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# Optimization in Solid Slab Design

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**ABSTRACT**

Simply supported solid deck slabs are provided for bridges having spans less than 15 m because of their simplicity in design as well as construction. The textbooks such as *Design of Bridge Structures* authored by T.R. Jagdeesh and M.A. Jayaram mentions that solid slabs are uneconomical for spans above 8.0 m due to considerable high thickness. In this paper attempt is made to verify the possibility of slab being feasible beyond 8.0 m. An MS Excel program for design calculation is created for the purpose taking example from same book *Design of Bridge Structures* of above authors.

All steps of design are converted into Excel Program and results are tallied with original example in book. Variable data cells left coloured in yellow for new cases with changed span or grade of concrete. This program was then checked for similar example in other text book such as *Design of Bridges* by Krishna Raju. After ascertaining the correctness of Excel Program Slab Design was carried out for different spans between 4 m to 12 m and for different grades of concrete from M25 to M35 considering reinforcement of Fe415.

The results of each case of slab design with fixed width of slab and load condition (IRC AA Class Tracked) tabulated in 'Results and Concluding Discussion' below. Finally, it was observed from the graph plotted below that span up to 9.0 m can be economical, i.e., 1 m beyond earlier concept of 8.0 m span as provided in abovementioned book.

**KEYWORDS:** *Design of bridges, Span, Solid Slabs, Economical, Excel Program*

## 1. INTRODUCTION

Solid slabs are simple structures that rest on abutments, piers of bridge to cross the stream. They are easy to design and to construct, but have limitation of span. For long spans these structures become uneconomical. To workout extent of feasible span an Excel program was created for slab having width 7.5 m and loading of IRC Class AA (Tracked) as fixed parameter and span and grade of concrete as variable parameters. The bending moments, stresses developed and reinforcement requirement is worked out for different spans and grades of concrete. Data obtained is tabulated showing spanwise required depth of slab, bending moments generated due to DL and LL, shear stresses and requirement of reinforcement, etc. It is observed that by taking higher grade of concrete the depth of slab or reinforcement requirement are not reduced. Therefore, another method adopted to know up to what length of span of solid slab are economical. In this method the bending moments generated due to dead load and live load are taken as parameter to decide feasibility of span. The spans generating higher Bending Moment due to Dead load than due to Live Load are considered non-feasible. The graph plotted for span on x-axis and ratio R of BM due to LL to BM due to DL on Y-axis. The slabs which takes more load than its self-weight has value of R more than 1, but when R value is less than one the slab can carry less load than its own weight. If this happens, some other type such as slab with girders shall be considered.

## 2. BACKGROUND OF SUBJECT

It is normally considered that solid slab of bridge is economical for small spans. The text book *Design of Bridge Structures* authored by T.R. Jagdeesh and M.A. Jayaram mentions economical limit up to 8.0 m. Yet, these type of deck slabs are constructed for spans up to 15 m for their simplicity in design and ease in construction. To know up to what extent of span solid slab is economical it was necessary to go through design of commonly adopted spans between 4.0 m to 12.0 m and grades of concrete M25, M30 and M35

## 3. REVIEW OF LITTERATURE AND METHODOLOGY USED

To carry out design of solid slab for variable spans and grades of concrete a special program in MS Excel is created. The design steps as given below are similar to that in text book ***Design of Bridge Structures* authored by T.R. Jagdeesh and M.A. Jayaram**. Yellow cells are input data cells where variable data has to be fed depending upon the case. Other cells display results or process the data.

**Design of deck slab**

**Data:**

| | | | | |
|---|---|---|---|---|
| 1 | Clear span | : | 7 | m |
| 2 | Width of footpath: | | 0.6 | m on either side |
| 3 | Wearing Coat | : | 80 | mm |
| 4 | Loading | | : | IRC AA Class (Tracked) |
| 5 | Material | : | M30 | Concrete and Fe 415 Steel |

**Design of slab**

*Design parameters*

$m = 9.33$

$n = \dfrac{9.33 \times 10}{9.33 \times 10 + 200} = 0.318$

$j = 1 - \dfrac{0.318}{3} = 0.894$

$q = 0.5 \times 10 \times 0.894 \times 0.318 = 1.42$

***Dead load, bending moment and shear force***

The overall thickness of the slab is assumed to be 80 -90 mm per metre span of the deck

80x7=560 & 90 x 7 = 630 , Provide 630 mm

Overall depth of slab= 80 -90 x 7 = 630 mm

Using 25 mm dia. Bar and a clear cover of 40 mm, we have

Effective depth of the slab = 630 - 12.5 - 40 = 577.5 mm

Bearing width of 300 mm is taken if the span is less than or equal to 3 m, and bearing with of 400 mm is taken if span is more than 3 m

