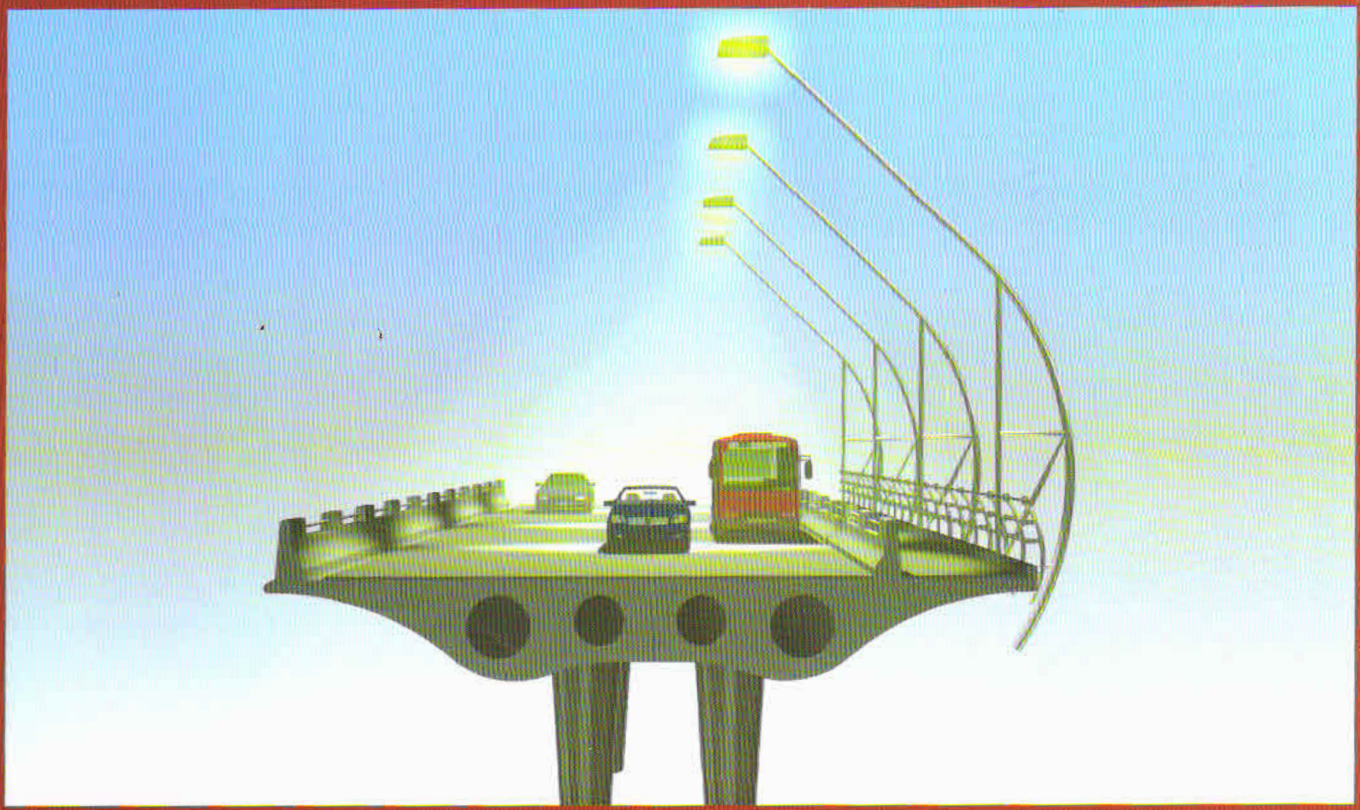
IRC:SP:64-2016

GUIDELINES FOR THE ANALYSIS AND DESIGN OF CAST-IN-PLACE VOIDED SLAB SUPERSTRUCTURE (FIRST REVISION)



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GUIDELINES FOR THE ANALYSIS AND DESIGN OF CAST-IN-PLACE VOIDED SLAB SUPERSTRUCTURE

1. INTRODUCTION

1.1. IRC: SP:64 "Guidelines for the Analysis and Design of Cast-in-Place Voided Slab Superstructure" was published by IRC in 2005. It is warranted to align these Special Publications of IRC with IRC:112 - "Code of Practice for Concrete Road Bridges", which is based on the Limit State approach.

1.2. Following is the composition of B-4 Concrete (Plain, Reinforced and Prestressed) Structures Committee (2015-17) of the Indian Roads congress:

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1.3. Mr. T. Viswanathan and Dr. N. Rajagopalan played the lead role in drafting the document. The revised draft document was approved by Bridges Specifications and Standards (BSS) committee in its meeting held on 20.09.2016 and IRC Council at its 209th meeting held on 26.09.2016 at Kumarakom (Kerala).

