Retrofitting of Bridge with Voided Slab to raise the Deck Level

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Abstract - *This article proposes a method to use voided slab over bridge deck. In present study a void slab is casted over deck slab to match the F.R.L of the highway. The RCC fill over a bridge deck is not feasible due to heavy dead weight of concrete. This practice is may be adopted for retrofitting and retaining existing bridge in lieu of demolishing and re-construction new bridge to accommodate new highway construction. In solid slabs, voids are added to the concrete section to lower the self-weight of the material without reducing its flexural strength. This technique offers many advantages over a conventional solid concrete slab like less material consumption, cheaper construction costs, and improved structural efficiency are all benefits of solid concrete slabs. This paper also introduces essential techniques for reducing the dead weight of the concrete by using voids above deck slab with help polystyrene boxes and its design to resist heavy traffic moment. Although, presence of voids within the concrete structure makes analysis of structure very complicated but still we have developed a rational and comprehension approach as per codal provisions.*

Key Words: *Voided slab, Retrofitting, Deck slab, Bridge and Staad Pro.*

1.0. INTRODUCTION:

A bridge is a building that crosses over the supports and distributes the weight to the supports using a slab deck, girders, and foundation piers. Slab deck is the key component for transmitting the weight of a vehicle and persons to the supports. The deck slab may be solid or contain longitudinal and cross girders to distribute the weight to the pedestals. For the same span, solid slab type bridges require more steel and concrete than girder bridges do. A solid portion, free of beams or cavities, makes up solid slab decks. Bridge building frequently use this style of deck. The cross section of the slabs is a homogenous construction since they are solid at all points. Concrete placement is made simpler as a result of the lack of reinforcing congestion. Solid slabs one and only significant drawback is the substantial amount of concrete they require. This has an impact on the bridge structure's cost and self-weight. These slabs have increased self-weight because of the high concrete volume. The span of the slab between columns/Piers is a major design restriction when creating a reinforced concrete structure. Large spans between columns sometimes call for particularly thick slabs and/or supporting beams, which adds to the structure's weight by requiring the use of a lot of concrete.

The present bridge is approximate 10 year old, width of bridge is 13 m and span 20 m. The deck slab is casted over 4 girders of depth 2 m each and spacing of 3 meters. As per IRC 6-2017 the current bridge was designed for 3 lane traffic moment with vehicle combination either deck width should be designed for 3 lane traffic maximum bending moment generated from either 3 lanes of class A loading , one lane class A+ one lane class 70R loading and one lane of special vehicle loading. Here in this case Special Vehicle loading produces the maximum bending moment which is acting as governing live load. Similarly wearing course load, Crash Barrier loading, deck slab weight and Self weight are acting on girders. The load combinations for SLS (Serviceability Limit State) and ULS(Ultimate limit State) loading state are as per IRC 6:2017.

The corresponding highway is upgraded, hence FRL is increased up to 801 mm on A1 side of bridge and 430 mm on A2 side of bridge. Seeing the current condition of bridge is was decided to retain the bridge and match the new road FRL by placing the fill on deck slab. Laying of RCC over deck slab to match the FRL was not safe as the ULS moment exceeded the Capacity of the bridge girders.Here we are using polystyrene foam boxes as a mean to cast voids slab. The density of box is 25 kg/m^3 and directly obtained from local manufacturer.