Effective span is the least of

(i) Clear Span + Effective depth = 7 + 0.578 = 7.578 m

(ii) Clear span + Bearing width = 7 + 0.4 = 7.4 m

Effective span is therefore taken as 7.4 m

Dead load of slab = 0.63 x 24 = 15.12 kN/$m^2$

Dead load of the wearing coat = 0.08 x 22 = 1.76 kN/$m^2$

16.88 kN/$m^2$

Dead load bending moment $= \frac{Wl^2}{8} = \frac{16.88 \times 7.4 \times 7.4}{8} = 115.54$ kN-m

Dead load shear force $= \frac{16.88 \times 7.4}{2} = 62.46$ kN-m

***Live load bending moment and shear force***

Width of deck slab (B) = 7.5 + 0.60 x 2 = 8.7 m

Therefore, $k$ = $B/l$ = 8.7 / 7.4 = 1.176

From Table 7.1, α = 2.6

Centre of gravity distance $x$ of the wheel from the support = 7.4 / 2

= 3.7 m

$b_1$= w + 2 h = = 0.85 + 2 x 0.08 = 1.01 m

Effective width of dispersion for single wheel,

$$b_{ef}= \alpha x\ (1 - x/l) + b_1 = 2.6 \times 3.7 \left( 1 - \frac{3.7}{7.4} \right) + 1.01$$

= 5.82 m

Effective width of dispersion for 2 wheels can be calculated by referring to Fig. 7.7. Thus, the net effective width for two wheels is= 2.23 + 2.05 + 2.91 = 7.19 m

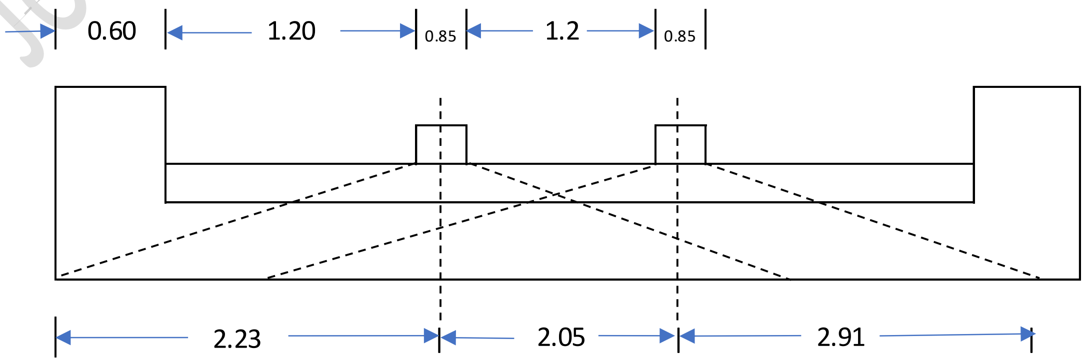


Fig.: Effective width of two wheels ( for B.M. )

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Effective length of dispersion = 3.6 + 2 x ( 0.63 + 0.08 ) = 5.02 m

As load dispersion gone out of slab span by -2.38 m the dispersion length can be taken equal to span of the slab. The intensity of load is reduced proportionately as slab does not provide complete dispersion of load.

$$\text{Proportional load} = \frac{7.4 \times 700}{5.02} = 1032 \text{ kN}$$

Impact factor is calculated by interpolation. ( Impact factor is 25% for span upto 5 m and linearly reduces to 10% for a span upto 9 m ). Therefore,

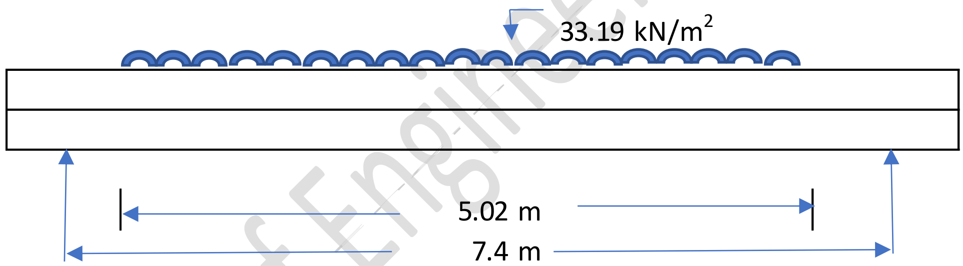
$$I_f = 10 + \frac{25 - 10}{9 - 5}\left( 9 - 7.4 \right)$$

= 16 = 16 %

= Maximum limited to = 25 %

$$\text{Intensity of loading} = \frac{1.16 \times 1032}{5.02 \times 7.19} = 33.19 \text{ kN/m}^2$$

Maximum live load bending moment occurs at the centre of the slab




$$\text{Maximum live load B.M.} = \frac{33.19 \times 5.02}{2} \times \frac{7.4}{2} - 33.19 \times \frac{5.02}{2} \times \frac{5.02}{4}$$

= 203.7 kN/m2

Design Bending Moment = dead load B.M. + live load B.M.

