ABSTRACT

Determination of deflection in structure is important from serviceability criteria. Coidal provisions are available to calculate deflections in RC members in general. The codal provisions for calculation of short-term deflection in RC two-way slabs are based on the effective moment of inertia ($I_{eff}$). The $I_{eff}$ depends on the cracking moment ($M_r$) and maximum moment due to service load ($M_s$). Short-term deflections determined based on the provision for two-way RC slabs, are not comparable with experimental values. Even sometime negative deflection is obtained with the procedure. Present paper gives a method designated as Equivalent Load Method, in which equivalent load is calculated using Grashoff-Rankine formulae, and is considered to be acting on the slab. The deflection calculated using equivalent load method is found to be closer to experimental values. The negative deflection has been tackled in literature by applying a factor of 0.7 to cracking moment ($M_r$). The deflection thus calculated again differs considerably with the experimental values. In the paper, with the method, a procedure has been proposed in which instead of the factor 0.7 being applied to $M_r$, cracking moment of inertia is proposed to be used in place of effective moment of inertia. The deflection thus calculated has been found to be comparable with experimental results. Experimental data obtained and data available in literature have been used to validate the procedure. Experimental work has been carried out for two end conditions i.e. fixed supported and simply supported two-way RC slab. Six separate specimens were casted for both end condition of different thickness, sizes and for different loads.

KEYWORDS: Two-way slab, short-term deflection, Reinforced Concrete, Equivalent Load Method, Effective Moment of Inertia.

1. INTRODUCTION

In limit state design deflection of slab has to be within permissible limit to satisfy the serviceability criterion. Deflection calculation in RC slab is difficult, due to the non-homogeneity of the material, the effects of cracking, and the time-dependent nature of material. Deflection also depends upon the type of slab and support conditions. Evaluation of deflection has been dealt in the codes by restricting span to depth ratio. This procedure is limited to rectangular slabs subjected to uniformly distributed loads with standard boundary conditions and for a limited span. ACI 318 (Clause 9.5.3.3) prescribes the limiting span-to-depth ratio for different categories of two-way slabs depending upon the yield strength of the reinforcing steel, slab aspect ratio and beam-to-slab relative flexural stiffness. Similarly BS 8110 and AS 3600 give equations for limiting span-to-depth ratio for slabs with different boundary conditions subjected to uniformly distributed load. IS 456 recommends span-to-depth ratios for two-way solid slabs up to a span of 3.5m and span-to-depth ratios for all categories of two-way slabs is not clearly spelt out. No direct formula is given in any of the code for calculating deflections of two way slabs. Generalized formula is given in different codes but it does not specify the span and the loading to be considered to calculate deflections in two way slabs.

ACI 318:2005 and AS 3600:2001 recommends an ‘effective moment of inertia’ approach, to calculate short-term deflections while BS 8110:1997 uses a smeared crack approach. IS 456:2000 and Eurocode 2 have not made any recommendations with regard to the estimation of short-term and long-term deflections in RC two-way slabs.

Arthur et al., 1975 had studied the deflection of floor system including two-way slab based on the equivalent frame method and compared with ACI code. It has been shown that results obtained from equivalent frame method are compatible with those obtained from ACI code method. The deflection of two-way RC slabs is also studied by Scanlon and Murray, 1982 and it has been proposed to make use of standard beam deflection formulae for calculating the deflection of RC flexural members. Chang, 1996 had developed an equation for estimation of mid panel deflection of two-way slabs subjected to uniformly distributed load. Although, the resulting expression provides better representation of mid span deflection, than the other method, but it is not very popular. Sherif and Walter, 1998 had studied the deflection of flat slab. Full-scale models of continuous flat slab had been tested and observed the deflection in the slab.

Gilbert, 1999 calculated the deflection in slab based on the ACI-318 and using AS3600-1994. The deficiencies of the existing approaches have been demonstrated and suggestions for improving the procedure have been proposed. Gilbert, 2003 had also studied the behavior of RC flexural members under sustained service loads using simplified deflection calculation procedure and suggested the changes in the available method.

Kollar, 2004 had given the new simple method for deflection calculation of one-way RC slabs but the method is not applicable for two-way slabs. Nayak et al., 2004 had carried out the experimental studies on six one-way slabs and compared the various methods given by various codes. It has been shown that considerable disparities in the prediction of the cracking moment, moment-curvature and load-deflection behavior exist.