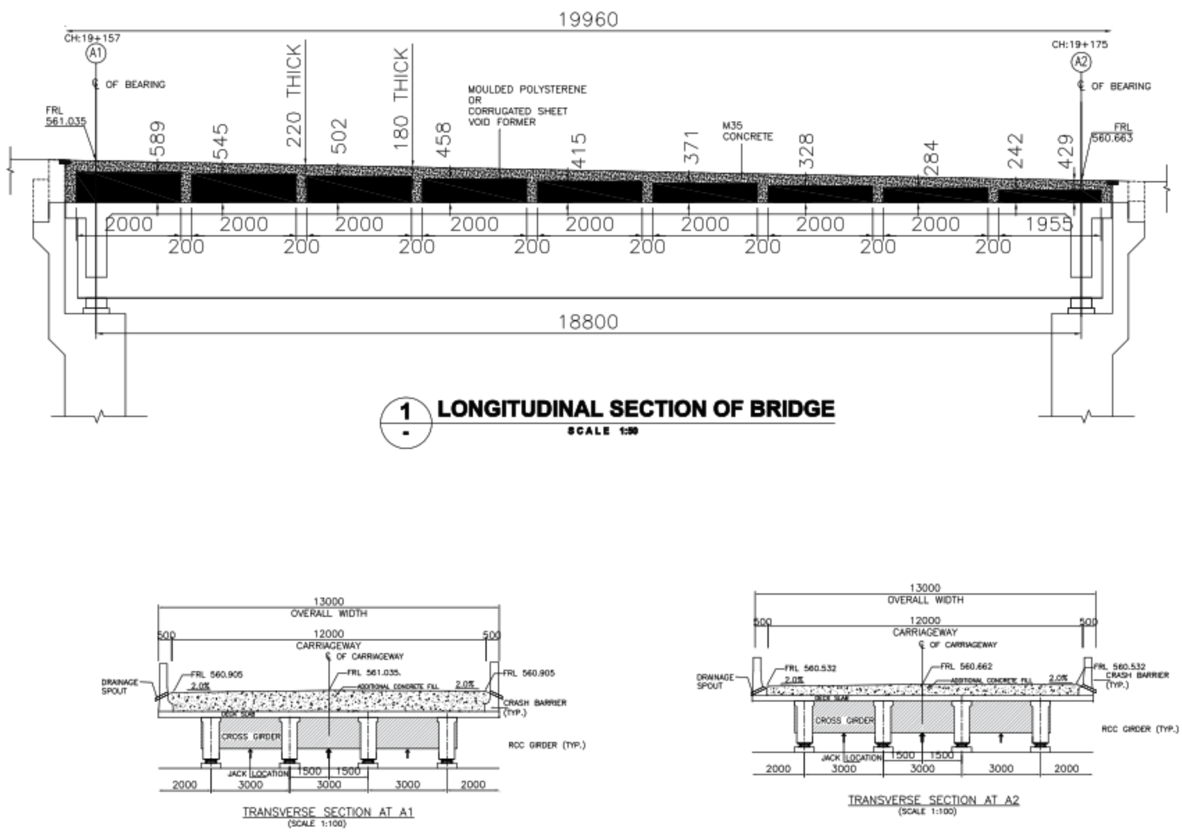

Figure.1

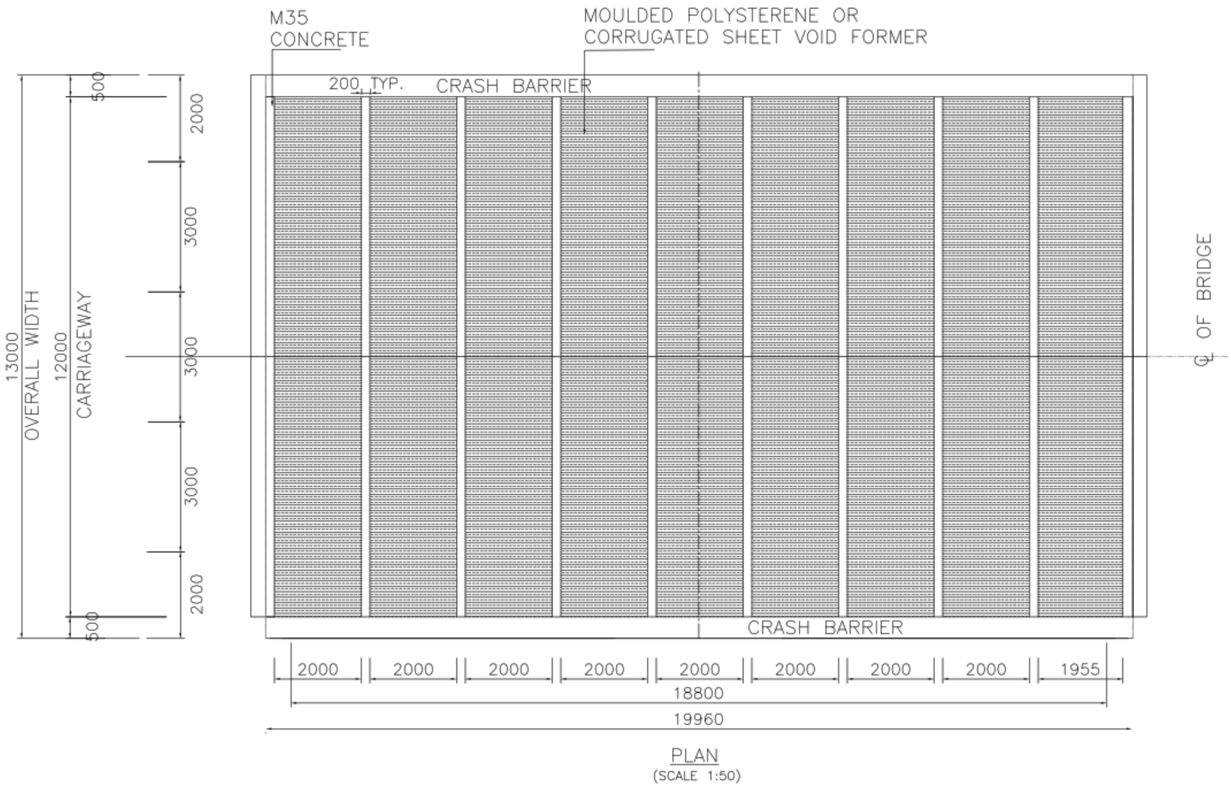

Figure.2

2.0 HISTORY OF VOIDED SLAB:

The void slab approach is a dated one. For a very long time, engineers and developers of forming equipment have reduced the weight of floor slabs by producing voids using a number of methods. However, more recent techniques now make it feasible to lower total costs and boost the effectiveness of cast-in-situ concrete structures. By reducing the structure's self-weight, voided slabs aim to maximize the benefits of concrete slab construction while eliminating the drawbacks of solid slabs. This section examines many previous uses of voided slabs as well as the idea of voided slab structure. Voided slabs are not a novel approach to construction. Voided slabs in various forms have been used for ages. Although the ideas of voided slabs were employed for ages, there are numerous structures developed since 20th century.