= 115.5 + 203.7

= 319.2 $kN/m^2$

$$\text{Effective depth required} = \sqrt{\frac{319.2 \times 10^6}{1.42 \times 10^3}} = \frac{3E+08}{1420} = 474.122$$

Effective depth actually provided = 577.5 mm OK

$$A_{st} = \frac{319.20 \times 10^6}{200 \times 0.894 \times 577.5} = 3091 \text{ mm}^2$$

25 mm bars provided spacing required = 158 , provided 100 mm c/c

Actual steel provided = 4.906 x 1000 ⁄ 100

49.06 Sq.cm = 4906 Sq.mm

Bending moment for distribution steel = 0.3 x 203.7 + 0.2 x 115.544

= 84.21 kN/m2

assuming 12 mm bars, the depth availble in the widthwise direction

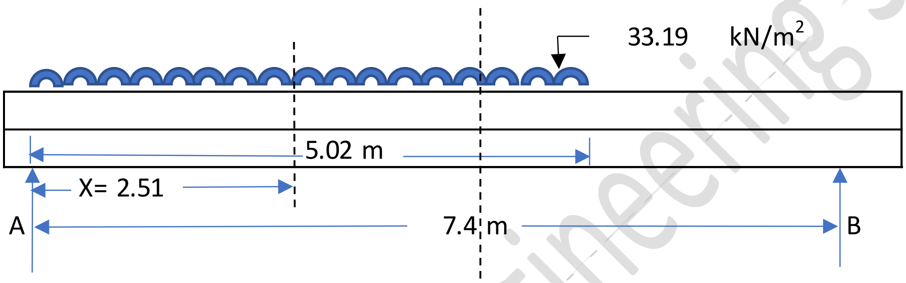
= 577.5 - 6 = 571.5

$$A_{st} = \frac{84.21 \times 10^{6}}{200 \times 0.894 \times 571.5} = 824.1\ mm^2$$

$$\text{Spacing of bars} = \frac{113}{824.1} \times 1000 = 137.2 \quad \text{say, } 130 \text{ mm c/c}$$

***Check for shear stress***

The loading shall should be arranged as shown below

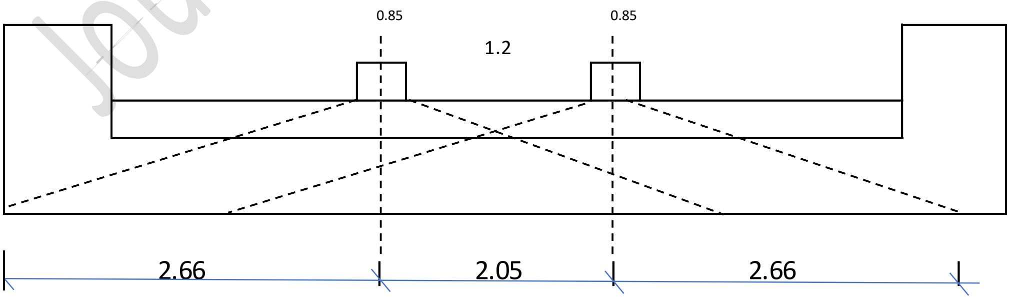



Distance of centre of gravity of the concentrated load from the nearest support A

x = 5.02 ⁄ 2 = 2.51 m

Effective width of dispersion = $2.6 \times 2.51 \left(1 - \frac{2.51}{7.4}\right) + 1.01 = 5.32$ m

effective width for two wheel = 2.66 + 2.05 + 2.66 = 7.37



Intensity of loading = $\dfrac{1.16 \times 1032}{5.02 \times 7.37}$ = 32.34 kN/m2

Maximum shear force is the reaction at A. Thus

Live load shear force = $\dfrac{32.34 \times 5.02 ) \times ( 7.4 - 2.51 )}{7.4}$ = 107.29 kN

Design shear force = 62.46 + 107.29 = 169.74 kN

Nominal shear stress= $\tau_v = \dfrac{169.74 \times 1000}{1000 \times 577.5}$ = 0.29 N/mm$^2$

