cell superstructure. In this I have taken Midas Civil for analyzing the decks.

II. VOIDED OR CELLULAR DECK SLAB:

A. *Need of Voided or cellular Deck Slab*

Slab bridges are under-used principally because of lack of refinement of the preliminary costings carried out by most of the contractors/Estimators. The unit costs of formwork, concrete, reinforcement and prestress tendons should be clearly be lower for a solid slab deck than for more complex cross sections such as voided slab or multicellular slab decks. However in early stages of the project when options are being compared, this is frequently overlooked.

Slabs allow the designer to minimize the depth of construction and provide a flat soffit where this is architecturally desirable. Their use is limited principally by their high self weight. Typical medium-span concrete bridge decks with twin rib or box cross sections have anequivalent thickness(cross section area divided by width) that generally lies between 450mm and 600mm. Thus when the thickness of slab exceeds about 700 mm, the cost of carrying the self-weight tends to outweigh its virtues of simplicity.

B. *Voids shape and Material:-*

Voids may be circular, quasi-circular such as octagonal, or rectangular. Rectangular voids are assimilated to multicell boxes.

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C. Methods are used to create voids:-

The commonest is to use expanded polystyrene, which has advantage that it is light easy to cut. In theory, Polystyrene voids can be made of any shape, either by building up rectangular sections, or by sharping standard sections. In practice, the labour involved in building up or cutting sections is not economical, and cylindrical voids are usually used, these cylinders may be cut away locally to widen ribs, or to accommodate prestress anchors, drainage gullies etc.

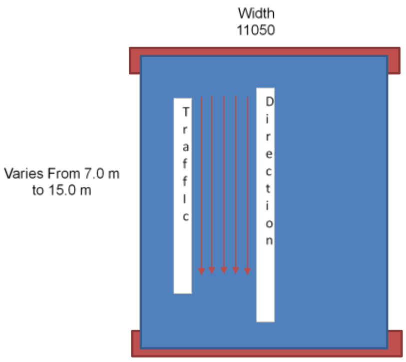
D. Development of voided slabs

The development of voided slab is similar to that of solid slabs. In decks where the maximum stress on the top and bottom fibers is less than the permissible limit, It is cost effective to create side cantilevers and to remove material from the centre of wide slabs, creating effectively a voided ribbed slab.

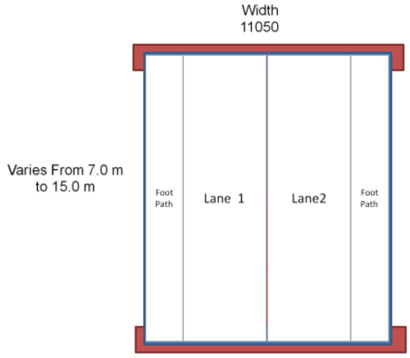
In this project the numerous finite element models are analyzed using Midas civil software by taking void as 60% of total deck depth and analyzed under various Indian code loading conditions as per IRC and results has been compared to know the behavior of the shape constraint for deciding a bridge deck. A voided slab model is taken for deciding dimensions as per . From that model keeping width of the deck slab as constant (i.e 11.05m) analysis on which supports on two piers of size 625mm and 725mm of 5.5m height has been taken just for showing supports and analysis has been done in midas civil for various spans ranging from 7.00m to 15.00m for an interval of 0.2m so total (41+41) models analyzed and their Beam forces, Reactions and Displacements in x,y and z directions have been compared interms of span wise.

III. MODELS OF VOIDED SLAB BRIDGE AND CELLULAR SLAB BRIDGE DECK IS SHOWN BELOW

Plan of Voided Slab



Plan of Voided Slab Showing Lanes



Side View of Both Decks resting on Pier

IV. OBJECTIVE OF THE STUDY

In this paper, the three dimensional finite element models are analyzed for parameters such as span length loadings. The parameters considered as follows:

1. Material Properties
   - Grade of Concrete – M35
   - Grade of steel – Fe415

2.Cross Section Specification
Span = 7m to 15 m at 0.2m interval
Total width = 11.050m
Road width = 7.510m
Wearing coat = 80mm

2. Spans
Overall Span lengths –

7 m	7.2 m	7.4 m	7.6m	7.8 m	
8 m	8.2 m	8.4 m	8.6 m	8.8 m	
9 m	9.2 m	9.4 m	9.6 m	9.8 m	
10 m	10.2 m	10.4 m	10.6 m	10.8 m	
11 m	11.2 m	11.4 m	11.6 m	11.8 m	
12 m	12.2 m	12.4 m	12.6 m	12.8 m	
13 m	13.2 m	13.4 m	13.6 m	13.8 m	
14 m	14.2 m	14.4 m	14.6 m	14.8 m	15 m
Total of (41+41 = 82) Models of Voided & 41Cellular Decks					

2. Loadings considered:
a) Self weight of box girder
b) Super-imposed dead load from wearing coat and foot path
c) Live loads as per IRC:6-2010 of following vehicles

- Class A Vehicle
- Class AA Vehicle
- Class B Vehicle
- Class 70 R Vehicle

3. Loading considered for lanes

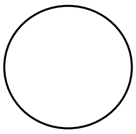
SL.No	*Lane 1*	*Lane 2*
1.	CLASS 70 R	CLASS B
2.	CLASS A	CLASS 70 R
3.	CLASS A	CLASS AA
4.	CLASS B	CLASS AA

4. Various Load Combinations

Sl. No	*Name*	*Active*	*Type*	*Description*
1	cLCB1	Strength/Stress	Add	No. I(Strn):D+1.0M[1]
2	cLCB2	Strength/Stress	Add	No. I(Strn):D+1.0M[2]
3	cLCB3	Strength/Stress	Add	No. I(Strn):D+1.0M[3]
4	cLCB4	Strength/Stress	Add	No. I(Strn):D+1.0M[4]
5	cLCB5	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[1]
6	cLCB6	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[2]
7	cLCB7	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[3]
8	cLCB8	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[4]
9	cLCB9	Serviceability	Add	No. I(Serv):D+1.0M[1]
10	cLCB10	Serviceability	Add	No. I(Serv):D+1.0M[2]
11	cLCB11	Serviceability	Add	No. I(Serv):D+1.0M[3]
12	cLCB12	Serviceability	Add	No. I(Serv):D+1.0M[4]
13	cLCB13	Serviceability	Add	No. IIIB(Serv):D+0.5M[1]
14	cLCB14	Serviceability	Add	No. IIIB(Serv):D+0.5M[2]
15	cLCB15	Serviceability	Add	No. IIIB(Serv):D+0.5M[3]
16	cLCB16	Serviceability	Add	No. IIIB(Serv):D+0.5M[4]
17	cLCB17	Strength/Stress	Add	No. I(Strn):D+1.0M[1]
18	cLCB18	Strength/Stress	Add	No. I(Strn):D+1.0M[2]
19	cLCB19	Strength/Stress	Add	No. I(Strn):D+1.0M[3]
20	cLCB20	Strength/Stress	Add	No. I(Strn):D+1.0M[4]
21	cLCB21	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[1]
22	cLCB22	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[2]
23	cLCB23	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[3]
24	cLCB24	Strength/Stress	Add	No. IIIB(Strn):D+0.5M[4]
25	cLCB25	Serviceability	Add	No. I(Serv):D+1.0M[1]
26	cLCB26	Serviceability	Add	No. I(Serv):D+1.0M[2]
27	cLCB27	Serviceability	Add	No. I(Serv):D+1.0M[3]

