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PARAMETRIC STUDY ON SLAB DECK BRIDGES USING RESPONSE SURFACE METHOD

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Abstract - *This paper is a parametric study is carried out on slab deck bridges by using RSM method. In order to discern the dependency of span, live load and thickness of wearing coat on all the aspects of the analysis and design of the slab deck bridges. After obtaining various design combinations of parameters/variable, design of slab deck is carried out by EXCEL program. An EXCEL program is generated to design deck slab by considering all the parameters in both working stress and limit stress method as per IRC 21:2000 and IRC 112:2011 respectively. The results obtained by EXCEL program are updated in the optimization model and ANOVA test is carried out to discern the dependency of variables. Set of linear equations are obtained by considering three and two parameters.*

***Key Words*: Bridges, cross obstruction, Slab Deck Bridge, Response Surface Method, fabrication of form work, reinforcement, placement of concrete.**

1. INTRODUCTION

In this study statistical approach is carried out to obtain optimum depth, moment and area of reinforcement of the decks slab by using statistically planned analytical program. By the parametric study various design parameters are considered such as span, live load and thickness of the wearing coat. To discern the dependency of these parameters on depth, moment and area of reinforcement Response Surface Method (RSM) is used. For all the unique design combination obtained RSM, design of deck slab is carried out by EXCEL program.

The regression model was developed using the analytical data Analysis of Variance (ANOVA) for depth, moment and area of reinforcement in terms of the three design factor.

1.1 SCOPE OF THE STUDY

The response equations are being obtaining for spans varying from 4m to 9m. The type of bridge of bridge considered is single span deck slab bridge with two lane carriage way. The design of slab is carried out IRC working stress and even the limit state method as per IRC 21:2000 and IRC 112:2011 respectively. An EXCEL program is used for the deck slab design. For the design of two lanes RC deck slab two load cases 1 and 2 as per IRC 6:2014 considered. The slab has to be designed for maximum of the two cases. The thickness of the wearing coat is limited to 25to 75mm. The regression equations are obtained by a generating optimizations model. The method of response surface is used to obtain the dependency of variable response by using DESIGN EXPERT v6.0.8 i software.

2. BRIGE REVOLUTION

Bridge is defined as a structure constructed to cross obstruction. The obstruction may be river, valley, roadway, and railway. The bridges have been constructed from the early human civilization spread over several centuries ago. The first bridge was constructed by timber trestle to cross river around 400 B.C. Later stone slabs were used to construct the bridges around 2800 B.C. Stone arches were widely constructed by roman's using massive piers in the period of 200 B.C. to 260 A.D. The Pont d' Avignon and old London bridges were constructed by arches in the 11th and 12th century. In the mid-19th century use of cast iron and wrought iron started for construction of bridges in order to make bridges stronger and bigger. The use of iron replaces the use of timber and stone for bridges. After the invention of pre-stressed concrete in 1928, it is used in the construction of bridges for increased span during1950.

The combination of Concrete, Iron and Cables were used to build modern bridges and can be used to build them from very small size up to incredible length that covers the whole mountain, rough landscapes, lakes, and even the seas.

2.1.1 TYPES OF BRIDGES

i. Beam Bridge.
ii. Arch Bridge.

iii. Truss Bridge.
iv. Cantilever Bridge.
v. Suspension Bridge.
vi. Cable Slayed Bridge.

2.1.2 REINFORCED CONCRETE DECK SLAB

A bridge with an upper horizontal beam that carries roadway or railway is called "deck" of the bridge. In a reinforced concrete deck slab bridge, decks are constructed by reinforced concrete. Reinforced concrete deck slab bridges are economical up to span 8 m, though it can be used up to 10 m. The thickness of the deck slab increases as the span increases. The construction is comparatively simpler due to easier fabrication of formwork and reinforcement and easier placing of concrete. This type of bridges can be used for both highway and railway.

2.1.3 DECK SLAB

Deck slab is the main element of the bridge, which is supported upon the abutments or piers.

It is perhaps constructed from concrete, the steel or even wood. The deck slab acts a shield to enable the passage of vehicles, since it is covered by asphalt concrete. The deck slab is sketched out as a one-way slab to carry dead along with live load with visible impact. As per Independent Review Committee 6 2014 National Highway deck slab is designed to carry Independent Review Committee CLASS AA or a type vehicle loads whichever gives the maximum worst effect. As per Independent Review Committee 7.5m width of carriage is to be provided for two lanes with raised Kerbs of Road.