2.1. Voided Slab:

Voided slabs are characterized by the presence of voids within the slab. The voids here are formed by using rectangular Polystyrene foam box placed along width of deck slab. Grade of concrete is M 35 .The minimum longitudinal reinforcement as per clause 305.19 of IRC:21-2000.The minimum transverse reinforcement 1% of area of slab. Voids in the slab help reduce the self-weight of the structure. Thus, the major function of voided slabs is to reduce the concrete volume and thereby decrease the self-weight of the slab. If designed properly, it can reduce the self-weight of the slab up to 60% as compared to a solid slab for the same section and span**(Figure 1)**. As per IRC-SP 64-2005, the voided slabs can be modeled and designed by the method same as that used for solid slabs, the average fill over boxes is of 200 mm and the fill is RCC deck slab of 220mm depth. The height of polystyrene box decreases form A1 side to A2 to match the Finish Road Level **(FRL).**

2.2. Application and method of Installation:

The two main techniques for building void slab systems are the filigree approach, in which some components are precast at a workshop or concrete yard, and the on-site method, in which the entire system is cast. Both methods use the basic three components. In both methods, Polystyrene box void is main component. These voids are often Tubular, spherical, hollow and rectangular which is made of polystyrene. The presence of voids makes the slab lighter than conventional concrete slabs. The steel cage is an additional component. The slab is reinforced with steel to prevent flexure, and the voids are held in place in the middle of the slab by a cage made of thin steel. Concrete, the third element, surrounds the voids and ultimately decides the strength of the slab Concrete, the third element, surrounds the voids and ultimately decides the strength of the slab. The last component is the vertical reinforcement of web which is drilled & inserted using HILTI Equipment and epoxy in the deck slab. The initial depth of vertical bar is 300 mm near A1 side of bridge and the 150 mm subsequently as shown in **Figure.1.**

3. DESIGN METHODOLOGY AND MODELLING OF POLYSTYRENE BOX TYPE VOIDED SLAB IN STAAD PRO:

The staad modelling was done using grillage analogy similar to the analogy employed in design of girders. The original Staad file is shown in **Figure 3**

In the first step; a grillage of 1.5x2.2 m was created. For Upper solid portion of Void Slab a concrete member (rectangular) of uniform thickness 200mm was defined. **Figure 4.**This property was assigned to the upper slab and vertical members that connect the slab to the deck slab cum girder arrangement thus creating a void slab grillage above the original bridge grillage file.

In second step; Loading was defined and imposed on the structure. Dead load comprised of loads due to Surfacing, Self-weight of slab, SIDL (Crash Barrier). Then for live load, vehicles as per IRC: 6 were defined in Vehicle Definitions and Combinations of the same were generated. Impact factor 1.15 as per IRC: 6:2017.The ULS Bending moment and Shear Force summary for girder with Voided Slab are shown in **Table.1** and the ULS design checks are shown in **Table. 2.** The ULS Bending moment and Shear Force summary for original bridge girder are shown in **Table.3** and the ULS design checks are shown in **Table. 4.**

All the loads were assigned to the grillage and the structure was analyzed. The results were obtained after analysis were the max/min values of moments and shear obtained from the table bending moment table in staad were divided by 2.2m to obtain the per meter values to be considered for further design of slab and reinforcement detailing. The detail calculation of web is show in Annexure –I and for flange in Annexure-II. The **Figure 5** shows the reinforcement detailing of voided slab after calculation.