Sl. No	*Name*	*Active*	*Type*	*Description*
28	cLCB28	Serviceability	Add	No. I(Serv):D+1.0M[4]
29	cLCB29	Serviceability	Add	No. IIIB(Serv):D+0.5M[1]
30	cLCB30	Serviceability	Add	No. IIIB(Serv):D+0.5M[2]
31	cLCB31	Serviceability	Add	No. IIIB(Serv):D+0.5M[3]
32	cLCB32	Serviceability	Add	No. IIIB(Serv):D+0.5M[4]

5. Dimensions shape and No. of Voids:-

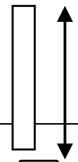
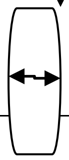
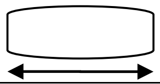
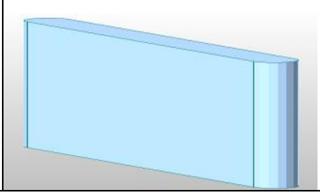
Description / Shape of void		
No of Voids	7 Nos	7Nos
Dia of Void	600 mm	-
Size of cell	-	600 x 472 mm
Area of Void For 7 Voids	3.14 x 300 x 300 = 282600 sqmm 7 x 282600 = 1978200 sqmm	-
Area of Cell For 6 cells	-	472 x 600 = 283200 sqmm 6 x 283200 = 1699200
Area of Edge Cell	-	2 x 469 x 600 = 562800
Depth of Deck	1000 mm	1000 mm
Criteria for making Voided to cellular	60% of Total Depth	60% of Total Depth

6.Dimension Checks as per Clause 3(Cross-section Dimension) in SP 64-2005For Circular Voidsand for rectangular Voids

Clause. No	*Description*	*Dimension Provided*	*Check*
3.1	The Voids can be rectangular or circular	Circular and Rectangular	OK
Clause. No	*Description*	*Dimension Provided*	*Check*
3.1.1	Centre to centre spacing of voids Shall not be less than the total depth of the slab	1040<1000 mm	OK
3.1.2	In case of Circular void,Diameter of total void / depth of Slab ≤ 75% to avoid transverse distortion effect.	600/1000 x 100 = 60% ≤ 75%	OK
3.1.3	The thickness of the web shall be as per clause 9.3.1 of IRC: 18-2000 for prestressed concrete slabs and as per clause 305.2 of IRC:21-2000 for reinforced concrete slabs		
Cl 9.3.1.1 of IRC 18-2000 for prestressed concrete slabs	The thickness of web shall not be less than 200 mm plus diameter of duct hole. Where cables cross within the web, suitable thickness over the above value shall be made	There is no duct hole and thickness of the web is 420 mm	OK
Cl 305.2 of IRC 21-2000 for reinforced concrete slabs	The minimum thickness of deck slab including that at the tip of the cantilever shall be 200 mm. However reduction in the thickness of slab upto a maximum of 50mm may be permitted at the cantilever tip subject to satisfactory detailing. The thickness of web shall not be less than 250mm.	200mm = 200mm Web thk = 420 mm< 250 mm	OK OK
3.1.4	For reinforced concrete slabs: The thickness of concrete above the void shall not be less than 200 mm and that below the void shall not be less than 175 mm	Top 200mm=200mm Bottom 200 mm >175 mm	OK OK
3.1.5	For Prestressed concrete slabs: if the cables are not located in the flange shall be governed by provision as in para 3.1.4. If the cables are located in flanges (not in the web region), the thickness of flanges shall be in accordance with the clause 16.1 of IRC 18-2000.	NA	OK
Cl 16.1 of IRC 18-2000	Wherever prestressing cable is nearest to concrete surface, the minimum clear cover measured from outside of sheathing shall be 75 mm.		
3.1.6	For rectangular voids, in addition to the above transverse width of the void shall not exceed 1.5 times the depth of the void.	NA	OK

3.2	The portion of the slab near the supports in the longitudinal direction on each side shall be made solid for a minimum length equivalent to the depth of slab or 5% of the effective span whichever is greater.	5%of7000=350mm < 1555mm 5% of 5000 =750mm<1555mm	OK OK

7. Piers of following sizes have been taken just to act as fixed support for the deck.

Description	Pier Left	Pier Right	
Height of pier	5000 mm	5000 mm	
Top Width of Pier	675 mm	725 mm	
Width of the Pier	7510 mm	7510 mm	
3 D View of Pier			

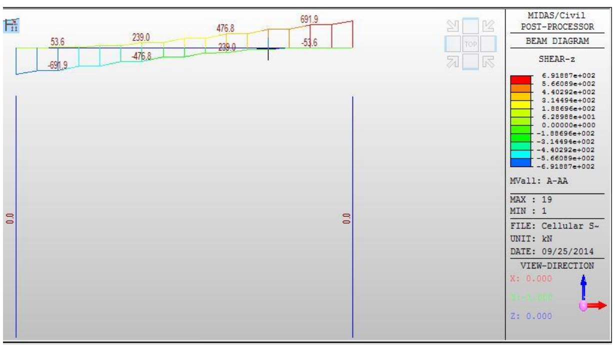
8. Results & Discussions

The Analysis of these 82 models of Voided Slab bridge deck and cellular slab bridge deck has been done using Midas Civil and the behaviour of bridge deck has been studied which yields the following results:

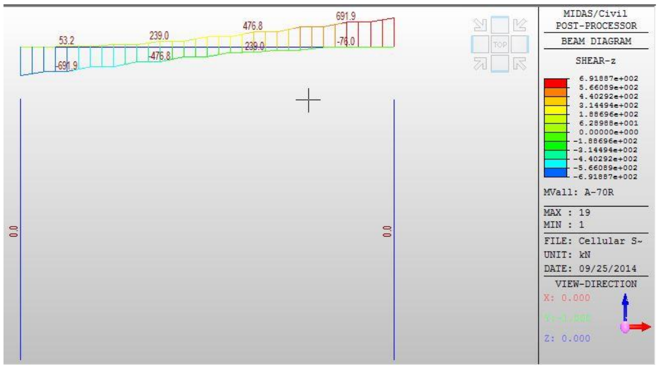
SHEAR FORCE & BENDING MOMENT DIAGRAMS OF CELLULAR & VOIDED DECK SLAB:-

7 M SPAN SHEAR FORCE CELLULAR

VEHICLE CLASS LOAD A-AA

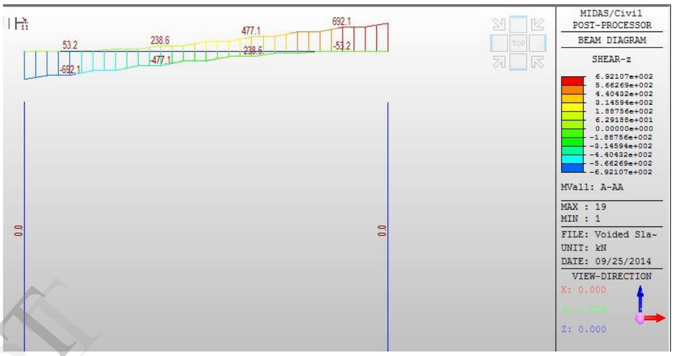


VEHICLE CLASS LOAD A-70R

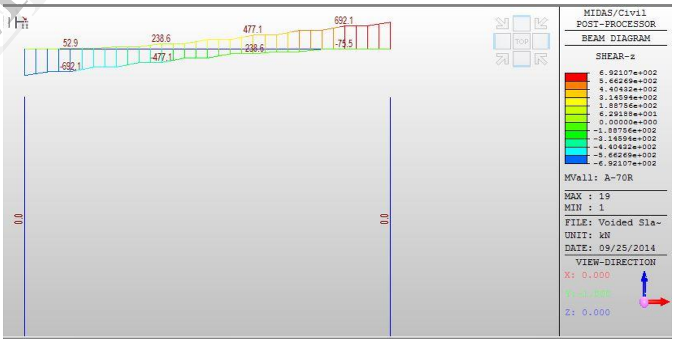


7 M SPAN SHEAR FORCE VOIDED

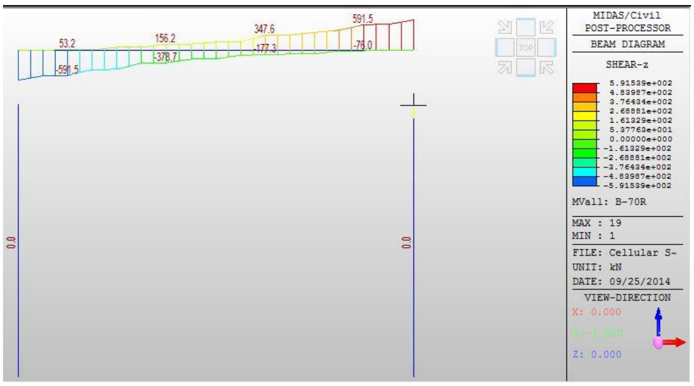
VEHICLE CLASS LOAD A-AA



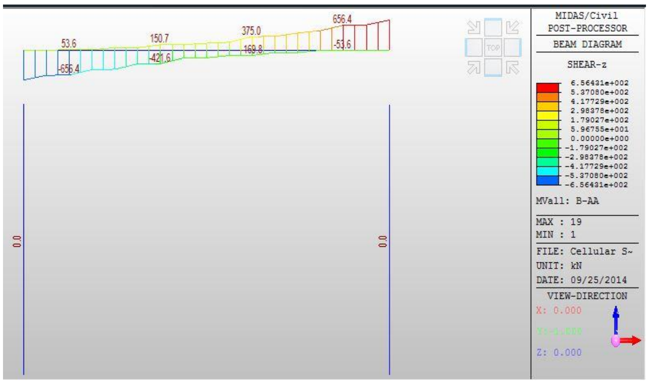
VEHICLE CLASS LOAD A-70R



VEHICLE CLASS LOAD B-70R

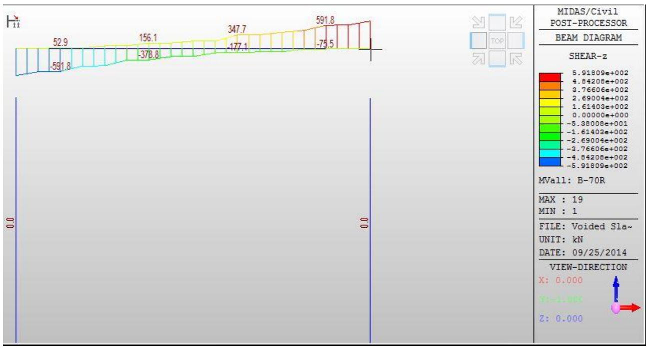


VEHICLE CLASS LOAD B-AA

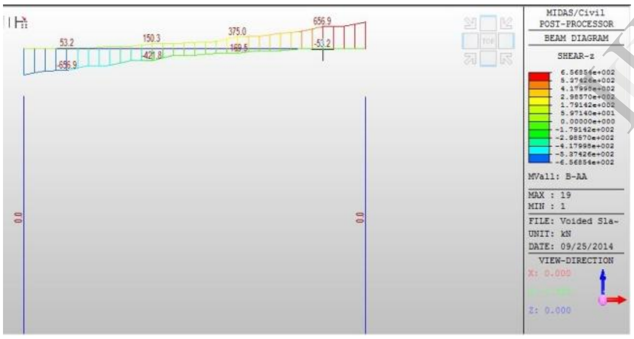


7 M SPAN SHEAR FORCE VOIDED

VEHICLE CLASS LOAD B-70R

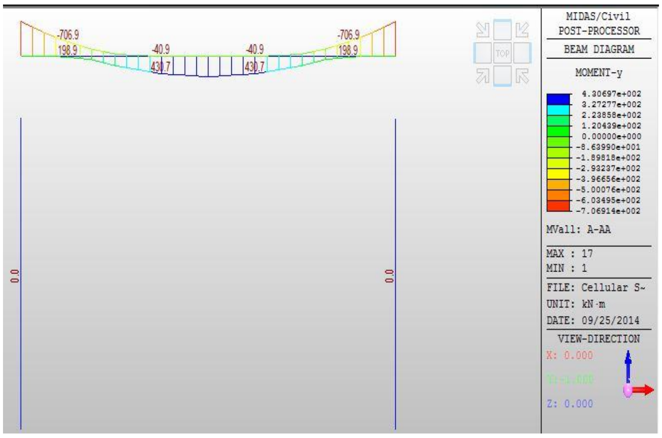


VEHICLE CLASS LOAD B-AA

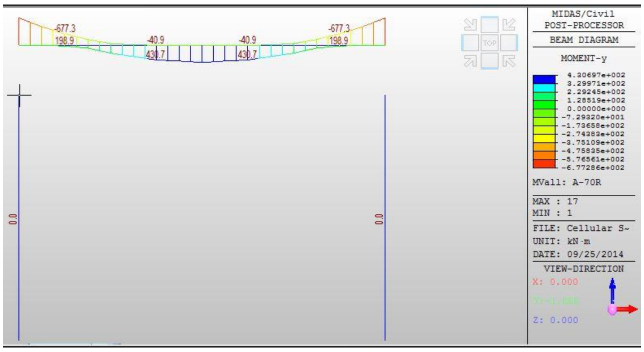


7 M SPAN BENDING MOMENT CELLULAR

VEHICLE CLASS LOAD A-AA