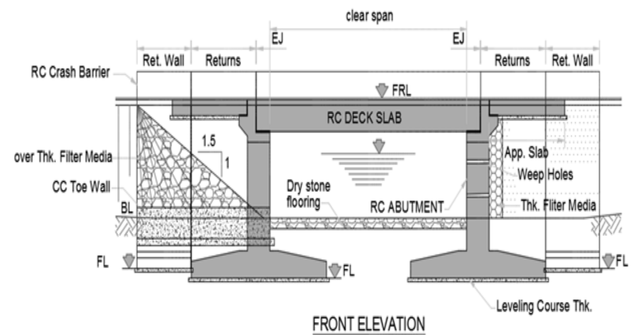
3.1 ABUTMENTS, WING WALL AND APPROACH SLABS

Abutment is a sub-structure component of bridge, and it acts as a support to the bridge. Abutments are the structural elements which carry the deck of the bridge and transfer the load into foundations. Opposite supports are called as Abutments whereas intermediate supports are called as Piers. This abutment prevents the lateral movement of earthen fill of the bridge approach and acts as a retaining wall.

Wing walls are the small walls attached at both ends of abutments to retain the earth. Wing walls are constructed using same material used for abutments. The wing walls may be attached to abutments, or it may be independent.

Approach slab is a medium which connects roadway pavement and bridge. It observes the impact load of vehicles passing from roadway to bridge.

3.2 FRONT ELEVATION OF THE DECK SLAB BRIDGE



3.2.1 METHODOLOGY OF STUDY

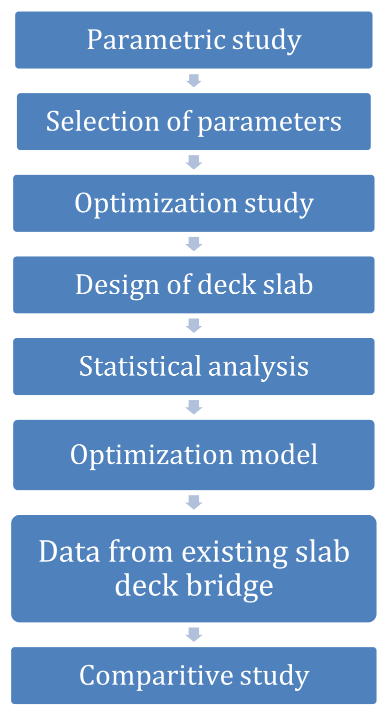


Fig. 3.1: Tabular representation of parametric study

Variables	Description /details of variables	
Span	4m, 5m, 6m, 7m, 8m and 9m	
Live load combination as per IRC 6:2014	Case 1	Case 2

Thickness of wearing coat	25mm, 50mm and 75mm	
Design method	Working stress method	Limit state method

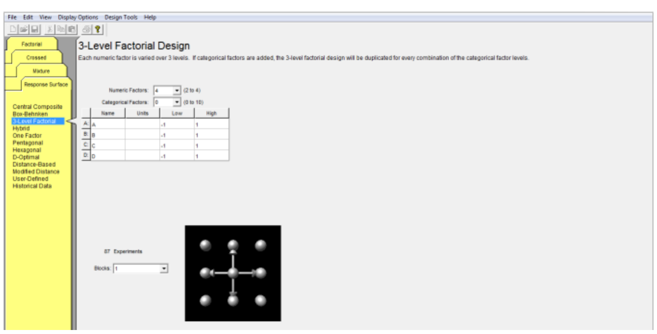
3.2.2 DESIGN OF EXPERIMENT

Design of Experiments (DOE) is a unique approach which helps in arriving at the relationship amongst the factors influencing a process and thereby the result of that particular process. Design of experiments is mainly a statistical method, it has different name such as experiment design methods using statistics and statistical factorial design methods and empirical methods. The methods comprise of models with fitted empirical values to the given data. Each response can be expressed as an algebraic function. The design of experiment is carried out by "DESIGN EXPERT v 6.0.8i" software.