Sarkar, 2008 had studied the different codal provisions and calculated the values of deflection for two-way RC slabs using IS 456-2000. It had been shown that the code provisions are not adequate to estimate deflection of two-way RC slabs, and that there is an urgent need to modify to these provisions.
Varma and Pendharkar, 2010 presented a rational approach for estimating short-term deflection in two-way RC slabs. The approach has been designated as Equivalent Load Method. The deflections calculated by this approach are found to be more comparable with experimental values.

It can be seen from the above the review of literature that no direct formula is available in any of the code for calculating deflection of two way slabs with varied boundary conditions and loading conditions. In the present work an experimental study has been carried out to determine the deflections in two slabs having different boundary and loading conditions. The results from this experimental study are compared with the results obtained from Equivalent Load Method and by using ACI and IS codal provisions.

2. AVAILABLE CODAL PROVISIONS

2.1 Indian Standards Provision (IS 456-2000): Short-term deflection

\[
I_{eff} = \frac{I_r}{1.2 - \frac{M_r}{M} z \left(1 - \frac{x}{d}\right) b} \quad \text{but (1)}
\]

Where,
- \(I_r\) = Moment of inertia of the gross section about the centroidal axis,
- \(M_r\) = Cracking moment, equal to \(f_{cr} \times I_{gr}\) where \(f_{cr}\) is the modulus of rupture of concrete, \(I_{gr}\) is the moment of inertia of the gross section about the centroidal axis, neglecting the reinforcement, and \(y_r\) is the distance from centroidal axis of gross section, neglecting the reinforcement, to extreme fiber in tension, \(M\) = Maximum moment under service load, \(z\) = Lever arm, \(x\) = Depth of neutral axis, \(d\) = Effective depth, \(b_w\) = Breadth of web, and \(b\) = Breath of compression face.

\[
X_e = k_1 \left[\frac{X_1 + X_2}{2}\right] + (1 - k_1) X_0 \quad \text{(2)}
\]

Where \(X_e\) = Modified value of \(X\), \(X_1\), \(X_2\) = Values of \(X\) at supports, \(X_0\) = Value of \(X\) at mid span, \(k_1\) = Coefficient given in IS 456-2000, and \(X\) = Value of \(I_r, I_{gr}\) or \(M\), as appropriate.

Note – \(k_2\) is given by

\[
k_2 = \frac{M_1 + M_2}{M_{F1} + M_{F2}} \quad \text{(3)}
\]

where \(M_1, M_2\) = Support moments, and \(M_{F1}, M_{F2}\) = Fiffed end moments.

2.2 ACI 318M-05 of American Concrete Institute:
The American concrete institute does not explicitly recommend any particular procedure to calculate the short-term deflection of two-way RC slab, but it gives some suggestion to calculate deflections. This code does not explicitly recommend any particular procedure. But it is mentioned (Clause 9.5.3.4) that deflections shall be computed taking into account, size and shape of panel, conditions of support, and nature of restraints at the panel edges. It refers to the procedure for short-term deflection estimation of one-way slab, which uses the Branson’s effective moment of inertia (\(I_{eff}\)) equation, for deflection calculations of two-way slab also.

\[
I_{eff} = \left(\frac{M_r}{M_a}\right)^3 I_{gr} + \left[1 - \left(\frac{M_r}{M_a}\right)^3\right] I_r \quad \text{(4)}
\]

Where, \(M_a\) = Maximum moment at stage deflection is computed.

2.3 AS 3600:2001 of Standards Association Institute: This code recommends Branson’s equation (Clause 9.3.3) for calculation of deflection of two-way slabs carrying uniformly distributed loads. According to Australian Standards the deflection calculations for a rectangular two-way slab supported on four sides on unyielding supports can be calculated by considering it as a prismatic beam of unit width through the centre of the slab, spanning in the short direction, with the same conditions of continuity as the slab in that direction and with the load distributed so that the proportion of the load carried by the beam is given by

\[
L_v^4 = \frac{\alpha L_s^4}{(\alpha L_s^4 + L_y^4)} \quad \text{(5)}
\]

Where,
- \(L_v\) = Effective spans in short direction.
- \(L_y\) = Effective spans in long direction.
- \(\alpha\) = Constant of proportionality depending on the slab-edge condition given in AS 3600-2001.