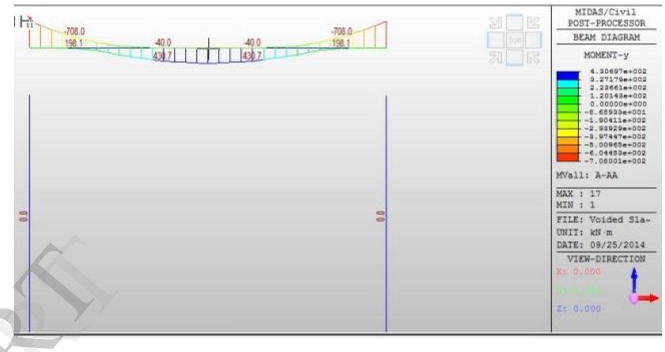


VEHICLE CLASS LOAD A-70R

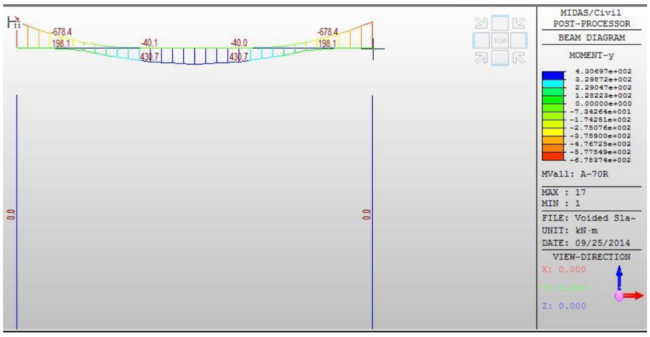


7 M SPAN BENDING MOMENT VOIDED

VEHICLE CLASS LOAD A-AA

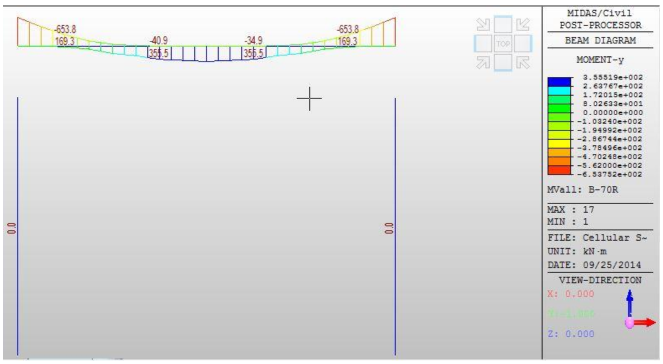


VEHICLE CLASS LOAD A 70R

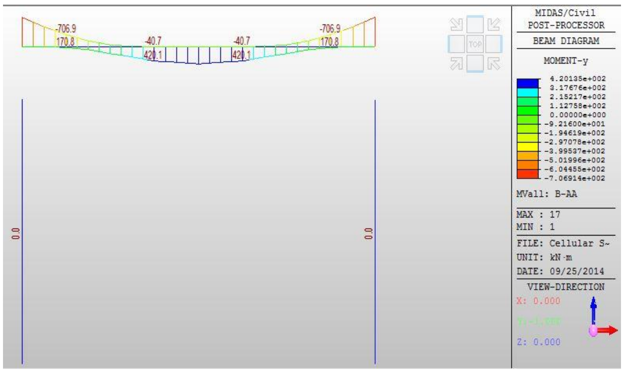


7 M SPAN BENDING MOMENT CELLULAR

VEHICLE CLASS LOAD B-70R



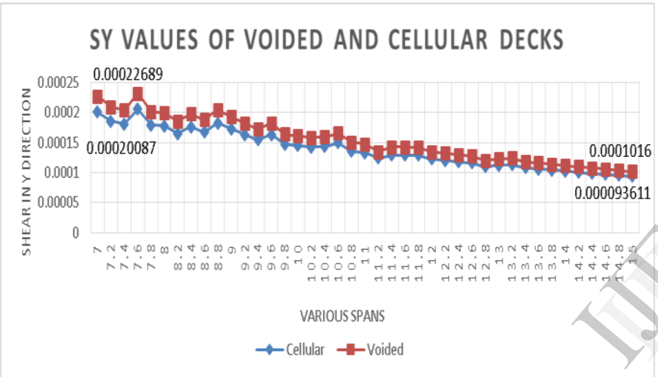
VEHICLE CLASS LOAD B-AA



RESULTS COMPARISON OF CELLULAR STRUCTURE AND VOIDED STRUCTURE:-

BEAM FORCES:-

Graph B.1

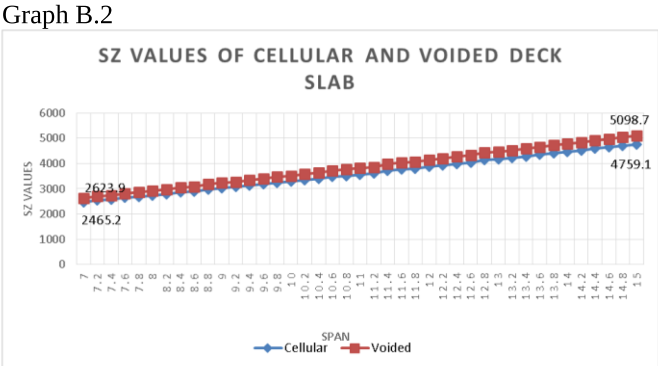


Shear in Y direction

	At Span is 7 m	At span is 15 m
Voided	0.00022689	0.000101600
Cellular	0.00020087	0.000093611

From the above results, the behaviour of both decks is similar, Cellular Deck slab yields less shear force in Y direction than Voided Deck Slab.