There are four important areas of general engineering in which DOE can be applied:

- Comparative
- Screening or Characterizing
- Modeming
- Optimizing

Fig. 3.2: Design of deck slab



3.3 STATISCTICAL ANALYSIS

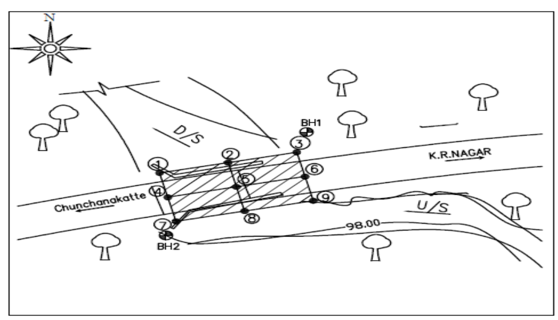
Statistical analysis is done with the help of Analysis of Variance. ANOVA is a group of statistical models and the estimation procedures which are associated (namely the "variation" among and also between the groups) used in analysing the differences amongst the group in a sample. ANOVA helps us to find out if there are any statistically occurring significant differences occurring between any of the means of three or more independent groups. The ANOVA test helps to compare more than two groups at single time to arrive at conclusion whether a relationship is existing between them. The findings of the ANOVA is that, the F statistic (also called the F-ratio), provides an allowance of multiple groups of data to be analysed and to determine any delectation between samples and within samples. If potential difference does not exists between these test groups, which is termed as the null hypothesis. The result of this ANOVA's F-ratio will be close to 1. Fluctuation occurring in the sampling is more likely follow the Fisher F distribution. In the probability theory and statistics, the F-distribution, also called as Snedecor's F distribution or the Fisher–Snedecor distribution is a continuous probability distribution that emerges routinely as the null distribution of a test statistic in the ANOVA.

4.1 OPTIMIZATION MODEL AND STUDY OF EXISTING BRIDGE

From the ANOVA linear regression equations were obtained to find the depth of the slab deck, design moment and area of reinforcement for RC deck slab. R square value and adjusted R square value shows how better the data points fit a curve.

The two lane state highway bridge is located in Krishnarajanagara, Mysore highway, Karnataka is shown in fig. 4.1

Fig. 4.1:



4.2 DATA FROM EXISTING DECK BRIDGE

Recently constructed RC slab Deck Bridge were selected as explained in the previous section. Field visit has been carried to obtain various data like span, width of carriage way etc. Including the field data, a structural drawing of the same bridge is collected for the RC detailing of the bridge. Fig 4.21 and 4.22 shows the different views of the RC bridge considered in the study.

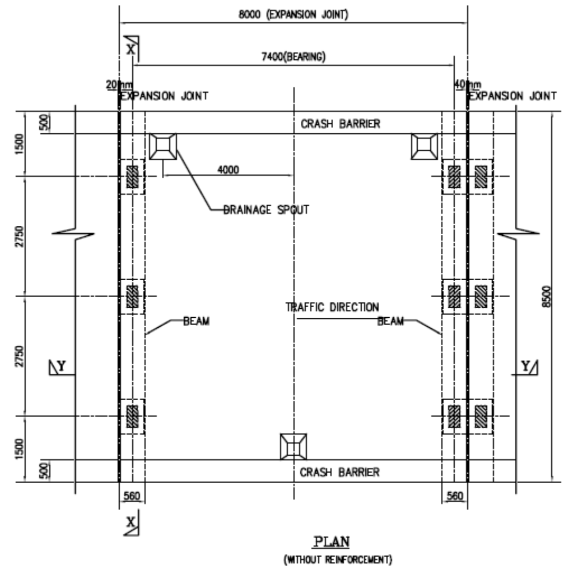
Fig. 4.21

Fig. 4.22

The structural drawing various data obtained which cannot be measured at the site. From the drawing it's obtained that depth of the slab is 650mm, diameter of 20 mm bars at 100 mm c/c spacing is provided as tensile reinforcement (bottom). Width of bearing is 560 mm and thickness of wearing coat provided is 50 mm. M30 and Fe 415 grade of concrete and steel provided respectively.