2.4 BS 8110:1997 of British Standards Institute: British code suggested equivalent beam method to calculate the deflection for two-way RC slabs. Clause 3.7.2 of BS 8110:1997 describes that the deflection of two-way slabs is best dealt by using the ratios of span to effective depth. But it has been suggested that if the calculation of the deflection of a two-way slab is essential it can be done by equivalent beam method. A slab strip of unit width spanning across each short dimension of the slab can be chosen as shown in Figure 1. For continuous beam deflection shall be calculated using the values \(\kappa\) on the assumption that the maximum moment along the strip is the maximum bending moment of the slab. The bending moment along the strip should preferably be obtained from an elastic analysis of the slab but may be assessed approximately by taking 70% of the moments used for the collapse design. The deflection of the strip is calculated as though it were a beam. A smeared crack approach is recommended to calculate the deflection. In this method a linearly varying tensile stress distribution, as shown in Figure 1 has been assumed. The tensile stress in the concrete at the level of steel is limited to 1 MPa for short-term deflection.

\[
k = \frac{f_s}{(d - x)E_s} \quad \text{(6)}
\]

Figure 1: Concrete stress distribution used for deflection calculation (BS 8110)

Using the above stress distribution, the depth of neutral axis \((x)\) and the steel stress \((f_s)\) are calculated at certain nominated sections by considering the equilibrium conditions. The resulting curvature \(\kappa\) is calculated using the following formula:

\[
\kappa = \frac{f_s}{(d - x)E_s}
\]
where, \( f_s \) = estimated design service stress in tension reinforcement, 
\( E_s \) = modulus of elasticity of reinforcement.

3. METHODOLOGY

Codal provisions and literatures show that, there is no method or formula available to calculate short-term deflection for two-way RC slabs. And also it is not clearly mention in any code which span and loading take in to account to calculate deflection. Author proposed a procedure designated as Equivalent Load Method. In which, equivalent load have been take into account to calculate deflection. Author clearly mention in any code which span and loading method or formula available to calculate short-term deflection.

Short-term deflection for fixed supported and simply supported two-way RC slabs has been calculated using Grashoff-Rankine formula. The loads calculated along the two spans have been calculated using equivalent load method. The loads calculated along longer span and along shorter span are given by following equations:

\[
w_x = \frac{w}{1 + \left( \frac{l_x}{l_y} \right)^4}
\]

\[
w_y = \frac{w}{1 + \left( \frac{l_y}{l_x} \right)^4}
\]

Deflection formula for fixed supported and for UDL.

\[
\varphi_{x1} = \frac{1}{384 \, E_{I_{ef}}} \frac{w_{xs}^4}{l_x}
\]

Deflection formula for simply supported and for UDL.

\[
\varphi_{x1} = \frac{5}{384 \, E_{I_{ef}}} \frac{w_{xs}^4}{l_x}
\]

Where, \( w = \) Uniform distributed load, \( l_x = \) longer span, \( E_c = \) Modulus of elasticity of concrete, and \( I_{ef} = \) Effective moment of inertia as per Eqn. 1.

4. CASE-IV: Deflection calculation by ACI method considering total load along shorter span.

Deflection formula for fixed supported and for UDL.

\[
\varphi_{y2} = \frac{1}{384 \, E_{I_{ef}}} \frac{w_{ys}^4}{l_y}
\]

Deflection formula for simply supported and for UDL.

\[
\varphi_{y2} = \frac{5}{384 \, E_{I_{ef}}} \frac{w_{ys}^4}{l_y}
\]

5. CASE-V: Deflection calculation by Equivalent load along longer span.

Deflection formula for fixed supported and for UDL.

\[
\varphi_{x3} = \frac{1}{384 \, E_{I_{ef}}} \frac{w_{xs}^4}{l_x}
\]

Deflection formula for simply supported and for UDL.

\[
\varphi_{x3} = \frac{5}{384 \, E_{I_{ef}}} \frac{w_{xs}^4}{l_x}
\]