Graph B.2

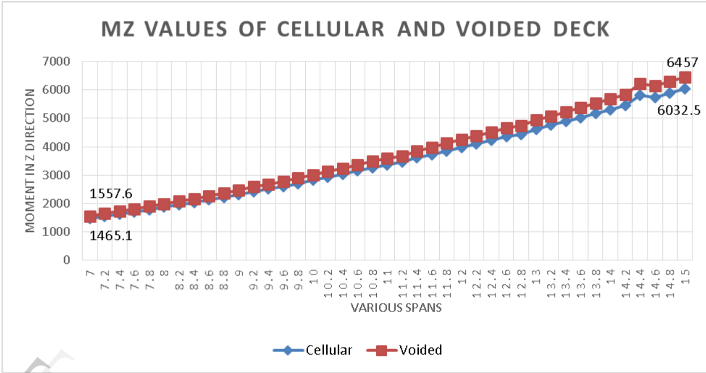


Shear in Z direction

	At Span is 7 m	At span is 15 m
Voided	2623.9	5098.7
Cellular	2465.2	4759.1

From the above results, the behaviour of both decks is similar, Cellular Deck slab yields less shear force in Z direction than Voided Deck Slab.

Graph B.3

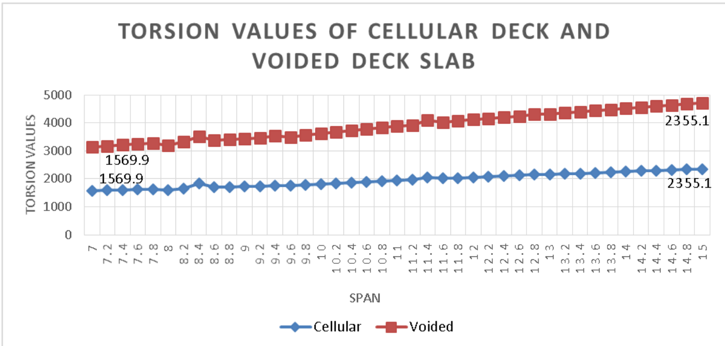


Moment in Z direction

	At Span is 7 m	At span is 15 m
Voided	1557.60	6457
Cellular	1465.10	6032.50

From the above results, the behaviour of both decks is similar, But Cellular Deck slab yields less Moment in Z direction than Voided Deck Slab.

Graph B.4

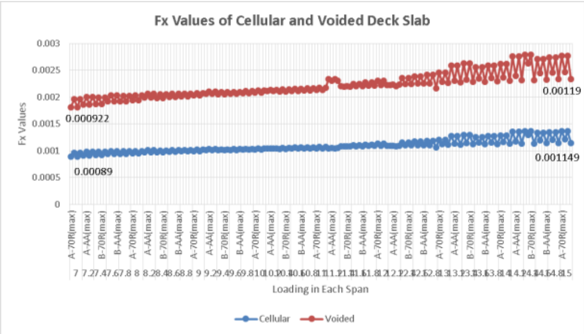


	At Span is 7 m	At span is 15 m
Voided	1569.9	2355.1
Cellular	1569.9	2355.1

Torsion behaviour for Both Cellular deck slab and voided deck slab are same.

REACTION RESULTS:-

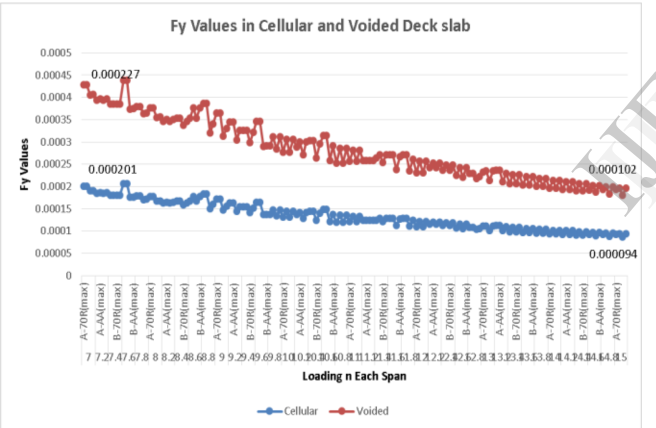
Graph R.1



	At Span is 7 m	*At span is 15 m*
Voided	0.000922	0.00119
Cellular	0.00089	0.001149

From the above results, the behaviour of both decks is similar, But Cellular Deck slab yields less Reaction force in X direction at span 7m than span 15m inVoided Deck Slab.

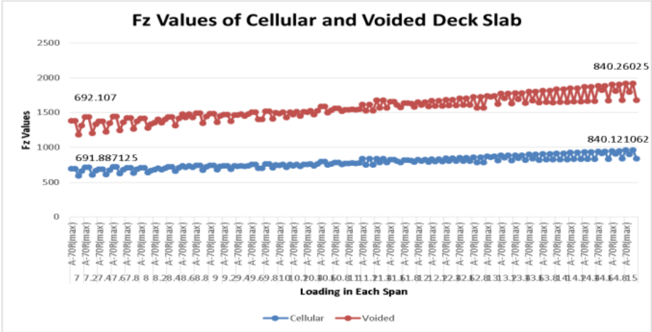
Graph R.2



	At Span is 7 m	*At span is 15 m*
Voided	0.000227	0.000102
Cellular	0.000201	0.000094

From the above results, the behaviour of both decks is similar, But Cellular Deck slab yields less Reaction force in Y direction than Voided Deck Slab.

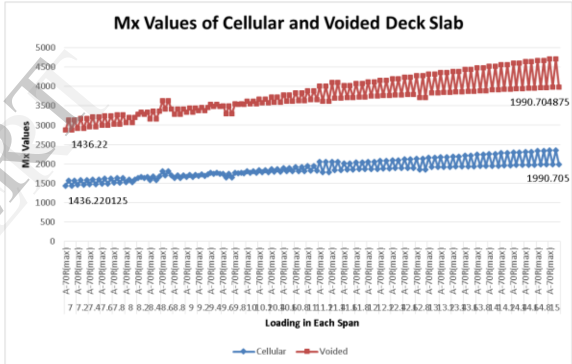
Graph R.3



	At Span is 7 m	*At span is 15 m*
Voided	692.107	840.26025
Cellular	691.887125	840.121062

From the above results, the behaviour of both decks is similar; But Cellular Deck slab yields less Reaction force in Z direction than Voided Deck Slab.