2. SCOPE

2.1 Ministry of Road Transport & Highways (MoRT&H), Govt. of India in order to align itself with the globally best practices for economical, durable, speedy and aesthetic construction of "Bridge Structures", MoRT&H vide para 12 of the Circular No.RW/NH/-34072/1/2015-S&R(B) dated 18.08.2016, has decided that "due to assured quality, inherent economy, durability and low maintenance, precast and pre-stressed concrete may be used for various bridge components like box structures for culverts, deck slab, T-beam girder and box girders etc. These components may be procured by contractors or concessionaires from pre-casting factories, to be set up in all major states. Standard designs and drawings of any bridge components and their connections based on **Limit State Design philosophy as per IRC:112 (or other applicable international Specifications/ Standards) should be got approved by each factory owner from Ministry of Road Transport & Highways (M/o RT&H) before their usage in the construction of culverts and bridge structures on National Highways.........**" Further, MoRT&H in supersession of the MoRT&H's earlier Circular issued vide Circular No. RW-NH-35075/9/2006-S&R (B) dated 18.06.2014 (published at page No.42 of April 2012 edition of Indian Highways) vide which it was decided that the use of working loads/Allowable Stress methods as given in Annexure A-4 of IRC:112-2011 allowed to be followed till the end of year 2015 (i.e. upto 31.12.2015) in order to smooth transition and gradual acquaintance of practicing Engineers, has now vide Circular No. RW-NH-35075/9/2006-S&R (B) dated 02.09.2016 has decided that henceforth, all new bridges and its components shall be structurally designed strictly as per IRC:112 after following the "Limit State Design Philosophy" except those components for which IRC Codes and standards based on limit state philosophy are not available. Loading will be considered as per IRC:6 including 385 Tonnes Special Vehicle. Latest edition of the code notified/published either at the time of project consideration/ conceptualization or at least 60 days prior to the last date of bid submission need to be considered for this purpose.

2.2 However, owing to its merits being in line with the provisions of IRC: 112 besides the guidelines for Self-Compacting Concrete, various agencies other than national highways are warranted to follow these Guidelines/Norms for all bridge structures to be constructed on State Highways, Major District Roads, Rural Roads and Municipal roads etc.

2.3 The guidelines provide the basic approach for analysis of voided slab superstructures by different methods, design of various members and information on general reinforcement detailing. The designer is advised to consult relevant specialist literature on the subject, if further information is required.

3. CROSS-SECTION DIMENSIONS

3.1. The voids can be rectangular or circular.

3.1.1. For slabs provided with circular voids, the centre-to-centre spacing of the voids should not be less than the total depth of the slab.

3.1.2. In case of circular voids, the ratio of the diameter of void to the total depth of slab shall not exceed 75 per cent in order to avoid transverse distortional effect.

3.1.3. The thickness of web in case of prestressed concrete slabs shall not be less than, the external dia of duct + the clear cover measured from outside of duct on either side. It shall also be ensured that the cover specified for un-tensioned reinforcement is satisfied. For reinforced concrete slabs the thickness of web shall be based on design requirement.

3.1.4. For reinforced concrete slab, the thickness of concrete above and below the void shall not be less than 175 mm.

3.1.5. For prestressed concrete slab, if the cables are not located in the flanges, the thickness of flange shall be governed by provision as in para 3.1.4. If the cables are located in the flanges (not in web region) the thickness of flange shall be such that it satisfies the minimum clear cover requirement for the pre-stressing duct measured from outside of duct. It shall also be ensured that the cover specified for un-tensioned reinforcement is satisfied.

3.1.6. For rectangular voids, in addition to the above the transverse width of the void shall not exceed 1.5 times the depth of the void.

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 per cent of the effective span whichever is greater.

3.3. Materials used for Void Formers

Void formers are required to possess the necessary rigidity and integrity of dimensions in addition to being water tight.

The void formers may be manufactured from materials, such as, steel sheets, card board, fibre reinforced cement, timber, expanded polystyrene, HDPE, etc. They are generally corrugated for rigidity. Special machines are available for manufacture of corrugated steel void formers, identical to those used for manufacture of prestressing cable ducts.

4. ANALYSIS OF STRUCTURE

4.1. The structure shall be analysed both for longitudinal as well as transverse structural actions.

4.1.1. Where the voids conform to the dimensional requirements given above and the void ratio does not exceed 40 per cent, the structure may be analyzed as a solid slab for bending moments and shear forces due to longitudinal actions. The transverse moment M_y shall be taken as 0.3 times the moment in the longitudinal direction due to live load plus 0.2 times the moment in the longitudinal direction due to dead load. Other transverse structural actions can be evaluated and design for the same can be carried out as outlined in Para 5.2.