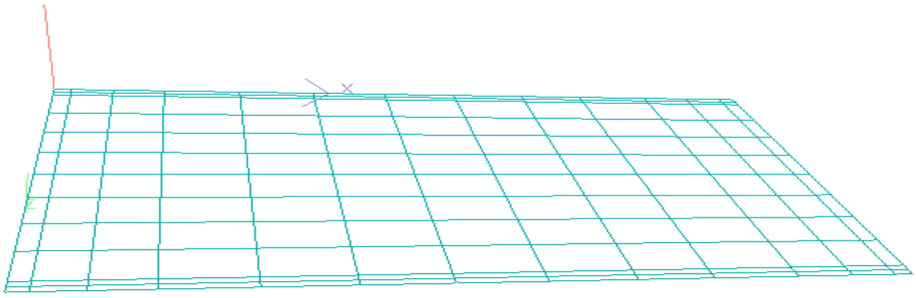

Figure 3

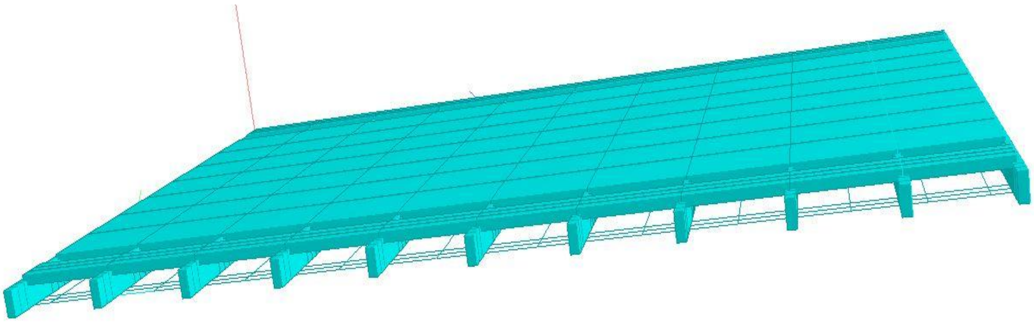

Figure 4

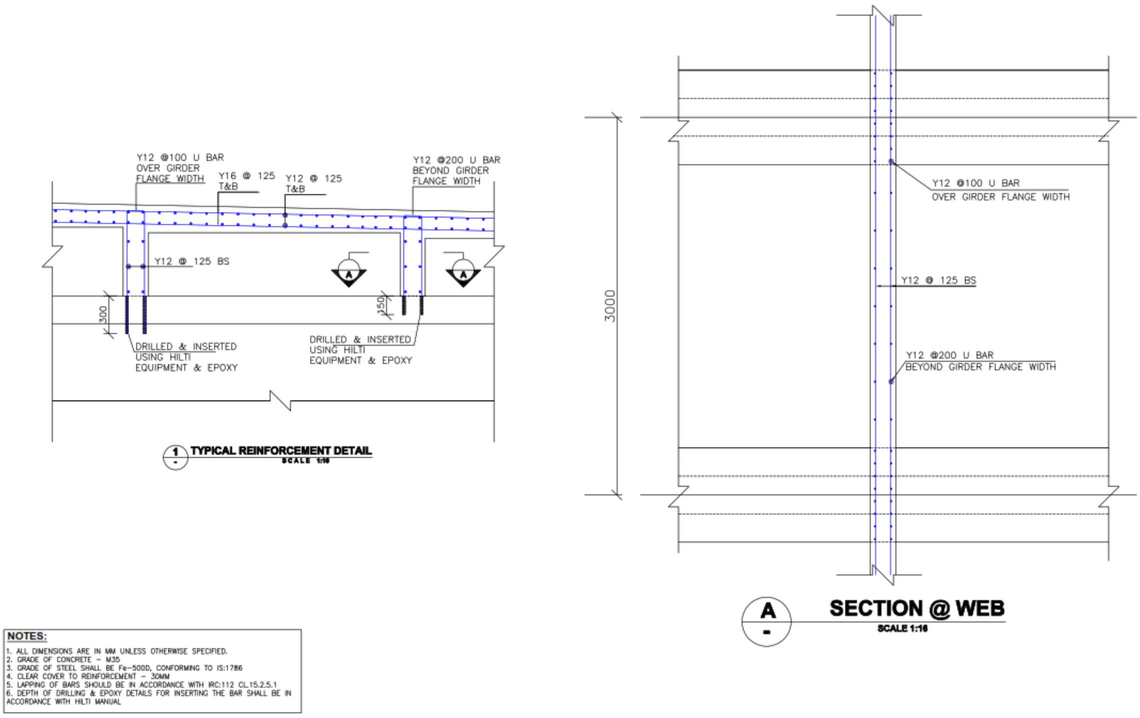

Figure 5

Bending Moment (kNm)		L/2	3L/8	L/4	L/8	Deff	Web Widening
DL of Precast Girder	1.35	744.30	698.61	561.54	332.97	251.15	155.01
DL of Slab	1.35	726.00	680.44	543.76	315.95	235.91	143.88
SIDL	1.35	418.74	390.96	309.69	180.78	69.14	72.45
Void Slab	1.75	778.98	728.79	579.85	328.75	227.34	123.96
FPLL	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(class A+ class 70 R)	1.5	2340.50	2188.42	1776.42	1077.63	471.22	471.22
Live Load(SV Loading)	1	1912.40	1785.15	1443.15	773.99	686.84	593.90
	TOTAL M_u	**7424.18**	**6947.53**	**5589.60**	**3311.85**	**1855.55**	**1425.07**
Shear Force (KN)		L/2	3L/8	L/4	L/8	Deff	Web Widening
DL of Precast Girder	1.35	0.00	38.89	77.77	117.67	131.22	147.11
DL of Slab	1.35	0.00	38.78	77.55	116.33	127.17	138.60
SIDL	1.35	12.17	35.63	56.68	74.16	90.56	90.56
Void Slab	1.75	10.14	41.92	61.78	125.48	160.35	159.29
FPLL	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(class A+ class 70 R)	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(SV Loading)	1	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL M_u	**34.18**	**226.38**	**394.31**	**635.60**	**751.70**	**786.74**