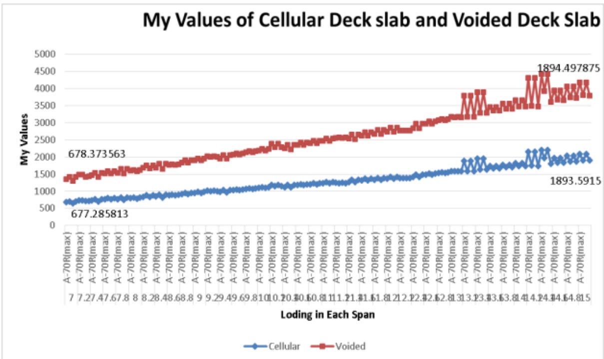
Graph R.4



	At Span is 7 m	*At span is 15 m*
Voided	1436.22	1990.705
Cellular	1436.22	1990.705

Mx i.e Moment in X Direction values and Behaviour is same for both Cellular deck slab and voided deck slab.

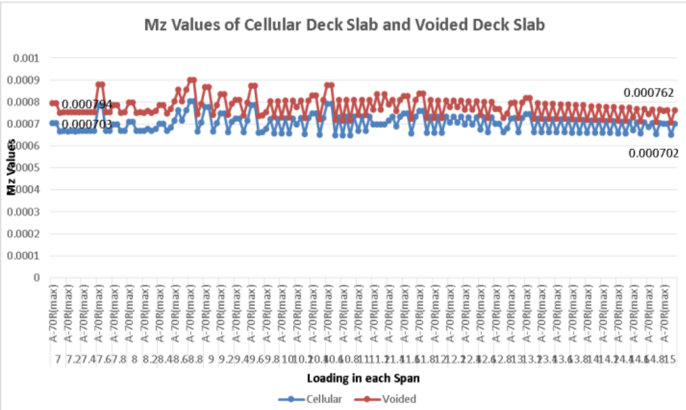
Graph R.5



	At Span is 7 m	*At span is 15 m*
Voided	678.375	1894.497
Cellular	677.285	1893.5915

Behaviour of Cellular Deck and Voided Deck are same but Cellular slab results are lower than voided slab.

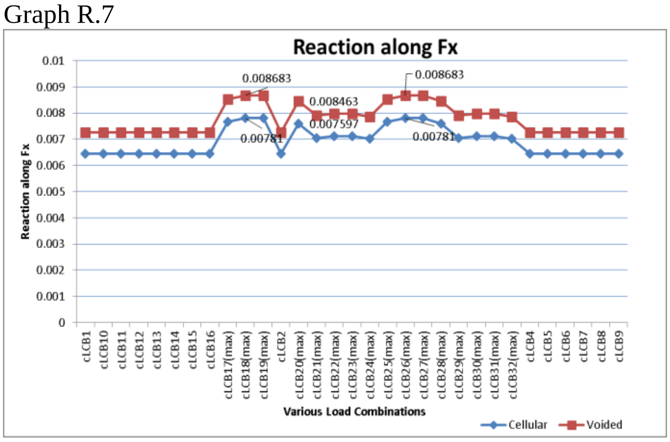
Graph R.6



	At Span is 7 m	*At span is 15 m*
Voided	0.000794	0.000762
Cellular	0.000703	0.000702

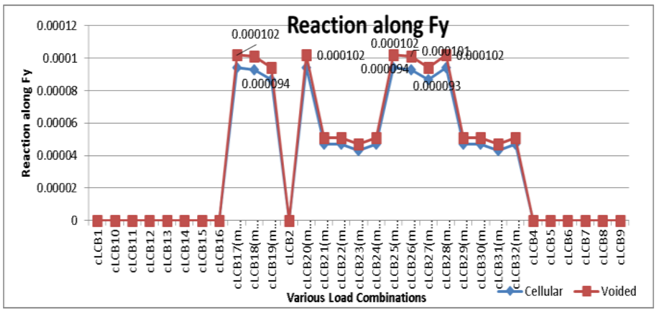
From the above Results behaviour of both the slabs are same, but results of cellular deck slab is lower than Voided deck slab.

Graph R.7



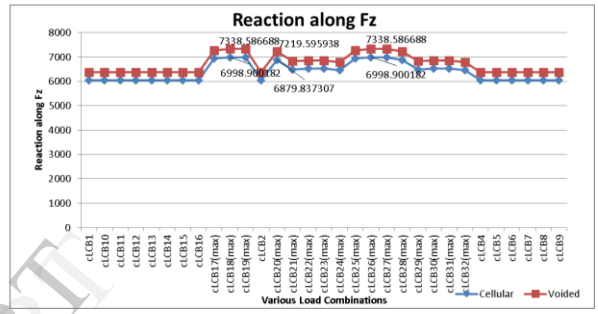
Maximum Fx values were at Load combination cLCB17, cLCB18, cLCB19, cLCB20, cLCB25, cLCB26, cLCB27, cLCB28& cLCB29. Behaviour of Both the decks are same, But Cellular slab gives less values than voided slab.

Graph R.8



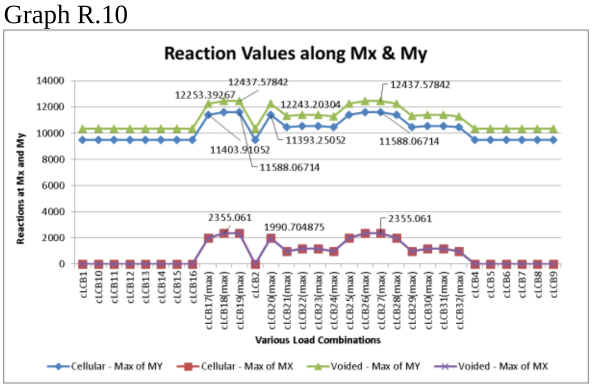
Maximum Fy values were at Load combination cLCB16, cLCB20, cLCB25, cLCB26, cLCB28. Behaviour of Both the decks are same, But Cellular slab gives less values than voided slab.