4.3 COMPARITIVE STUDY

The results obtained from the statistical analysis such as depth of deck slab, design moment and area of reinforcement of deck slab were compared with the existing RC slab deck bridge, as shown in fig. 4.31 and fig 4.32



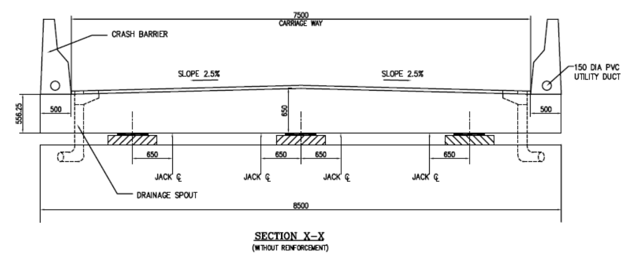


Fig 4.31 and Fig 4.32 respectively

5. RESULTS

By using design of experiments, analysis of variance is carried out to discern the dependency of span, live load combination and thickness of wearing coat on the depth of slab , design moment and area of tensie reinforcement of the slab. By using RSM various design combinations are obtained. An EXCEL program has carried out to obtain the depth,moment and area of reinforcement for design combinations obtained be RSM.The design of slab deck is carried out for all the combinatin by using EXCEL program. The reponses obtained for the correseponding design combination is updated in the DESIGN EXPERT and ANOVA test is carried out to obtain linear equations. The linear regression eqation is obtained in both working stress and limit stress method.

5.1 RESULTS OF RSM AND ANOVA FOR VARIOUS COMBINATION IN WORKING STRESS METHOD

By considering various combination of parameters obtained RSM depth, moment and area of reinforcemnt is calculated. Four combination of parameters are considered in the study are:

a) Span, live load and thickness of wearing coat.
b) Span and live load.
c) Span and thickness of wearing coat combination.
d) Live load and thickness of wearing coat.

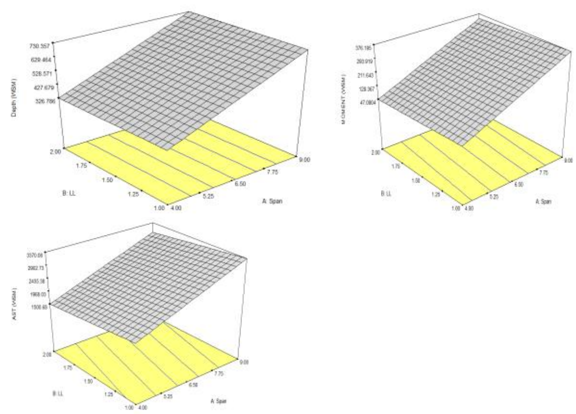
5.1 .1 SPAN, LIVE LOAD AND THICKNESS OF WEARING COAT:

The results/responses obtained from the design are updated in the DESIGN EXPERT and ANOVA test is carried out to discern the dependency of two variables on the responses.

Run	Factor 1	Factor 2	Factor 3	Respon se 1	Respons e 2	Respo nse 3
	A: Span (m)	B: LL (no)	C: Thk (mm)	Depth (mm)	Moment (kN-m)	Ast (mm^2)
1	4	2	50	325	78.51	1683
2	4	1	50	325	88.64	1901
3	4	2	75	325	78.90	1692
4	4	1	75	325	88.41	1896
5	4	1	25	325	88.78	1904
6	4	2	25	325	78.12	1675
7	5	1	25	400	125.85	2103
8	5	1	50	400	126.28	2110
9	5	1	75	400	126.88	2120
10	5	2	25	400	104.53	1747
11	5	2	50	400	105.78	1768
12	5	2	75	400	107.03	1789
13	6	1	25	500	172.99	2234
14	6	1	50	500	174.13	2249
15	6	1	75	500	175.51	2266
16	6	2	25	500	144.75	1869
17	6	2	50	500	146.79	1869
18	6	2	75	500	148.79	1921
19	6.5	2	25	525	175.92	2150
20	6.5	2	75	525	181.78	2221
21	6.5	1	75	525	226.13	2763
22	6.5	2	50	525	178.85	2185
23	6.5	1	50	525	224.15	2739
24	6.5	1	25	525	221.90	2711
25	7	1	25	575	253.96	2802
26	7	1	50	575	256.75	2833
27	7	1	75	575	259.32	2861
28	7	2	25	575	205.53	2268
29	7	2	50	575	209.00	2306
30	7	2	75	575	212.51	2345
31	8	1	25	650	315.89	3042
32	8	1	50	650	319.75	3079
33	8	1	75	650	323.41	3115
34	8	2	25	650	315.89	3042
35	8	2	50	650	319.74	3079
36	8	2	75	650	323.41	3115
37	9	2	50	725	342.17	2924
38	9	1	50	725	392.61	3354
39	9	2	75	725	348.04	2974
40	9	1	25	725	387.52	3311
41	9	2	25	725	336.54	2874
42	9	1	75	725	397.56	3397

Table 5.1.1 shows the ANOVA results for depth of slab, design moment and area of reinforcement of the RC slab deck. Its shows all the models are significant. The Model F value indicates that model is significant and there are only 0.01% of chances of making wrong decision when the null hypothesis is true.