Table 1 ULS Bending moment and Shear Force for voided slab over of bridge

SNO	Description	unit	L/2	3L/8	L/4	L/8	Deff	Web Widening
1	**Design Bending Moment M_{ED}**	**KN-m**	**7424.18**	**6947.53**	**5589.60**	**3311.85**	**1855.55**	**1425.07**
	Area of Steel required (flexure+torsion)	mm²	10500.00	10200.00	8000.00	4500.00	2300.00	2000.00
2	Area of Steel Provided	mm²	11259.5	11259.5	8042.5	8042.5	8042.5	8042.5
	Check for steel provided		OK	OK	OK	OK	OK	OK
3	Depth of Neutral Axis x_u	mm	121.16	127.43	100.00	100.00	100.00	93.24
4	Critical Depth of N.A $x_{u,max}$	mm	1043.88	1043.88	1060.79	1060.79	1060.79	1060.79
5	Check for section		Under reinforced	Under reinforced	Under reinforced	Under reinforced	Under reinforced	Under reinforced
6	Total Depth required D_{reqd}	mm	703.72	679.46	656.67	610.89	581.61	572.96
7	Total Depth Provided	mm	1820.00	1820.00	1820.00	1820.00	1820.00	1820.00
8	Area of Steel Required A_{st}	mm²	10500.00	10200.00	8000.00	4500.00	2300.00	2000.00
9	**Moment of Resistance M_R**	**KN-m**	**8034.24**	**8034.24**	**5886.90**	**5886.90**	**5886.90**	**5886.90**
	Check for Moment Capacity		OK	OK	OK	OK	OK	OK
10	Addtional tensile Force ΔF_d	KN	24.83	105.93	203.02	305.47	346.66	368.89
11	$M_{ED}/Z+\Delta Fd$	KN	4873.7026	4560.796177	3669.3695	2174.11	1218.0981	935.506478
12	M_{RD}/Z	KN	5274.1874	5274.187363	3864.5328	3864.5328	3864.5328	3864.53279
	Check (As per Cl 16.5.1.3 IRC 112:2011)		OK	OK	OK	OK	OK	OK

Table 2 ULS Design check for vioded slab over bridge

Bending Moment (kNm)		L/2	3L/8	L/4	L/8	Deff	Web Widening
DL of Precast Girder	1.35	744.30	698.61	561.54	332.97	251.15	155.01
DL of Slab	1.35	726.00	680.44	543.76	315.95	235.91	143.88
SIDL	1.35	418.74	390.96	309.69	180.78	69.14	72.45
Surfacing	1.75	308.03	289.78	234.92	61.35	61.35	58.40
FPLL	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(class A+ class 70 R)	1.5	2340.50	2188.42	1776.42	1077.63	471.22	471.22
Live Load(SV Loading)	1	1912.40	1785.15	1443.15	773.99	686.84	593.90
	TOTAL M_u	**6600.01**	**6179.25**	**4985.97**	**2843.90**	**1565.07**	**1310.33**
Shear Force (KN)		L/2	3L/8	L/4	L/8	Deff	Web Widening
DL of Precast Girder	1.35	0.00	38.89	77.77	117.67	131.22	147.11
DL of Slab	1.35	0.00	38.78	77.55	116.33	127.17	138.60
SIDL	1.35	12.17	35.69	56.68	74.16	90.56	90.56
Surfacing	1.75	10.89	27.03	43.47	55.56	62.18	52.14
FPLL	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(class A+ class 70 R)	1.5	0.00	0.00	0.00	0.00	0.00	0.00
Live Load(SV Loading)	1	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL M_u	**35.49**	**200.33**	**362.28**	**513.25**	**579.91**	**599.22**

Table3 ULS Bending moment for existing bridge

SNO	Description	unit	L/2	3L/8	L/4	L/8	Deff	Web Widening
1	Design Bending Moment M_{ED}	KN-m	6600.01	6179.25	4985.97	2843.90	1565.07	1310.33
	Area of Steel required (flexure+torsio	mm^2	10500.00	10200.00	8000.00	4500.00	2300.00	2000.00
2	Area of Steel Provided	mm^2	11259.5	11259.5	8042.5	8042.5	8042.5	8042.5
	Check for steel provided		OK	OK	OK	OK	OK	OK
3	Depth of Nuetral Axis x_u	mm	121.16	127.43	100.00	100.00	100.00	93.24
4	Critical Depth of N.A $x_{u,max}$	mm	1043.88	1043.88	1060.79	1060.79	1060.79	1060.79
5	Check for section		Under reinforced	Under reinforced	Under reinforced	Under reinforce	Under reinforced	Under reinforced
6	Total Depth required D_{reqd}	mm	670.36	663.77	644.54	601.48	575.78	570.65
7	Total Depth Provided	mm	1820.00	1820.00	1820.00	1820.00	1820.00	1820.00
8	Area of Steel Required A_{st}	mm^2	10500.00	10200.00	8000.00	4500.00	2300.00	2000.00
9	Moment of Resistance M_R	KN-m	8034.24	8034.24	5886.90	5886.90	5886.90	5886.90
	Check for Moment Capacity		OK	OK	OK	OK	OK	OK
10	Addtional tensile Force ΔF_d	KN	24.83	105.93	203.02	305.47	346.66	368.89
11	$M_{ED}/Z+\Delta Fd$	KN	4332.668	4056.4544	3273.107	1866.92	1027.414	860.1858
12	M_{RD}/Z	KN	5274.187	5274.1874	3864.533	3864.53	3864.533	3864.533
	Check (As per 16.5.1.3 IRC 112 2011)		OK	OK	OK	OK	OK	OK

Table 4 Design check for ULS existing bridge

4.0 ADVANTAGES OF VOIDED SLAB:

- Cost reduction for the substructure, such as footings and piers, is possible with a decrease in dead weight of up to 35%. The structural engineer may lighten the slab by utilizing the concrete more effectively. Reduction in concrete is very environmentally friendly and sustainable—lower energy and carbon emissions.