Void ratio is the ratio of area of the voids to the total area of the slab without deducting the area of voids.

This method is applicable to right and skew bridges with skew angle upto 20°.

4.1.2. If the void ratio exceeds 40 per cent, the structure shall be analysed by any one of the following methods:

(i) Orthotropic Plate

(ii) Grillage Analogy

(iii) Three Dimensional Continuum

4.1.3. If the dimensional parameters mentioned in para 3.1.1., 3.1.2 and 3.1.6 above are not satisfied, any other appropriate method of analysis shall be carried out for taking into account the distortional effect.

5. ORTHOTROPIC PLATE METHOD

The effects of live load can be obtained by adopting the orthotropic plate theory. This method is applicable to right and skew bridges with skew angle upto 20°.

5.1. Analysis & Design for Longitudinal Action

The design forces (bending moment and shear) for longitudinal structural action shall be calculated using the parameters given in **Appendix-I**.

The design shall be carried out both for ultimate and service ability limit states according to IRC: 112.

5.2. Analysis and Design for Transverse Shear Action

5.2.1. Evaluation of Q_y: The shear force in the transverse direction due to 20T axle load can be evaluated by using the graph shown in **Appendix-II**. For any other axle load, the value can be evaluated by multiplying the transverse shear obtained from the graph by the ratio of heaviest axle load in tonnes to 20 tonnes.

The design for transverse shear action both for flanges and web shall be carried out under Ultimate Limit State only.

5.2.2. Evaluation of global M_y and axial forces in the flanges: The global transverse moment M_y may be obtained and resolved as axial forces in the top and bottom flanges by using centre-to-center distance of flanges as lever arm.

5.2.3 Design of bottom and top flanges: When the global transverse moment M_y is sagging as shown in fig.1, the bottom flange shall be designed for an axial tensile force of $\frac{M_y}{h_e}$ and reversible bending moment of $M_v = \frac{Q_v}{2} x \frac{d}{4}$ and the top flange shall be designed for an axial compressive force of $\frac{M_y}{h_e}$ and reversible bending moment of $M_v = \frac{Q_y x d}{4}$ where Q_y is the transverse shear force, d is the diameter of the void, is the centre-to-centre distance of bottom and top flanges. In case of rectangular void, the top flange shall be designed for a reversible moment of $M_v = \frac{Q_y \times s}{4}$ of along with the axial compressive force and the bottom flange shall be designed for a reversible moment of $M_v = \frac{Q_y \times s}{4}$ along with the axial tensile force where S is distance between centre-to-centre of void. When the global transverse moment M_y is hogging the effects on the bottom and top flanges will get reversed.

5.2.4. Design of web

5.2.4.1. Rectangular voids: In case of rectangular voids, the web shall be designed for local bending moment of $M_v = \frac{Q_y S}{2}$. This reinforcement requirement shall be provided in the form of links, however, only one leg of such link may be considered to contribute to the required area of reinforcement. This area should be added to the required area to resist the longitudinal shear to give the total area of link reinforcement.

5.2.4.2. Circular Voids:

In case of circular voids, the occurrence of cracks initiating from the inside of void has to be prevented by limiting the maximum tensile stresses at the surface of the voids. The maximum tensile stresses and their angular location (ϕ) shall be computed using the graph shown in Appendix-III and it shall be ensured that the tensile stresses shall not exceed the allowable value of $0.7f_{ctm}$ where f_{ctm} and the allowable tensile stress both are in MPa. Following two cases have to be considered.

(i) Tensile stresses less than allowable tensile stresses

Cracking at the inside of a void would not occur in this situation and vertical reinforcement in the webs should be provided to resist the bending moment of $\left(Q_y \, S/h_e\right) \times \left(d/4\right)$

This reinforcement requirement shall be provided in the form of links; however, only one leg of such link may be considered to contribute to the required area of reinforcement. This area should be added to the required area to resist the longitudinal shear to give the total area of link reinforcement.

(ii) Tensile stresses more than allowable limits

In this case, cracking would occur at the inside of the void and inclined reinforcement shall be provided. The inclined reinforcement shall be provided to resist the tensile force of $T = \frac{Q_y S}{2 h_e \cos\alpha}$, where α is the slope of the inclined reinforcement (to the horizontal). This reinforcement shall be provided in the form of bars, and it shall be anchored by lapping with top and bottom flange reinforcement.