6. CASE-VI: Deflection calculation by Equivalent load along longer span.

Deflection formula for fixed supported and for UDL.

\[
\varphi_{y4} = \frac{1}{384 \, E_{I_{ef}}} \frac{w_{ys}^4}{l_y}
\]

Deflection formula for simply supported and for UDL.

\[
\varphi_{y4} = \frac{5}{384 \, E_{I_{ef}}} \frac{w_{ys}^4}{l_y}
\]

4. EXPERIMENTAL DETAILS

The experimental work was performed consisted of casting and testing of twelve two-way RC slabs, under the uniformly distributed load. Out of these twelve slabs constructed, six slab specimens were with fixed support and the remaining six were with simple support, naming TWFS-1 to TWFS-6 for two-way fixed support slabs and TWSS-1 to TWSS-6 for two-way simply support slabs. The experimental set-up are shown in Figure 2. The size, thickness and loading for the above mentioned fixed supported and simply supported two way RC slab specimens are shown in Table 1 and Table 2 respectively. The objective of the experiment was to cast the two-way RC slabs of different dimensions and to test their short-term mid span deflection for uniformly distributed load. M-20 concrete mix was used for all the test specimens. The reinforcement consisted of 6mm diameter bars spacing 200mm in both directions.
for the slabs TWFS-1, TWFS-4, TWSS-1, and TWSS-4. The reinforcement consisted of 6mm diameter bars at a spacing of 180 mm in both direction was provided in slabs TWFS-2, TWFS-5, TWSS-2 and TWSS-5. The reinforcement for TWFS-3, TWFS-5, TWFS-3, and TWSS-6 slabs consists of 6mm diameter bars at 170mm in both directions. The concrete cover varied according to the depth of the slabs, as is shown in Table 1 and Table 2 respectively for simply supported and fixed supported RC two-way slabs. While constructing these slabs, for simulation of simply support ends, they were supported on three sides on brick masonry wall and on fourth side the slab were supported on precast in-situ RC beam. For simulating fixed end condition the 100 mm thick and 600 mm high masonry was constructed all along the periphery of the slab so as to effectively held the ends of slab. In order to ensure that the ends are effectively held in position, glass strips of 4mm thick and 80mm x 200mm have been provided along the edge on the wall at a spacing of 150 mm c/c as shown in Figure 3. Mid span deflection in twelve number of slabs has been observed under static load conditions. In these testing, load has been applied on the slabs fourteen days after their casting. In the experimental three load intensities were applied viz. 10 kN/m$^2$, 7.5 K/N/m$^2$, and 6 KN/m$^2$ by using uniform layer of oven dried sand over the slabs of weight density of 25.7 KN/m$^3$ with three respective thicknesses of 13 cm, 11.1 cm and 9.82 cm. In the loading simulation process impact loading was carefully avoided and the distribution of sand was absolutely uniform. During the load distribution the dial gauges were connected at the mid span of all the slabs to deflections. This experimental work was performed under the shed to protect the construction work from rain water. Also the dimensions of slab, reinforcement, gravity and depth of sand for loading were carefully supervised in order to attain proper results.

Figure 2: Experimental Set-up

![Figure 2: Experimental Set-up](image)

Figure 3: Fixidity at Support

![Figure 3: Fixidity at Support](image)

| Sr. No. | Longer Span in mm | Shorter Span in mm | Overall Depth in mm | Total Load in KN/Sq.M | Name of Slab |
|---------|------------------|--------------------|---------------------|-----------------------|-------------|
| 1       | 1750             | 1200               | 90                  | 10                    | TWFS-1      |
| 2       | 1650             | 1150               | 80                  | 7.5                   | TWFS-2      |
| 3       | 1525             | 1525               | 70                  | 6                     | TWFS-3      |
| 4       | 1750             | 1200               | 70                  | 10                    | TWFS-4      |
| 5       | 1650             | 1150               | 60                  | 7.5                   | TWFS-5      |
| 6       | 1525             | 1525               | 50                  | 6                     | TWSS-6      |