Graph R.9



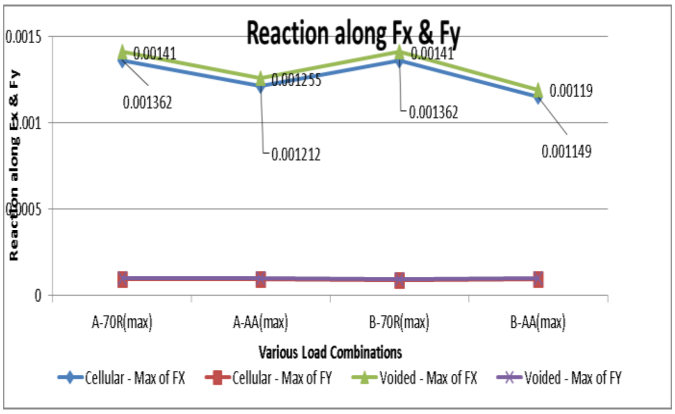
Maximum Fz values were at Load combination cLCB17, cLCB18, cLCB19, cLCB20, cLCB25, cLCB26, cLCB27, cLCB28& cLCB29. Behaviour of Both the decks are same, But Cellular slab gives less values than voided slab.

Graph R.10



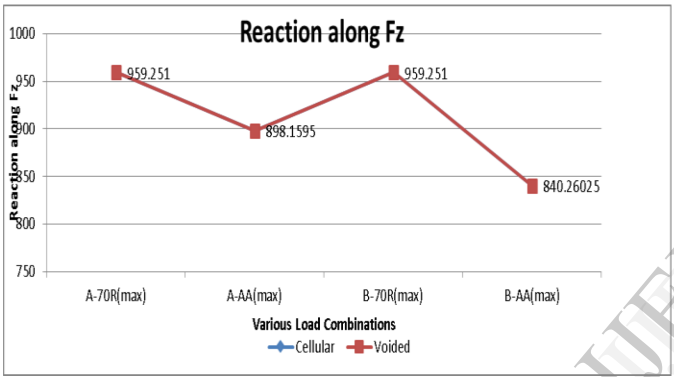
Maximum Mx and My values were at Load combination cLCB17, cLCB18, cLCB19, cLCB20, cLCB25, cLCB26, cLCB27, cLCB28& cLCB29. Behaviour of Both the decks are same, Mx values are same But Cellular slab gives less values than voided slab.

Graph R.11



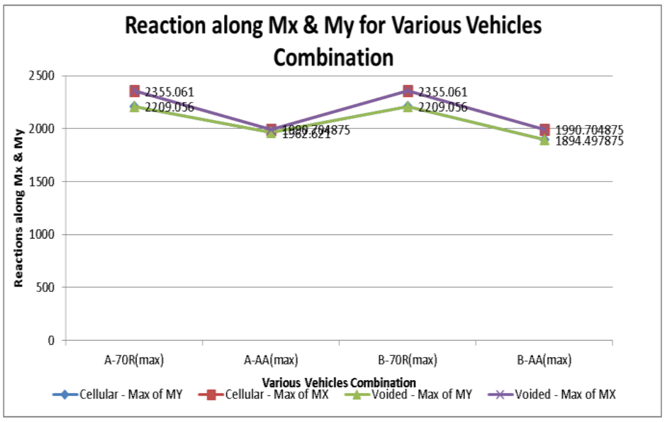
Maximum Fx and Fy values were at vehicle class combination A-70R & B-70R. Behaviour of Both the decks are same, But Cellular slab gives less values than voided slab.

Graph R.12



Maximum Fx and Fy values were at vehicle class combination A-70R & B-70R. Behaviour and values of both the decks are same

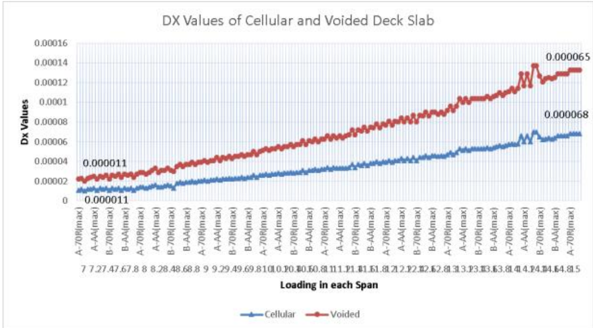
Graph R.13



Combination of Vehicles A-70R and B-70R yields maximum Reactions. Voided Deck gives lesser values than Cellular Deck Slab

DISPLACEMENTS:-

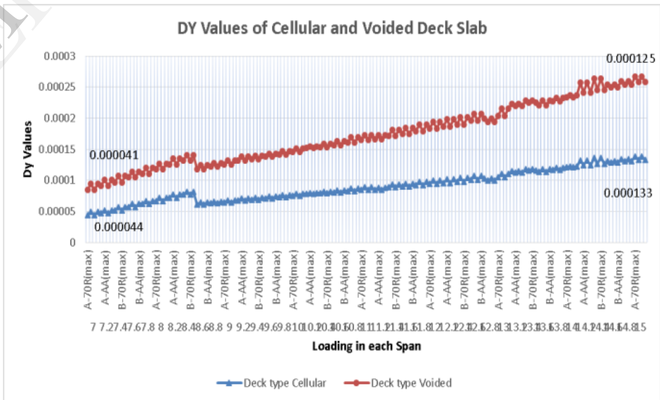
Graph D.1



	At Span is 7 m	*At span is 15 m*
Voided	0.000011	0.000065
Cellular	0.000011	0.000068

As the span is increasing displacement is also getting increasing. In this also cellular Slab gives less displacements than Voided Slab.

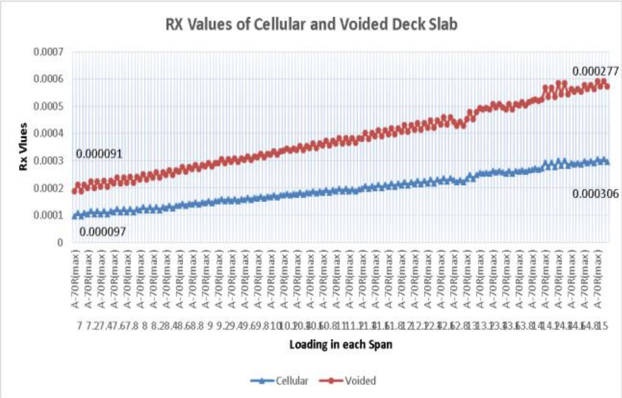
Graph D.2



	At Span is 7 m	*At span is 15 m*
Voided	0.000041	0.000125
Cellular	0.000044	0.000133

As the span is increasing displacement is also getting increasing. In this Voided Slab gives less displacements than Cellular Slab in Y direction.