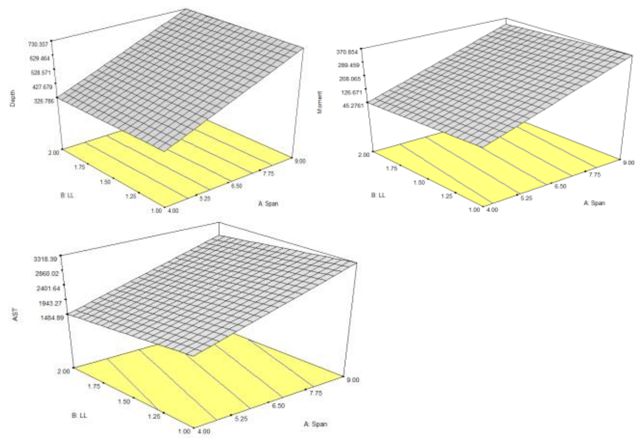
Fig 5.1.1 (a) (b) and (c) shows the 3D response surface plots for depth, moment, and area of reinforcement against span, live load and thickness of wearing coat. Fig 5.1.1(a) indicates that depth of slab increases as span increases and moment increases with the increase in span and decreases for the case 2 live load as shown in Fig 5.1.1(b). The decrease in moment is due to two axle loads of each 114 kN is specified in IRC 6:2014 for case 2, whereas two axle loads of 350 kN is specified in IRC 6:2014 for case 1. Fig 5.1.1(c) indicates that area of reinforcement increases as the span increases and decreases for the case 2 live load.



5.1.2 SPAN AND LIVE LOAD

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	A: Span (m)	B: LL (no)	Depth (mm)	Moment (kN-m)	Ast (mm^2)
1	4	1	325	88.64	1901
2	4	2	325	78.51	1683
3	5	1	400	126.28	2110
4	5	2	400	105.78	1768
5	6	1	500	174.13	2249
6	6	2	500	146.76	1896
7	6.5	2	525	178.85	2185
8	6.5	1	525	224.15	2739
9	7	1	575	256.75	2833
10	7	2	575	209.00	2306
11	8	1	650	319.75	3079
12	8	2	650	269.53	2596
13	9	1	725	392.61	3354
14	9	2	725	342.17	2924

Fig 4.3 (a) (b) and (c) 4.3 shows the 3D response surface plots for depth, moment and area of tensile reinforcement against span and live load. Fig 4.1(a) indicates that depth of slab increases as span increases and Fig 4.1(b) indicates that moment increases with the increase in span and decreases for the case 2 live load. The decrease in moment is due to two axle loads of each 114 kN is specified in IRC 6:2014 for case 2, whereas two axle loads of 350 kN is specified in IRC 6:2014 for case 1. Fig 4.4(c) indicates that area of tensile reinforcement increases as the span increases and decreases for the case 2 live load.

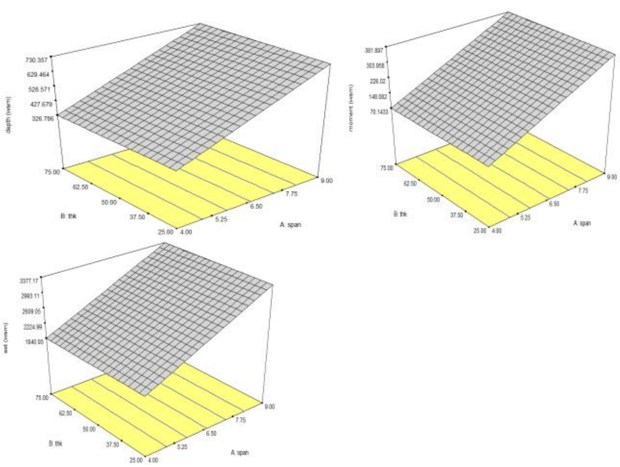


5.1.3 SPAN AND THICKNESS OF WEARING COAT COMBINATION

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	A:Span (m)	B:Thk (mm)	Depth (mm)	Moment (kN-m)	Ast(mm^2)
1	4	50	325	88.64	1901
2	4	75	325	88.41	1896
3	4	25	325	88.78	1904
4	5	25	400	125.85	2103
5	5	50	400	126.28	2110
6	5	75	400	126.88	2120
7	6	25	500	172.99	2234
8	6	50	500	174.13	2249
9	6	75	500	175.51	2266
10	6.5	50	525	224.15	2739
11	6.5	75	525	226.13	2763
12	6.5	25	525	221.90	2711
13	7	25	575	253.96	2802
14	7	50	575	256.75	2833
15	7	75	575	259.32	2861