Table 1: Size and Loading of Slab for Fixed Supported Two-Way Slab

| Sr. No. | Longer Span in mm | Shorter Span in mm | Overall Depth in mm | Total Load in KN/Sq.M | Name of Slab |
|---------|------------------|--------------------|---------------------|-----------------------|-------------|
| 1       | 1750             | 1200               | 90                  | 10                    | TWSS-1      |
| 2       | 1650             | 1150               | 80                  | 7.5                   | TWSS-2      |
| 3       | 1525             | 1525               | 70                  | 6                     | TWSS-3      |
| 4       | 1750             | 1200               | 70                  | 10                    | TWSS-4      |
| 5       | 1650             | 1150               | 60                  | 7.5                   | TWSS-5      |
| 6       | 1525             | 1525               | 50                  | 6                     | TWSS-6      |

Table 2: Size and Loading of Slab for Simply Supported Two-Way Slab

5. RESULTS AND DISCUSSION

1. The analytically calculated values of deflection in fixed supported two way-RC Slabs are tabulated in Table 3 and Table 4 for longer and shorter span respectively.

2. Similarly, Table 5 and Table 6 show results for simply supported two-way RC Slabs for longer and shorter span respectively.

3. These analytical results have been compared with experimental values of deflection..
measured at mid-span of the slabs that is also tabulated in the above mentioned tables.

4. The experimental results are also available in literature (Kulkarni 1976, Hung and Nawy 1971). They had worked on unyielding fixed supported and simply supported two-way RC slabs. The overall size of fixed supported slabs was 2314 mm×2314 mm×63.5 mm with different loading i.e. 20 KN/m², 30 KN/m², 40 KN/m², 50 KN/m², 60 KN/m², 70 KN/m², 80 KN/m², 90 KN/m² and 100 KN/m². And for simply supported slab overall size was 1780mm×1270mm×50mm with different loading i.e. 15 KN/m², 30 KN/m², 45 KN/m², and 60 KN/m². These experimental results have been compared with analytically calculated values as per proposed Equivalent Load Method and code provisions of IS, ACI and tabulated in Table 7 and the comparison also shown in Figure 4 for fixed supported slabs and for simply supported two-way slabs results are tabulated in Table 8 and Table 9 and shown in Figure 5 and Figure 6 along longer span and shorter span respectively.

Table 3: Deflection in mm along longer span for Fixed Supported Two-way RC Slab

| Sr. No. | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------|--------|-------------------|---------------|
| By L    | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 2.17      | 0.85   | 0.96             | 0.90          |
| 2       | 1.95      | 0.63   | 0.95             | 0.76          |
| 3       | 1.90      | 0.63   | 0.95             | 0.76          |
| 4       | 1.89      | 0.23   | 0.95             | 0.76          |
| 5       | 6.09      | 1.30   | 0.95             | 0.76          |
| 6       | 7.86      | 1.30   | 0.95             | 0.76          |

Table 4: Deflection in mm along shorter span for Fixed Supported Two-way RC Slab

| Sr. No. | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------|--------|-------------------|---------------|
| By L    | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 4.02      | 0.99   | 1.79             | 1.70          |
| 2       | 4.60      | 0.85   | 1.79             | 1.70          |
| 3       | 4.90      | 0.63   | 1.79             | 1.70          |
| 4       | 2.89      | 0.23   | 1.79             | 1.70          |
| 5       | 6.09      | 1.30   | 1.79             | 1.70          |
| 6       | 7.86      | 1.30   | 1.79             | 1.70          |

Table 5: Deflection in mm along longer span for Simply Supported Two-way RC Slab

| Sr. No. | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------|--------|-------------------|---------------|
| By L    | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 2.27      | 0.85   | 0.96             | 0.90          |
| 2       | 1.95      | 0.63   | 0.95             | 0.76          |
| 3       | 1.90      | 0.63   | 0.95             | 0.76          |
| 4       | 1.89      | 0.23   | 0.95             | 0.76          |
| 5       | 6.09      | 1.30   | 0.95             | 0.76          |
| 6       | 7.86      | 1.30   | 0.95             | 0.76          |

Table 6: Deflection in mm along shorter span for Simply Supported Two-way RC Slab

| Sr. No. | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------|--------|-------------------|---------------|
| By L    | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 4.02      | 0.99   | 1.79             | 1.70          |
| 2       | 4.60      | 0.85   | 1.79             | 1.70          |
| 3       | 4.90      | 0.63   | 1.79             | 1.70          |
| 4       | 2.89      | 0.23   | 1.79             | 1.70          |
| 5       | 6.09      | 1.30   | 1.79             | 1.70          |
| 6       | 7.86      | 1.30   | 1.79             | 1.70          |