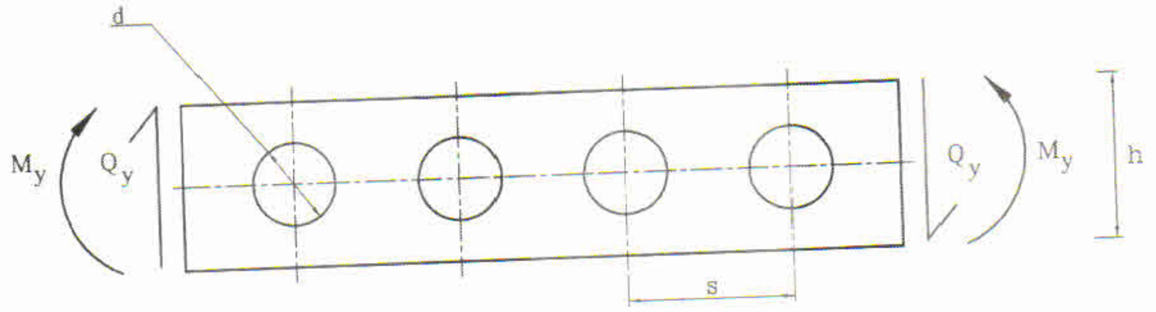
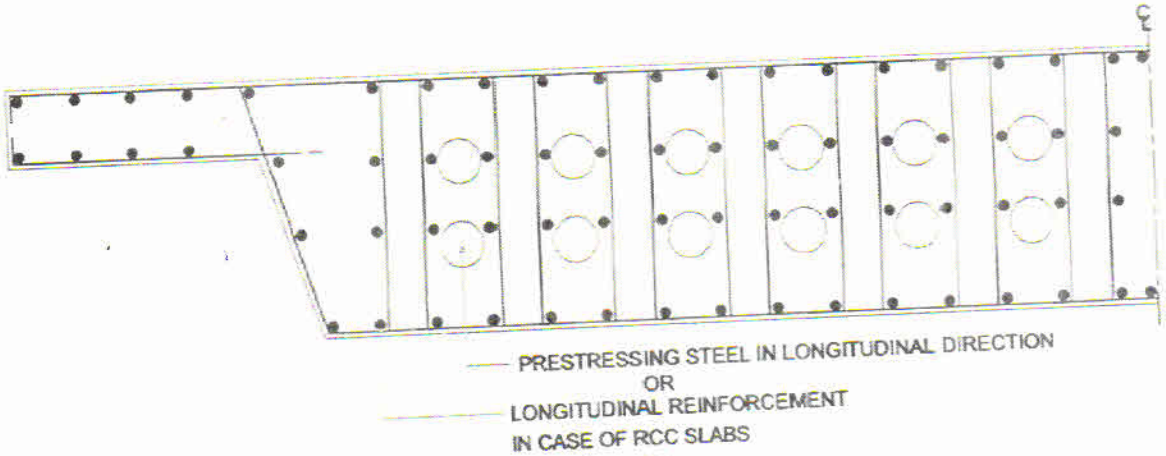
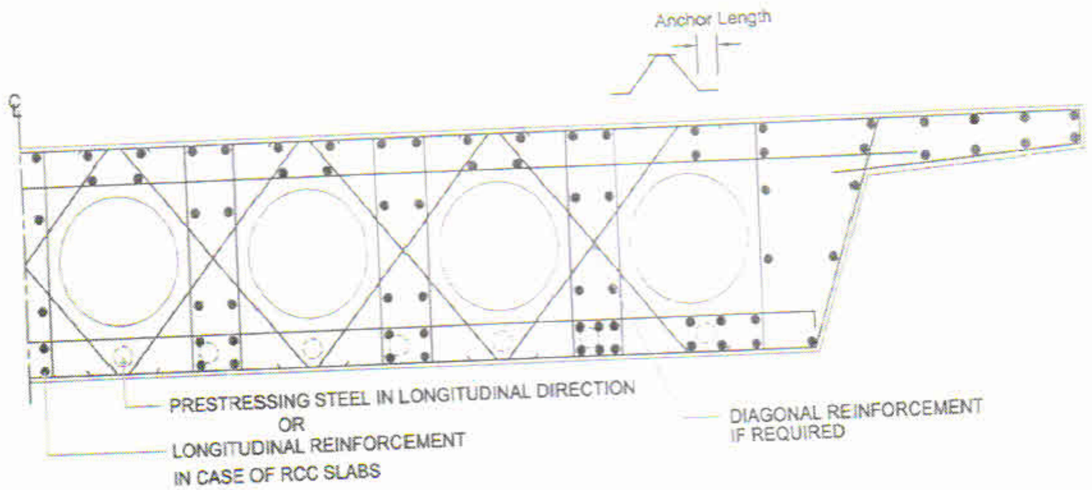


Fig. 1 Action on a Transverse Strip



Notes: 1. Reinforcements are as per design requirements.
2. The Sketch is indicative only.