Permissible shear stress, $\tau c$ = $k \tau c$ $k$ = 1 (for slab depth more than 300 mm)

For arriving at $\tau c$, we need ρ ( % of steel) = $\dfrac{100 \times 2453}{1000 \times 577.5}$ = 0.42

for ρ = 0.42 & M30 concrete τc from the table 12B of IRC is 0.29 N/mm2

$\tau_c$ = 1 x 0.29 = 0.29 N/mm2 ,actual shear stress τv is not higher than permissible shear stress, Hence the slab is safe against shear

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**Analysis of results:**

(1) % of reinforcement area in cross section of slab per meter length of span

Depth = 63 cm

Main steel = 4906 Sq.mm = 49.06 Sq.cm per meter width

% area of steel = 0.779

Factor = 0.779 / 7.00

= 0.111 (% area of reinforcement in cross section per metre length of span

Analysis (2): Ratio of BM generated due to self-weight of slab upon Live Load

BM due to Live load = 203.7 kN/m$^2$

BM due dead load = 115.5 kN/m$^2$

Ratio of BM due to LL upon DL = 1.763

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## 4. Following Standard Data adopted from IRC 21

| Value of α for slabs ( IRC 21 ) | | |
|---|---|---|
| | | |
| *B/l* | α for sss | α for cs* |
| | | |
| 0.1 | 0.4 | 0.4 |
| 0.2 | 0.8 | 0.8 |
| 0.3 | 1.16 | 1.16 |
| 0.4 | 1.48 | 1.44 |
| 0.5 | 1.72 | 1.68 |
| 0.6 | 1.96 | 1.84 |
| 0.7 | 2.12 | 1.96 |
| 0.8 | 2.24 | 2.08 |
| 0.9 | 2.36 | 2.16 |
| 1 | 2.48 | 2.24 |
| 1.1 | 2.6 | 2.28 |
| 1.2 | 2.64 | 2.36 |
| 1.3 | 2.72 | 2.4 |
| 1.4 | 2.8 | 2.48 |
| 1.5 | 2.84 | 2.48 |
| 1.6 | 2.88 | 2.52 |
| 1.7 | 2.92 | 2.56 |
| 1.8 | 2.96 | 2.6 |
| 1.9 | 3 | 2.6 |
| 2 | 3 | 2.6 |
| Above 2 | 3 | 2.6 |

Table 12 B. Permissible Shear Stress in Concrete

| 100 * As | Permissible Shear Stress in Concrete, τv | | | | |
|---|---|---|---|---|---|
| b*d | M20 | M25 | M30 | M35 | M40 |
| | | | | | |
| 0.15 | 0.18 | 0.19 | 0.2 | 0.2 | 0.2 |
| 0.25 | 0.22 | 0.23 | 0.23 | 0.23 | 0.23 |
| 0.5 | 0.3 | 0.31 | 0.31 | 0.31 | 0.32 |
| 0.75 | 0.35 | 0.36 | 0.37 | 0.37 | 0.38 |
| 1 | 0.39 | 0.4 | 0.41 | 0.42 | 0.42 |
| 1.25 | 0.42 | 0.44 | 0.45 | 0.45 | 0.46 |
| 1.5 | 0.45 | 0.46 | 0.48 | 0.49 | 0.49 |
| 1.75 | 0.47 | 0.49 | 0.5 | 0.52 | 0.52 |
| 2 | 0.49 | 0.51 | 0.53 | 0.54 | 0.55 |
| 2.25 | 0.51 | 0.53 | 0.55 | 0.56 | 0.57 |
| 2.5 | 0.51 | 0.55 | 0.57 | 0.58 | 0.6 |
| 2.75 | 0.51 | 0.56 | 0.58 | 0.6 | 0.62 |
| 3 | 0.51 | 0.57 | 0.6 | 0.62 | 0.63 |
| | | | | | |
| 0.42 | 0 | 0 | 0.285931 | 0 | 0 |

| Table 12 C | | Values of *K* for Solid Salb | | | | | |
|---|---|---|---|---|---|---|---|
| Overall depth of slab, mm | 300 | 275 | 250 | 225 | 200 | 175 | 150 |
| K | 1 | 1.05 | 1.1 | 1.15 | 1.2 | 1.25 | 1.3 |

## 5. OBJECTIVE

Using specially created Slab Design program in MS Excel, bending moments at center of span due to IRC Class AA Tracked load and shear stresses are worked out for spans 4m, 6m, 7m, 9m, 10m, 12m and grade of concrete M25, M30 and M35 and tabulated. The ratio (R) of bending moment developed due to live load and dead load is calculated. The objective was to find out relation between Span and Ratio R