- Longer column spacing is made possible without significantly thickening the slab. To provide a thin slab a broader span, voided slabs can benefit from post-tensioned reinforcement.

- Construction times can be shortened by some voided-slab systems, notably those that are precast or mounted on flat-plate forming processes.

- Although concrete cannot be eliminated from all areas in a floor slab, voids are excluded near columns to retain slab punching-shear capability. This decreased weight of building floors also enables engineers to reduce columns, walls, and foundations by up to 40%.

5.0 CONCLUSIONS

In the present paper, we proposed the advantages of voided deck slab. A comprehensive study is done to understand the behavior of deck slab with increase in FRL. A comparison of Solid Deck Fill versus Void deck slab is done for our bridge and it found that an approximate volume of 58.368 m^3 is saved using voided slab construction hence less self-weight and eventually passing all the design checks for girder, bearings and foundation. The ULS moment (Demand) is found to be less than MOR-Moment of Resistance (Moment Capacity) (**Table 3 & 4**), hence we are able to retain our existing bridge and save the cost for new bridge. The quantity of RCC fill to match FRL was calculated to be approximately 147.6 m^3, whereas when this voided slab technique is used the fill void is around 58.368 m^3. Results show that concrete volume can be reduced significantly by 60.4%,

REFERENCES

[1] IRC: 5-2015, 'General Specifications for Road Bridges'.
[2] IRC: 6-2017, 'Road Bridges, Sec-II Loads & Stresses'.
[3] IRC: 78-2014, 'Road Bridges, Sec-VII, Foundations & Substructures'.
[4] IRC: 112-2011, 'New RCC Design'.
[5] IRC SP 105-2015, 'Explanatory Handbook to IRC 112-2011'.
[6] IS: 456-2000, 'Plain & Reinforced Concrete'.
[7] IS: 1893_3-2014, 'Bridges & Retaining Walls'.
[8] IRC SP 64-2005 Guidelines for the analysis and design of cast-in-place voided slab superstructure

Annexure-1

Design of web of voided slab:

Unit weight of RCC concrete =	25	kN/m^3	
Unit weight of PQC =	24	kN/m^3	
Height of section, h =	0.800	m	
Depth of footing, D_f =	1.000	m	
For Grade of concrete M( ), f_{ck} =	35	MPa	
Secant Modulus of Elasticity of Concrete, E_{cm}=	32000	MPa	(IRC-112 Table 6.5)
For Grade Fe500D steel, f_{yk} =	500	MPa	
Clear Cover to reinforcement =	30	mm	
Mean Axial Tensile Strength of Concrete, f_{ctm}=	2.80	MPa	(IRC-112 Table 6.5)
Allowable Bond Stress, t_{bd} =	1.8	MPa	(IS-456 Cl. 26.2.1.1)
b_1 =	0.8		(SP 105 Table 8.2)

b_2 =	0.4		
Design Compressive Strength of concrete, f_{cd}=	$\alpha * f_{ck}/g_m$		
where, α =	0.67	(IRC-112 Cl.6.4.2.8)	
g_m=	1.50	Basic/Seismic	
=	1.20	Accidental	
f_{cd}=	15.63	MPa	Basic/Seismic
=	19.54	MPa	Accidental

FLEXURAL DESIGN OF WEB SECTION OF SLAB:

Depth of Section =	200	mm	
Effective depth, d =	164	mm	
Effective width, b_w =	1000	mm	
Braking Force = 255.4 kN (IRC:6-2017 Cl.211.2)	Deck width = 13m		Braking load = 19.65 kN/m
Height of section, h =	0.80	m	
Bending Moment due to braking force, $M_{braking}$ =	15.72	kN-m/m	(Braking load x h)
Moment due to live load, M_{LL} =	21.68	kN-m/m	(STAAD)
Design Moment, M_{ED} =	**37.40**	kN-m/m	
Neutral Axis depth, x =	$[(d/2b_2)-\{(d/2b_2)^2-(M_{ED}/b_1b_2bf_{cd})\}^{0.5}]$		
=	19.1	mm	
Lever arm, z =	$d-b_2x$		
=	156.4	mm	
Area of Steel required, A_{streqd}=	$M_{ED}/(0.87fyz)$		
=	5.5	cm^2/m	
$A_{st\ min}$=	$(0.26 \times f_{ctm} \times b \times d)/ f_{yk}$		As per Clause 16.5.1.1
=	2.4	cm^2/m	IRC:112-2020
$A_{st\ min}$=	0.0013 x b x d		
=	2.1	cm^2/m	
Provide Rebar Dia. f =	12	mm	
Spacing =	200	mm	
$A_{s\ prov.}$ =	5.7	cm^2/m	***Satisfactory***