16	9	50	725	392.61	3354
17	9	25	725	387.52	3311
18	9	75	725	397.56	3397
19	8	25	650	315.89	3042
20	8	50	650	319.75	3079
21	8	75	650	323.41	3115

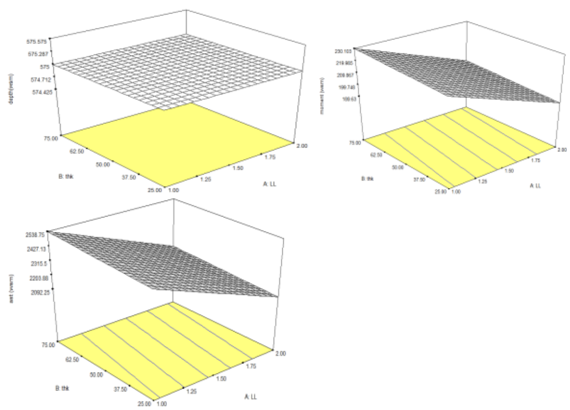
Fig 5.1.3(a) (b) and (c) shows the 3D response surface plots for depth, moment and area of tensile reinforcement against span and thickness of wearing coat. Fig 5.1.3(a) indicates that depth of slab increases as span increases and Fig 5.1.3(b) indicates that moment increases with the increase in span. Fig 5.1.3(c) indicates that area of tensile reinforcement increases as the span increases.



5.1.4 LIVE LOAD AND THICKNESS OF WEARING COAT COMBINATION

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	A:LL (m)	B:Thk (mm)	Depth (mm)	Moment (KN-m)	Ast (mm^2)
1	1	25	575	225.47	2488
2	2	25	575	189.24	2088
3	2	50	575	192.17	2120
4	1	50	575	227.49	2510
5	2	75	575	195.07	2152
6	1	75	575	229.76	2535

Fig 5.1.4 (a) (b) (c) shows the 3D response surface plots for depth, moment and area of reinforcement against live load and thickness of wearing coat. Fig 5.1.4.(a) indicates that depth of slab is constant because in this case span is kept constant. Fig 5.1.4 (b) indicates that moment decreases with the increase in live load. The decrease in moment is due to two axle loads of each 114 kN is specified in IRC 6:2014 for case 2, whereas two axle loads of 350 kN is specified in IRC 6:2014 for case 1.



5.2 RESULTS OF RSM AND ANOVA FOR VARIOUS COMBINATION IN LIMIT STATE METHOD

By considering various combination of parameters obtained RSM depth, moment and area of reinforcemnt is calculated. Four combination of parameters are considered in the study are:

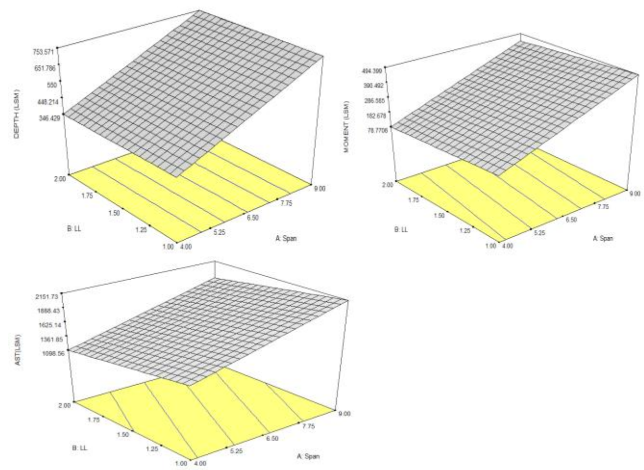
a) Span, live load and thickness of wearing coat
b) Span and live load
c) Span and thickness of wearing coat combination.
d) Live load and thickness of wearing coat