Table 7: Deflection in mm along longer span for Fixed Supported two-way slab

| Sr. No. | Load on slab in KN/m² | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------------------|------------|--------|-------------------|---------------|
|        |                        | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 20                     | 8.02      | 9.80   | 2.05             | 2.05          |
| 2       | 30                     | 13.98     | 14.87  | 3.02             | 3.02          |
| 3       | 40                     | 19.94     | 19.86  | 3.02             | 3.02          |
| 4       | 50                     | 25.91     | 24.84  | 3.02             | 3.02          |
| 5       | 60                     | 31.87     | 29.81  | 3.02             | 3.02          |
| 6       | 70                     | 37.84     | 24.79  | 3.02             | 3.02          |
| 7       | 80                     | 43.80     | 29.76  | 3.02             | 3.02          |
| 8       | 90                     | 49.77     | 44.73  | 3.02             | 3.02          |
| 9       | 100                    | 55.73     | 40.70  | 3.02             | 3.02          |

Table 8: Deflection in mm along longer span for simply supported two-way slab

| Sr. No. | Load on slab in KN/m² | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------------------|------------|--------|-------------------|---------------|
|        |                        | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 15                     | 34.06     | 35.26  | 3.02             | 3.02          |
| 2       | 20                     | 38.5      | 32.70  | 3.02             | 3.02          |
| 3       | 45                     | 122.13    | 109.38 | 3.02             | 3.02          |
| 4       | 60                     | 156.73    | 145.96 | 3.02             | 3.02          |

Table 9: Deflection in mm along shorter span for simply supported two-way slab

| Sr. No. | Load on slab in KN/m² | By IS Code | By ACI | By Equivalent Load | By Experiment |
|---------|------------------------|------------|--------|-------------------|---------------|
|        |                        | By L₀     | By L₀  | By L₀            | By L₀         |
| 1       | 15                     | 6.76      | 7.46   | 3.02             | 3.02          |
| 2       | 20                     | 18.12     | 18.33  | 3.02             | 3.02          |
| 3       | 45                     | 29.47     | 26.10  | 3.02             | 3.02          |
| 4       | 60                     | 48.82     | 37.69  | 3.02             | 3.02          |
6. CONCLUSION

The result shows that analytically calculated values of deflection as per IS and ACI codes have been found unlike under the same parameters, and also these values are quite different from experimental results, while deflection calculated by proposed method are very close to the experimental results.

The overall conclusions of studies and observations have been made and are as follows:

- Experimental results are not supporting the results obtained by standard codes.
- Deflections for longer and shorter span are unequal for the same slab and under the same parameters with standard codes.
- There is inadequate information given in all the standard codes for calculating deflection of two ways RC.
- Sometimes deflection has been come out impracticable and infeasible under downward loading.
- The negative deflection could have been avoided by cracking moment of inertia \( I_{cr} \) is used in place of effective moment of inertia \( I_{eff} \).
- Deflections calculated by proposed equivalent load method agree with the experimental results.

7. NOMENCLATURE

\[ I_{eff} = \text{Effective moment of inertia}, \]
\[ I_{g} = \text{Gross moment of inertia}, \]
\[ E_{c} = \text{Modulus of elasticity of concrete}, \]
\[ f_{ck} = \text{Characteristic strength of concrete}, \]
\[ f_{cr} = \text{Modulus of rupture of concrete}, \]
\[ M_{cr} = \text{Cracking moment per unit width}, \]
\[ M_{xx} = \text{Maximum moment in the short span}, \]
\[ M = \text{Maximum moment under service load}, \]
\[ z = \text{Lever arm}, \]
\[ x = \text{Depth of neutral axis}, \]
\[ d = \text{Effective depth}, \]
\[ b_{w} = \text{breadth of web}, \]
\[ b = \text{Breath of compression face}, \]
\[ \delta = \text{deflection of the plate/slab}, \]
\[ l = \text{longer span length}, \]
\[ w = \text{uniform transverse load}. \]

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