Fig.2. Detailing of Reinforcement at Solid Section near Support



Notes: 1. Reinforcements are as per design requirements.
2. The Sketch is indicative only.

Fig.3. Detailing of Reinforcement at Solid Section near Support

Alternative to inclined reinforcement, one additional layer of bottom horizontal reinforcement in the top flange may be provided to resist the bending moment of $M_v = Q_y d \sin \phi/2$ at a distance of $d \sin \phi/2$ as shown in **Appendix - IV**.

6. GRILLAGE ANALOGY

Standard grillage programme can be used to analyse the structure. This method can be adopted for right, skew and curved bridges. The boundary conditions for the grillage elements shall be properly introduced based on the direction of placement of bearing.

The bending moment and shear forces will be taken as it is for longitudinal structural action. The global M_y bending moment is the moment obtained for the transverse beam of the grillage system. For transverse design, the corresponding design forces, such as, transverse shear, bending moment and axial forces in the flanges and bending moment and shear force in the web shall be evaluated as outlined under orthotropic plate method (para 5.2).

7. THREE DIMENSIONAL CONTINUUM ANALYSIS

Three dimensional continuum analysis shall take care of all structural action both in longitudinal and transverse directions with appropriate structural properties. This can be achieved by performing finite element analysis using stiffness approach by discretizing the structure into number of elements and having the displacement evaluated using the appropriate boundary conditions and loading. Discretization of the elements can be left to the designer. However, it shall only be surface element, such as, plate element, plate shell element, solid brick element with or without shear deformations.

The bending moment and shear forces will be taken as it is for longitudinal structural action. For transverse structural action, the corresponding design forces, such as, transverse shear, bending moment and axial forces in the flanges and bending moment and shear in the web shall be evaluated as outlined under the orthotropic plate method.

8. MINIMUM TRANSVERSE REINFORCEMENT IN FLANGES

The transverse reinforcement in flanges shall be provided in two layers, one layer closer to the crown of the void and other closer to the outer surface. The area of transverse reinforcement in compression flange should be lesser of 1000 mm^2/m (500 mm^2/m in each layer) or 0.7 per cent of the minimum flange area. The tension flange shall be provided with transverse reinforcement of 1500 mm^2/m (750mm^2/m in each layer) or 1 per cent of the minimum flange area whichever is lower.

For the purpose of calculation the reinforcement, the minimum flange area of each layer of concrete shall be arrived at by taking the thickness of concrete layer equal to twice the relevant cover plus the bar diameter.

9. MINIMUM LONGITUDINAL REINFORCEMENT

9.1. RCC Slabs

The minimum longitudinal tensile reinforcement in slab shall be as per Section 16 or 12 of IRC: 112 whichever gives higher reinforcement. The minimum reinforcement shall be provided according to method of analysis adopted. Curtailment of designed reinforcement shall be as per Section 16 of IRC: 112. In the compression zone the reinforcement shall be 0.13% area of concrete in compression.

9.2. Prestressed Slabs

The minimum longitudinal reinforcement in prestressed slabs shall be provided as follows:

a) Fully prestressed slabs where no tension is occurring.

0.13% of gross section area.

b) In partially prestressed slabs:

In the tension zone, it shall not be less than given in Section 16 or 12 whichever gives higher reinforcement. In the compression zone it shall not be less than 0.13% of area of concrete in compression.

10. DETAILING

Typical reinforcement detailing for voided slab in showing in **Fig.2**and **Fig.3.**

11. REFERENCES

In this publication reference to the following IRC, AASHTO Standards has been made. At the time of publication, the editions indicated were valid. All Standards are subject to revision and the parties to agreements based on these guidelines are encouraged to investigate the possibility of applying the most recent editions of the Standards.

11.1. Code and Specifications

1. IRC: 112 Code of practice for concrete Bridges.
2. AASHTO LRFD Bridge Design Specifications.

11.2. Papers & Publications

1. Baidar Bakht & Leslie G. Jaeger 'Bridge Analysis Simplified.
2. Derrick Beckett 'An Introduction to Structural Design'
3. Edmund C. Hambly 'Bridge Deck Behavior'
4. L.A. Clark 'Concrete Bridge Design to BS:5400'
5. G. Elliot, L.A. Clark and R.H. Symmons 'Test of Quarter Scale Reinforced Concrete Voided Slab Bridge' (Cement and Concrete Association, London)
6. L.A. Clark and P. Thorogood 'TransverseShear in RC Circular Voided Slabs' Institutionof Structural Engineers (UK), 2P' June, 1994.