5.2.1 SPAN, LIVE LOAD AND THICKNESS OF WEARING COAT:

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
	A:Span(m)	B:LL (no)	C:Thk (mm)	Depth (mm)	Moment (kN-m)	Ast(mm^2)
1	4	2	50	350	120.23	1208
2	4	1	50	350	140.62	1426
3	4	2	75	350	120.9	1215
4	4	1	75	350	140.68	1427
5	4	1	25	350	140.28	1428

6	4	2	25	350	119.61	1201
7	5	1	25	425	194.84	1557
8	5	1	50	425	195.79	1565
9	5	1	75	425	196.91	1575
10	5	2	25	425	149.42	1179
11	5	2	50	425	151.48	1196
12	5	2	75	425	153.5	1213
13	6	1	25	500	260.06	1716
14	6	1	50	500	262.14	1731
15	6	1	75	500	264.41	1747
16	6	2	25	500	204.76	1337
17	6	2	50	500	207.93	1359
18	6	2	75	500	211.11	1380
19	6.5	2	25	550	238	1392
20	6.5	2	75	550	245.64	1439
21	6.5	1	75	550	302.42	1787
22	6.5	2	50	550	241.8	1415
23	6.5	1	50	550	299.69	1770
24	6.5	1	25	550	296.85	1752
25	7	1	25	600	337.53	1803
26	7	1	50	600	340.79	1821
27	7	1	75	600	344.35	1841
28	7	2	25	600	275.92	1462
29	7	2	50	600	280.2	1487
30	7	2	75	600	284.89	1511
31	8	1	25	675	420.55	1969
32	8	1	50	675	425.27	1992
33	9	2	50	750	459.73	1908
34	9	1	50	750	524.54	2188
35	9	2	75	750	467.34	1941
36	9	1	25	750	517.8	2159
37	9	2	25	750	452.09	1875
38	9	1	75	750	530.95	2216
39	8	1	75	675	430.36	2017
40	8	2	25	675	355.79	1655
41	8	2	50	675	361.71	1684
42	8	2	75	675	367.69	1712

Fig 5.2.1(a) (b) and (c) shows the 3D response surface plots for depth, moment and area of reinforcement against span, live load and thickness of wearing coat. Fig 5.2.1(a) indicates that depth of slab increases as span increases and moment increases with the increase in span and decreases for the case 2 live load as shown in Fig 5.2.1(b). The decrease in moment is due to two axle loads of each 114 kN is specified in IRC 6:2014 for case 2, whereas two axle loads of 350 kN is specified in IRC 6:2014 for case 1. Fig 5.2.1(c) indicates that area of reinforcement increases as the span increases and decreases for the case 2 live load.

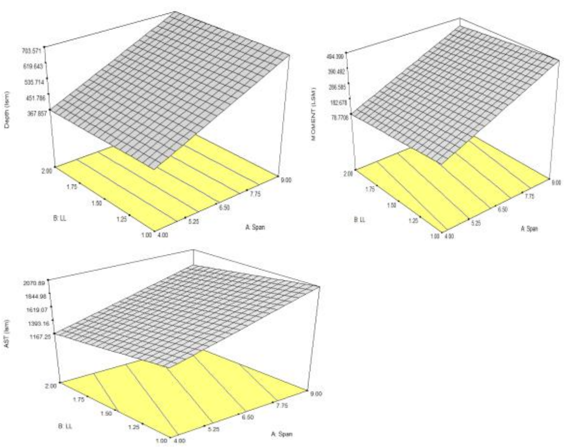


5.2.2 SPAN AND LIVE LOAD COMBINATION

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	A:Span (m)	B:LL (no)	Depth (mm)	Moment (kN-m)	Ast (mm^2)
1	4	1	350	140.62	1426
2	4	2	350	120.23	1208
3	5	1	425	195.79	1565
4	5	2	425	151.48	1196
5	6	1	500	264.46	1747
6	6	2	500	209.07	1366
7	6.5	2	550	245.64	1439
8	6.5	1	550	305.41	1805
9	7	1	600	350.14	1873

10	7	2	600	285.86	1517
11	8	1	675	436.85	2048
12	8	2	675	369.62	1722
13	9	2	750	469.50	1950
14	9	1	550	305.41	1805