## 6. RESULTS AND CONCLUDING DISCUSSION

Following two types of data is obtained from different cases of slab design

(1) Table shows % of Steel reinforcement required per meter of length span for different span of Solid Slab

| | Span length (in meters) of Solid Slabs | | | | | |
|---|---|---|---|---|---|---|
| | **4.0** | **6.0** | **7.0** | **9.0** | **10.0** | **12.0** |
| **M25** | 0.17 | 0.13 | 0.11 | 0.07 | 0.05 | 0.03 |
| **M30** | 0.17 | 0.13 | 0.11 | 0.07 | 0.04 | 0.02 |
| **M35** | 0.17 | 0.13 | 0.11 | 0.07 | 0.04 | 0.02 |

**Observations from data in above Table-**

i. If M25 Grade Concrete used for 4 m span the reinforcement required is 0.17% of slab area in lateral cross section per meter length of span.
ii. Depth of Slab required is same even if higher grade of concrete used for a given span.
iii. Use of higher grade of concrete does not reduce % of reinforcement
iv.

(2) Following table indicates Ratio (R) of BM developed in slab due to LL upon DL for various Span and for different grades of concrete

| Span → | **4.0** | **6.0** | **7.0** | **9.0** | **10.0** | **12.0** |
|---|---|---|---|---|---|---|
| **M25** | 2.87 | 2.10 | 1.76 | 1.26 | 1.28 | 0.93 |
| **M30** | 2.87 | 2.10 | 1.76 | 1.26 | 1.28 | 0.93 |
| **M35** | 2.87 | 2.10 | 1.76 | 1.26 | 1.28 | 0.99 |

**Observations from data in above Table-**

i. If M25 grade of concrete is used for 4.0 m span the ratio of BM generated due to live load to self-weight is 2.87
ii. For 12.0 m span BM generated due to Dead load is more than Live load. Hence Solid slab more than 12 m span is not feasible.
iii. Between 4.0 m and 9.0 m spans ratio of BM high for all grades, but beyond 9.0 m ratio is low. That means Solid slabs are economical up to span 9.0 m and beyond 9.0 m and up to 11.0 m feasibility is limited and hence other type of superstructure such as slab with girders shall be provided
iv. Above analysis is plotted graphically that indicates sudden change in gradient of line at 9.00 m and 12 m.

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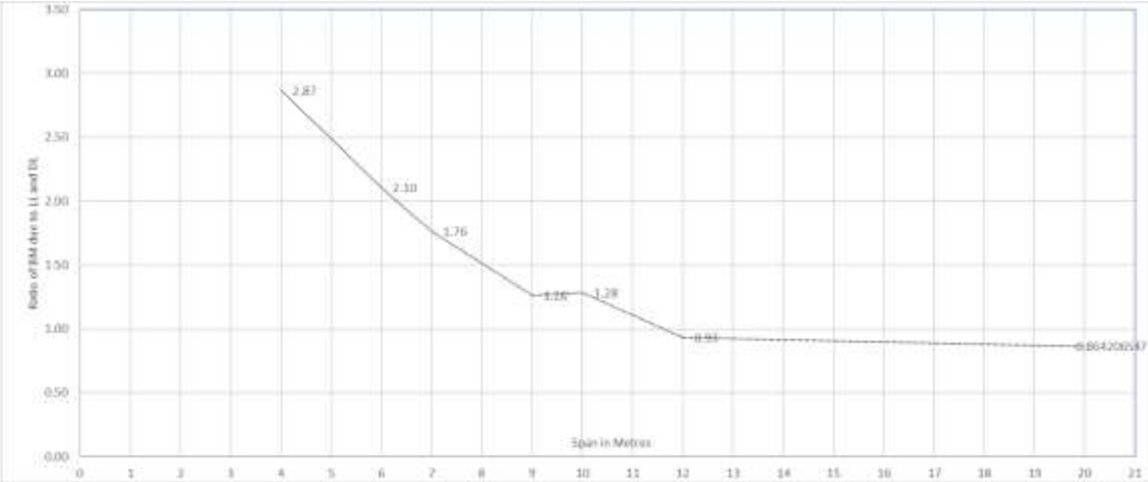


**Final conclusion:**

**From the data analysed the span up to 9.0 m can be economical, i.e., 1 m beyond earlier concept of 8.0 m span as provided in abovementioned book.**

## REFERENCES


i. **"Guidelines of Bridge Design''. Published by Govt. of Maharashtra. 2000**

ii. **Jagadeesh, T.R. & Jayaram, M.A. Design of bridge structures. PHI Learning Pvt. Ltd., 2nd Edition. 2019.**