Annexure-II

Design of Slab portion of voided slab

Material Specification					
Concrete Grade	=	M	35		
Characteristic Compressive	=	35.00	Mpa at 28 days		- Refer Table No 6.5 of IRC : 112-2011
Design Compressive strength of Concrete, fcd	=	15.63	Mpa at 28 days	).67/1.5 * fck)	- Refer Fig 6.5 of IRC : 112-2011
Tensile strength of concrete , fctm	=	2.77	MPa		-Refer Table 6.5 of IRC:112-2011 and Annexure -A-2.2
Strain at reaching Characteistic Strength, $\varepsilon c2$	=	0.02			- Refer Table No 6.5 of IRC : 112-2011
Ultimate Strain, $\varepsilon cu2$	=	0.035			- Refer Table No 6.5 of IRC : 112-2011
Ecm	=	3.23E+04	N/mm^2		- Refer Table No 6.5 of IRC : 112-2011 and Annexure A-2.2
Steel Grade	=	Fe	500	D (HYSD Steel)	
Yield Strength of Reinforcement, fy or fyk	=	500	Mpa		- Refer Table No 18.1 of IRC : 112-2011
Design Yield Strength of Reinforcement, fyd	=	434.78	Mpa	(1/1.15 * fy)	- Refer Fig 6.4 of IRC : 112-2011
Modulus of Elasticity of Steel (Es)	=	2.00E+05	Mpa		- Refer Clause 6.3.5 of IRC : 112-2011
Dry weight of Concrete	=	25	kN/m^3		- Refer Clause 203 of IRC: 6-2017
Dry unit weight of soil	=	20	kN/m^3		- Refer Clause 203 of IRC: 6-2017
Permissible Crack Width	=	0.3	mm - For Severe Exposure Conditio		- Refer Table 12.1 of IRC: 112-2011
Maximum compressive stress in concrete under rare combination	=	0.48 fck			- Refer Clause 12.2.1 of IRC:112-2011
	=	16.8	N/mm^2		
Maximum tensile stress in steel under rare combination	=	300	N/mm^2		- Refer Clause 12.2.2 of IRC:112-2011

Support Reinforcement Calculation:						
Thickness of slab			=	180	mm	
Thickness of slab			=	180	mm	
Clear Cover to outer steeel			=	30	mm	
Maximum Diameter of Reinforcement			=	16	mm	
Effective Depth Provided (deff)			=	142	mm	
Design bending moment (HOGGING)			=	21.68	kNm/m	**(FROM STAAD RESULTS) with IF=1.15**
Mulim	=	0.165 x fck x b x d^2	=	21.68	kNm/m	(Equation derived based on IRC:112-2011)
Effective Depth of Cap Required (dreq)			= SQRT(	21.68 x / 0.165 x 35.00	1000000 / x 1000)	
Effective Depth of Cap Required (dreq)			=	61.271	mm	
Total Depth Required (Dreq)			=	99.27	mm	
Total Depth Provided (Dprov)			=	180.00	mm	**OK**
R= $M_{RD}/(b\ d^2)$			=	1.08		
Design Moment of Resistance		**M_{RD}**	=	$0.87f_yA_{st} * (d-(\lambda x_u/2))$		
		21.68	=	$0.87f_yA_{st} * (d-(\lambda x_u/2))$		
		η	=	1		
		f_{cd}	=	15.61	N/mm^2	
		fy	=	500	N/mm^2	
		λ	=	0.8		
		M_{RD}	=	$0.87f_yA_{st} * (d-(0.87*fy*Ast/(b*n*fcd*2))$		
Area of Steel Required, Ast_{red}						
			=	**363.98**	mm^2/m	
	Ast_{req}		=	363.98	mm^2/m	

Minimum Longitudinal Reinforcement :									
	As. Min	=	0.26 x	fctm / fyk	x	b . d	- Refer Eq. 16.5.1.1 & 16.6.1.1 of IRC: 112-2011		
Whichever is higher		OR	=	0.0015	x	b . d	-Refer Clause 16.9 of IRC:112-2011'		
		b	=	1000.00	mm				
		d	=	142.00	mm				
		Ast min	=	**213.00**	mm^2/m				
Governing Reinf. Ast			=	**363.98**	mm^2/m				
Provide	16	mm dia @	125	mm c/c	+	0	mm dia @	250	mm c/c
Area provided=	**1608.50**	**mm^2/m**	**>**	**363.98**	**mm^2/m**	**OK**			
Percentage of Steel (pt%)		**=**	**1.13**	**%**					
Maximum Spacing of Bars :		as per Clause 16.6.1.1 of IRC:112-2011							
	Smax	=	2 h	=	284.00				
			OR	=	250.00	mm	whichever is max		
Provided Spacing is less than Smax, Hence OK									
Moment of Resistance of Section corresponding to Provided Ast									
		M_{RD}	=	$0.87f_yA_{st} * (d-(0.87*fy*Ast/(b*n*fcd*2))$					
			=	83.68	kNm	>	21.68	kNm	
							SAFE		
Distribution reinforcement:									
Effective Depth in Long. Direction			=	128	mm				
As per Clause 16.6.1.1. of IRC:112-2011 , Secondary Reinforcement shall be at least 20 % of the main reinforcement									
	20.00 / 100.00	x	1608.50	=	321.699	mm^2/m			
Provide	12	mm dia @	125	mm c/c at Trans direction in top face. (Providing =				904.779	mm^2)