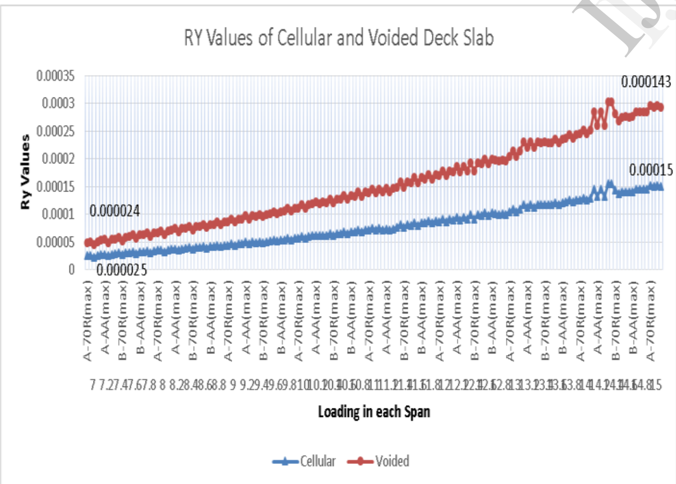
Graph D.3



	At Span is 7 m	*At span is 15 m*
Voided	0.000091	0.000277
Cellular	0.000097	0.000306

As the span is increasing displacement is also getting increasing. In this Voided Slab gives less displacements than Cellular Slab in Rx direction.

Graph D.4

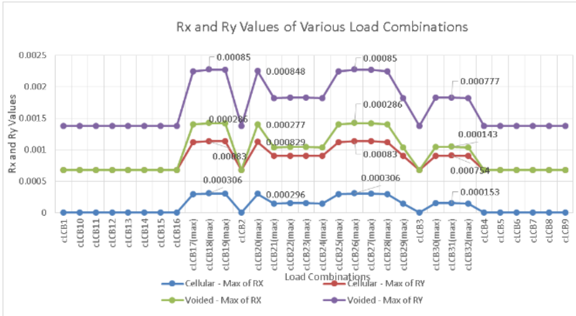


	At Span is 7 m	*At span is 15 m*
Voided	0.000024	0.000143
Cellular	0.000025	0.000150

As the span is increasing, displacement is also getting increasing. In this Voided Slab gives less displacements than Cellular Slab in Ry direction.

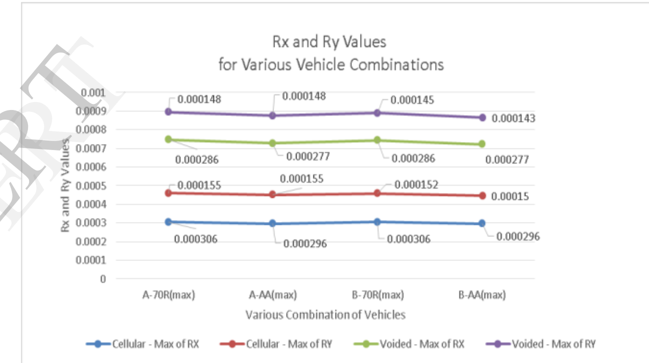
Comparison of Displacements for Various Loadings and Various Vehicle Combinations:

Graph D.5



Maximum Displacements Rx & Ry values were at Load combination cLCB17, cLCB18, cLCB19, cLCB20, cLCB25, cLCB26, cLCB27, cLCB28& cLCB29. And Cellular deck slab gives less results than Voided Deck Slab.

Graph D.6



Maximum Displacements Rx & Ry values were at vehicle combination A-70R & B-70R. And Voided deck slab gives less results than Cellular Deck Slab.

Abstract of Results:-

Graph No	*Type of Result*	*Graph Between*	*Lower Value*
B.1	Beam Forces	Sy values vs span	Cellular
B.2	Beam Forces	Sz values vs span	Cellular
B.3	Beam Forces	Mz Values vs span	Cellular
B.4	Beam Forces	Torsion values vs span	Equal
R.1	Reaction	Fx Values vs Span	Cellular

R.2	Reaction	Fy Values vs Span	Cellular
R.3	Reaction	Fz Values vs Span	Cellular
R.4	Reaction	Mx Values vs Span	Equal
R.5	Reaction	My Values vs Span	Cellular
R.6	Reaction	Mz Values vs Span	Cellular
R.7	Reaction	Fx vs Load combinations	Cellular
R.8	Reaction	Fy vs Load combinations	Cellular
Graph No	*Type of Result*	*Graph Between*	*Lower Value*
R.9	Reaction	Fz vs Load combinations	Cellular
R.10	Reaction	Mx & My Values vs Load Combination	Cellular
R.11	Reaction	Fx & Fy Values vs Vehicles combination	Cellular
R.12	Reaction	Fz Values vs Vehicles combination	Equal
R.13	Reaction	Mx & My Values vs Vehicles combination	
D.1	Displacements	Dx Values vs span	Cellular
D.2	Displacements	Dy Values vs span	Voided
D.3	Displacements	Rx Values vs span	Voided
D.4	Displacements	Ry Values vs span	Voided
D.5	Displacements	Rx, Ry Values vs Load combination	Cellular
D.6	Displacements	Rx, Ry Values vs Vehicles combination	Voided

CONCLUSIONS

The object of this paper is the study of the representation of the Voided and Cellular slab models with which different spans of bridge decks can be represented for various Vehicle class Combination and Various Load Combinations. The purpose of the work is to contribute to this type of approach through the introduction of the effects of Shape constraint and voided ratio to depth of deck and depth of void, which is usually neglected.
The introduction of these effects in analysis is obtained by Analyzing series of different spans using Midas civil.
From the analysis comparison, it's appeared how the use of different shapes effects the Bending Moments, Shear forces, Reactions and displacements results from 7.0m to 15.0m span with a interval of 0.2m.
By Observing the results the following variations are occurred:-

1. Beam Forces of cellular deck slab gives lesser values in Sy, Sz and Mz than voided deck slab.
2. Beam forces of Torsion is same for both decks.
3. Reactions of cellular deck slab Fx, Fy and Fz values gives lesser values than voided deck slab.
4. Reactions of Mx values are same for both decks.
5. Reactions of cellular deck slab gives lesser results in My,Mz values than voided deck slab when compared with various load combination and various class Vehicles.
6. Displacements of voided deck slab gives lesser values in Dy,Rx, Ry than cellular deck slab when compared with various load combination and various class Vehicles.
7. Displacements of cellular deck slab gives lesser values in Dx,Rx,Ry values than voided deck slab when compared with various load combination and various class Vehicles.

When compared with cellular deck slab only voided deck slab have lesser displacements which is very neglible. So rectangular shape cellular deck is best in withstanding more load than voided slab with same dimensions.

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