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Appendix - I

ANALYSIS BY ORTHOTROPIC PLATE METHOD

Flexural Parameter

$$\theta = \frac{b}{L}\left(\frac{D_x}{D_y}\right)^{0.25}$$

Torsional Parameter

$$\alpha = \frac{D_{xy} + D_{yx} + D_1 + D_2}{2\left(D_x D_y\right)^{0.5}}$$

$$D_x = E_c\left(\frac{t^3}{12} - \frac{\pi\, t_v^4}{64 P_y}\right)$$

$$D_y = \frac{E_c t^3}{12}\left[1 - 0.95\left(\frac{t_v}{t}\right)^4\right]$$

$$D_{yx} = D_{xy} = \frac{G_c t^3}{6}\left[1 - 0.84\left(\frac{t_v}{t}\right)^4\right]$$

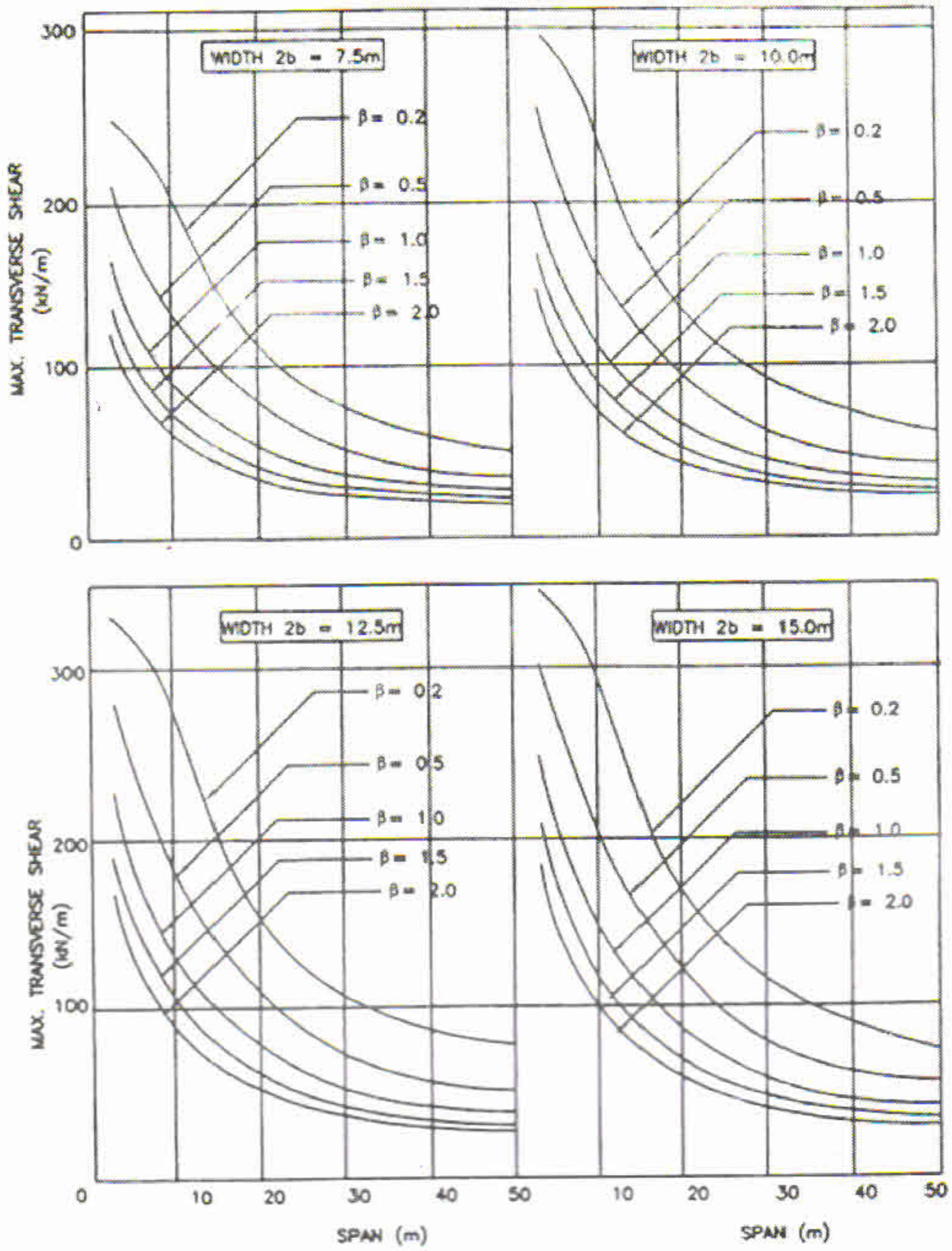
$$D_1 = \mu_c D_y;\ D_2 = \mu_c D_y$$

θ	=	Flexural parameter
α	=	Torsional parameter
b	=	½ the width of the equivalent orthotropic plate
L	=	Effective span
D_x	=	The longitudinal flexural rigidity per unit width
D_y	=	The transverse flexural rigidity per unit length
D_{xy}	=	The longitudinal torsional rigidity per unit width
D_{yx}	=	The transverse torsional rigidity per unit length
t	=	The thickness of slab
t_v	=	The diameter of the void
P_y	=	Spacing of the void
μ_c	=	Poission's ratio
D_1	=	The longitudinal coupling rigidity (which is the contribution of transverse flexural rigidity to Longitudinal torsional rigidity through Poisson's ratio) per unit width
D_2	=	The transverse coupling rigidity per unit length
E_c	=	Modulus elasticity of concrete
G_c	=	Shear modulus of concrete

In the absence of more accurate methods, the above expressions may also be used for those voided slab bridges in which the circular voids are not symmetrically placed between the top and bottom surfaces.