Span Reinforcement Calculation: (SAGGING AT MID SPAN)

Clear Cover to outer steeel	=	**30**	mm		
Maximum Diameter of Reinformcement	=	**16**	mm		
Effective Depth Provided (deff)	=	142	mm		
Design bending moment (SAGGING)	=	7.32	kNm/m	**(FROM STAAD RESULTS) with IF=1.15**	
Mult	=	0.165 x fck x b x d^2	=	7.32	kNm/m
Effective Depth of Cap Required (dreq)	= SQRT(	7.32 x 1000000 / (0.165 x 35.00 x 1000)	)		
Effective Depth of Cap Required (dreq)	=	35.590	mm		
Total Depth Required (Dreq)	=	73.59	mm		
Total Depth Provided (Dprov)	=	180.00	mm	**OK**	
R= Mu/(b d^2)	=	0.36			

Ast Required:

M_{RD} = $0.87 f_y A_{st}$ * (d-(0.87*fy*Ast/(b*n*fcd*2))

Area of Steel Required, Ast_{red} = **119.83** mm^2/m

Ast_{req} = 119.83 mm^2/m

Minimum Longitudinal Reinforcement :

As. Min = 0.26 x fctm / fyk x b . d - Refer Eq. 16.5.1.1 & 16.6.1.1 of IRC: 112-2011

Whichever is higher OR = 0.0015 x b . d -Refer Clause 16.9 of IRC:112-2011'

b	=	1000.00	mm
d	=	142.00	mm
Ast min	=	**213.00**	mm^2/m
Governing Reinf. Ast	=	**213.00**	mm^2/m

Provide 16 mm dia @ 125 mm c/c + 0 mm dia @ 100 mm c/c

Area provided=	**1608.50** mm^2/m	**>**	**213.00**	mm^2/m	OK
Percentage of Steel (pt%)	**=**	**1.13**	**%**		

Maximum Spacing of Bars : as per Clause 16.6.1.1 of IRC:112-2011

Smax	= 2 h	=	284.00		
	OR	=	250.00	mm	whichever is max

Provided Spacing is less than Smax, Hence OK

Moment of Resistance of Section corresponding to Provided Ast

M_{RD} = $0.87 f_y A_{st}$ * (d-(0.87*fy*Ast/(b*n*fcd*2))

= 83.68 kNm > 7.32 kNm SAFE

Distribution reinforcement:

Effective Depth in Long. Direction = 132 mm

As per Clause 16.6.1.1. of IRC:112-2011 , Secondary Reinforcement shall be at least 20 % of the main reinforcement

$\frac{20.00}{100.00}$ x 1608.50 = 321.699 mm^2/m

Provide 12 mm dia @ 125 direction in top face. (Providing = 904.7786842 mm^2)

Check For Shear

	SF =	58.4	kN	from STAAD results	

Design Shear Strength of Concrete,(τ_c) without Shear Reinforcement:

As per Clause 10.3.2 of IRC:112-2011,

Design shear resistance of the member without shear reinforcement is given by:

$$V_{Rd,c} = \left[0.12K(80\rho_1 f_{ck})^{0.33} + 0.15\sigma_{cp}\right]b_w\, d \quad \textbf{eq.1}$$

Subjected to minimum of

$$V_{Rd,c} = \left(V_{\min} + 0.15\sigma_{cp}\right)b_w\, d \quad \textbf{eq.2}$$

	where,						
	K=	1 + SQRT(200/d)		≤ 2.0 , where d is depth in mm			
	K=	2.00					
	vmin=	0.031 $K^{3/2}$ $fck^{1/2}$		, fck =	35.00	N/mm^2	
Hence	**vmin=**	**0.519**	**N/mm^2**				
	σ_{cp} =	Concrete compressive stress in concrete at centroidal axis in the direction of axial load or prestressing					
	σ_{cp} =	N_{Ed}/A_c	< 0.2 f_{cd}	where , f_{cd} =	0.67 fck/1.5		
	σ_{cp} =	**0.00**	N/mm^2				
Hence,							
	τ_c =	$V_{Rd,c}/(b_w.d)$ =		V_{min} + 0.15 σ_{cp} =	0.5187	N/mm^2	**From eq.1**
	ρ1 =	Steel Ratio = Asl/(bw . d) ≤ 0.02					
Hence	ρ1 =	0.0113					
	τ_c =	$V_{Rd,c}/(b_w.d)$ =		0.760	N/mm^2	**From eq.2**	
	Max of eq.1 & eq.2						
	τ_c =	**$V_{Rd,c}/(b_w.d)$ =**		**0.760**	**N/mm^2**	Corresponds to steel ratio = 1.133% & M35 Grade of Concrete	
	Shear stress(v_{Ed})		=	Ved/(bw*z)	, where z = 0.9 deff		

v_{Ed}	=		**58400.000**		=	**0.457**	**N/mm^2**	<
		1000.00	**x**	**127.80**				**0.760 MPa**

AsTv is lesser than Tc Hence No Shear Reinforcement is need to be provided.