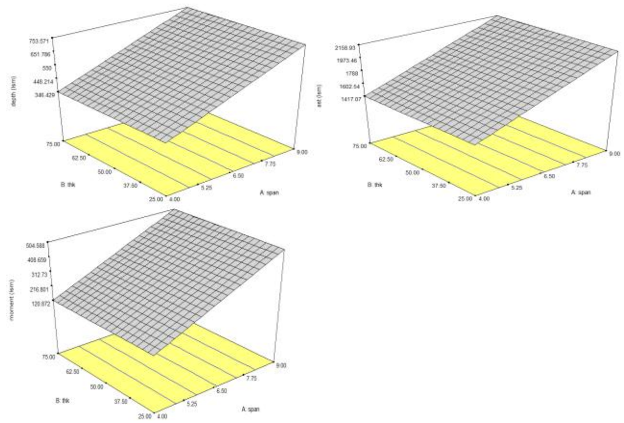
Fig 5.2.2 (a) (b)and (c) shows the 3D response surface plots for depth, moment and area of tensile reinforcement against span and live load. Fig 5.2.2(a) indicates that depth of slab increases as span increases and Fig 5.2.2(b) indicates that moment increases with the increase in span and decreases for the case 2 live load. The decrease in moment is due to two axle loads of each 114 kN is specified in IRC 6:2014 for case 2, whereas two axle loads of 350 kN is specified in IRC 6:2014 for case 1. Fig 5.2.2(c) indicates that area of tensile reinforcement increases as the span increases and decreases for the case 2 live load.



5.2.3 SPAN AND THICKNESS OF WEARING COAT COMBINATION

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	A:Span (mm)	C:Thk (mm)	Depth (mm)	MOMENT (kN-m)	AST (mm²)
1	4	75	350	140.68	1427
2	4	50	350	140.62	1427
3	4	25	350	140.78	1428
4	5	25	425	194.84	1557
5	5	50	425	195.79	1565
6	5	75	425	196.91	1575
7	6	25	500	260.06	1716
8	6	50	500	262.14	1731
9	6	75	500	264.41	1747
10	6.5	75	550	302.42	1787
11	6.5	50	550	299.69	1770
12	6.5	25	550	296.85	1752
13	7	25	600	337.53	1863
14	7	50	600	340.79	1821
15	7	75	600	344.35	1841
16	8	25	675	420.55	1969
17	8	50	675	425.27	1992
18	8	75	675	430.36	2017
19	9	75	750	530.95	2216
20	9	25	750	517.80	2159
21	9	50	750	524.54	2188

Fig 5.2.3 (a) (b) (c) shows the 3D response surface plots for depth, moment and area of tensile reinforcement against span and thickness of wearing coat. Fig 5.2.3 indicates that depth of slab increases as span increases and moment increases with the increase in span. Fig 5.2.3(c) indicates area of tensile reinforcement increases as the span increases.



5.2.4 LIVE LOAD AND THICKNESS OF WEARING COAT COMBINATION

Run	Factor 1	Factor 2	Response 1	Response 2	Response 3
	B:LL (no)	C:Thk(mm)	Depth (mm)	Moment (kN-m)	AST (mm^2)
1	2	75	575	195.07	2152
2	2	50	575	192.17	2120
3	1	50	575	227.49	2510
4	1	25	575	225.47	2488
5	1	75	575	229.76	2535
6	2	25	575	189.24	2088

6. RESULT ON EXISTING BRIDGE DATA

The regression equations obtained through the ANOVA by working stress design method were considered for comparing the two variables (Such as Depth, and span) with statistical studies. The depth of the bridge found to be 650mm and effective span of 7.4 m. The results from the analysis shows that the regression equation (see equation 1) obtained with span as variable gives 601 mm depth, which is less than the actual depth provided. There is a variation of 7.5% in the depth, suitably this method of analysis can be adopted with ±10% allowable errors. Further, the errors can be lowered by increasing the number of parameters in the analysis.

7. CONCLUSIONS

1) The obtained results from ANOVA, linear regression equation obtained for both working stress and limit state design methods were reliable.

2) Since the model is insignificant no relation between span and thickness of wearing coat is obtained. The equation were obtained for forecasting depth, moment and area of reinforcement of the deck slab for span varying from 4 to 9m and thickness of wearing coat from 25 to 75mm.

3) The linear equation obtained by working stress method by considering three variables shows the variation of 7.5% in the depth and area of reinforcement using Response Surface Method (RSM).

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