Appendix - II

MAXIMUM TRANSVERSE SHEAR FOR DIFFERENT PLATE WIDTHS

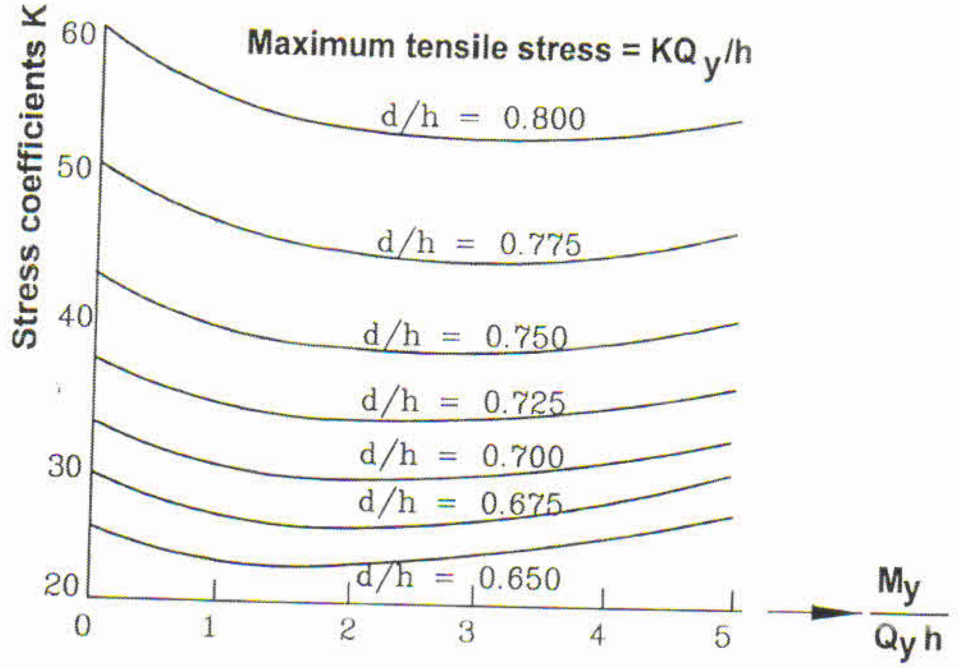


Maximum Transeverse Shear Intensity due to 20-Tonne Axle Load

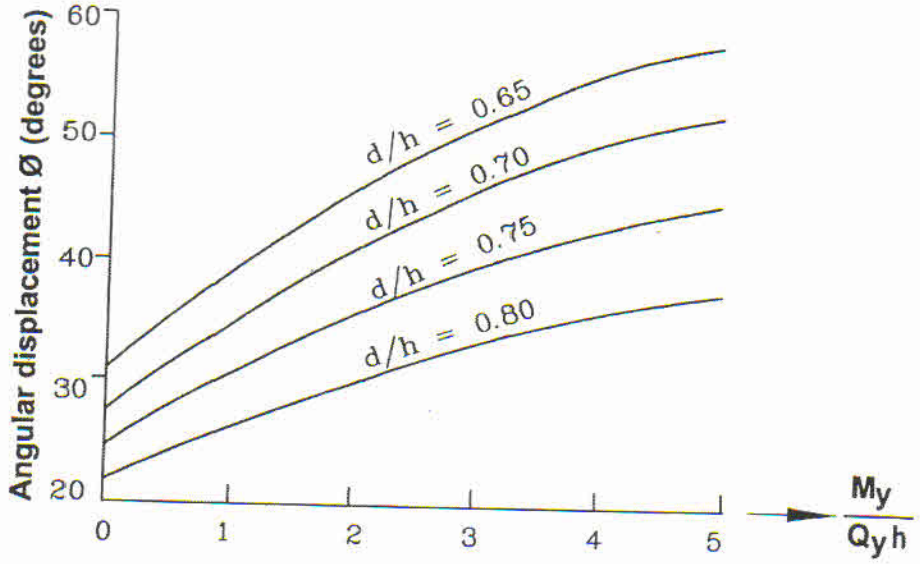
$$\beta = \pi\left(\frac{2b}{L}\right)\left(\frac{D_x}{D_{xy}}\right)^{0.5}$$

Appendix - III

MAXIMUM TENSILE STRESS AT DIFFERENT LOCATIONS



a) Maximum tensile stress at face of void



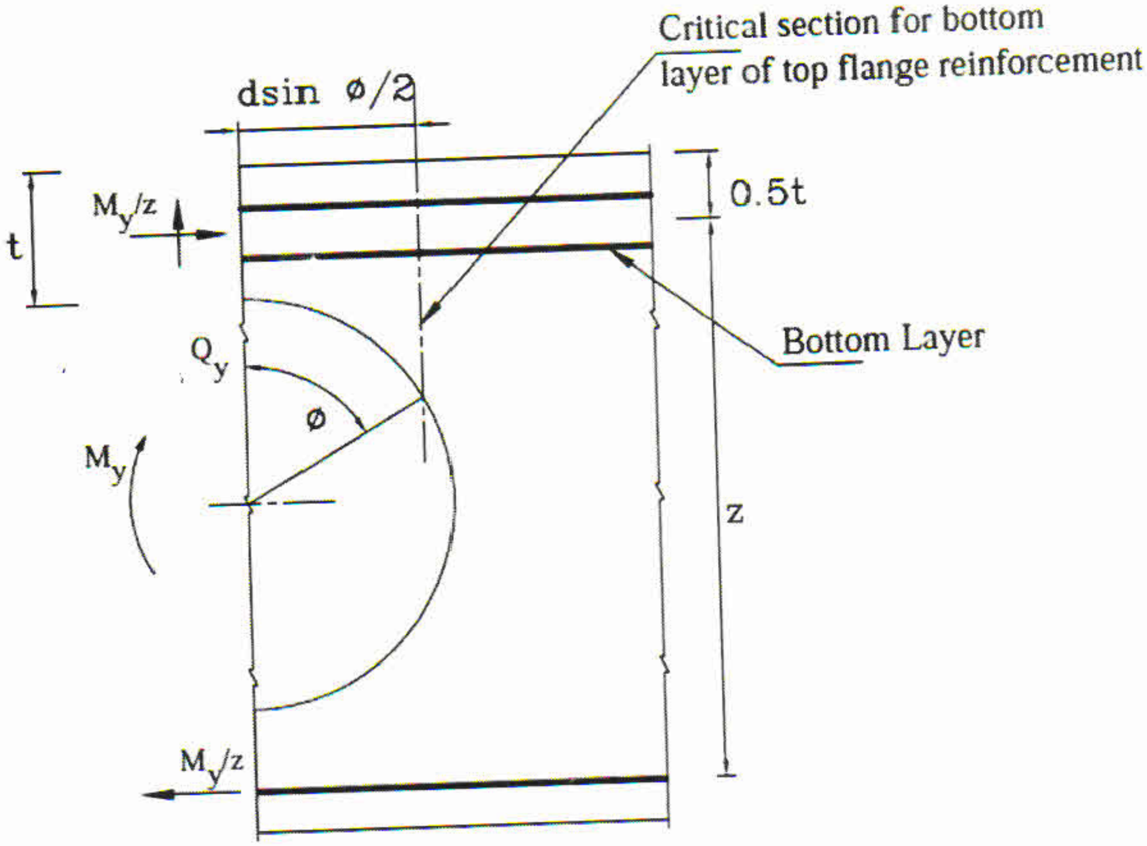
b) Location of maximum tensile stress

d = diameter of the void

h = height of the slab

Appendix - IV

SECOND LAYER OF FLANGE REINFORCEMENT



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