DEFLECTION CONTROL MEASURES FOR SLABS AS PER IS : 456-1978

By

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SYNOPSIS

In order to satisfy the limit state of serviceabilty in deflection, IS : 456-1978 prescribes the procedure for computing the short term and long term deflections and to limit them within the prescribed limits. In the absence of such calculations, code recommends certain span/depth values for use in design and assumes that the deflection will remain within the permitted limits. Since, the span to depth ratios given by this code differ considerably from those recommended by IS : 456-1964 and appear to be on highly conservative side, span to depth ratios have been computed by carrying out the actual deflection calculations on the basis of the procedure recommended by IS : 456-1978. From this study, it has become evident that the L/d ratios prescribed by IS : 456-1978 are too conservative and lead to an uneconomical design. On the basis of this study, final span / depth ratios have been recommended for adoption in the prcatical design.

NOTATIONS AND SYMBOLS

The symbols used in the paper have following meanings unless otherwise mentioned :

a = long span of the slab

b = short span of the slab

d = effective depth of the slab

D = overall depth of the slab

E_c = short term modulus of elasticity$=5700\sqrt{f_{ck}}$ in N/mm^2

f_{ck} = characteristics strength of concrete in N/mm^2

f_{cr} = modulus of rupture of concrete$=0.7\sqrt{f_{ck}}$ in N/mm^2

I_{eff} = effective moment of inertia in mm^4 per unit width

I_{gr} = moment of inertia of the gross section excluding reinforcement in mm^4 per unit width

I_r = moment of inertia of cracked section in mm^4 per unit width

L = short span of the slab in m

m = modular ratio

M = maximum moment under service loads in kN-mm per unit width

M_r = cracking moment$=f_{cr}\, I_{gr}/y_t$ in kN-mm per unit width

r = aspect ratio$=(a/b)$

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w = the intensity of working loads in N/mm^2
x = depth of neutral axis in mm
y_t = distance from centroidal axis of gross section, neglecting the reinforcement to extreme fibre in tension in mm
z = lever arm in mm
θ = the creep coefficient

1. INTRODUCTION

For the rational design of reinforced concrete members, IS : 456-1978 has incorporated the limit state method of design. This code has identified various limit states amongst which the limit state of serviceability deserves special attention because of the need to limit the deflections at service loads. The code specifies certain L/d ratios for achieving control of deflection for beams and one way slabs in clause 22.2.1 and for two way slabs in clause 23.1. The L/d values prescribed in this code are on the lower side as compared to those given by IS : 456-1964, thus requiring larger thickness of slab which leads to a conservative design as compared to the old code. The L/d values, particularly for slabs, appear to be too conservative for some loading classes. In fact, the L/d ratio shall be a function of load, aspect ratio and the boundary conditions of the slab. Since the L/d ratios specified by the code are too stringent, actual deflection calculations become necessary to satisfy the deflection requirements as per clause 22.2 of the code. The procedure recommended by the code[1] for computations of deflections in its Appendix B leads to an iterative process which is time consuming.

So far. the work done in the direction of carrying out actual deflection calculations by using the code formulae has been rather insignificant. SP : 16 (S&T)-1980[2] demonstrates the use of the formulae given in the code[1] by computing deflection of one beam but ends up with the recommendations for the provision of camber. This does not satisfy the codal requirements. Had the provison of camber been the acceptable solution, any thickness could be adopted for the slab design and undesirable deflections could be avoided by providing suitable camber. In that case, there was no necessity of prescribing L/d ratio or the limiting deflection by the IS code. The information, thus, provided by SP : 16-1980 in this respect is misleading and insufficient for an actual practical design. Santhakumar[3] has presented theoretical basis for justifying the adoption of expressions for short term and long term deflection calculations in the code, but again there is nothing in his paper for the guidance to a designer. Ghanekar[4] has given slab thicknesses for design purposes assuming that the deflection requirements of the code are satisfied as these are based on L/d ratios prescribed by the code. Actual deflection calculations are not carried out and therefore the values given in this paper cannot be justified.

1.1. Object of Study

From the preceeding review, it is evident that for practical design it becoms desirable to have a more realistic estimate of span to depth ratios for the slabs with various slab parameters for the different loading cases on the basis of actual deflection computation.

To meet the above objective, short term and long term deflections in the slabs have been computed according to the procedure prescribed by IS : 456-1978. The following parameteric variation is considered for this study —

i) Weight of floor finishes has been taken as 1.0 kN/m² in addition to the self weight of slabs.

ii) Live load is taken from 2.0 kN/m² to 9.0 kN/m². The values considered are 2.0, 3.0, 5.0, 7.0 and 9.0 kN/m² respectively.

iii) Aspect ratio is varied from 1.0 to 2.0.

iv) Short span is taken from 2.0 m to 10.0 m.

v) Slabs do not have any compression reinforcement.

vi) Effective cover is taken as 20 mm.

vii) Concrete grade is M15 and steel grade is Fe415.

This Paper presents the results obtained from the above study. The checks on limiting the deflection in slabs have been applied as per clause 22.2 of the code. Explicit values of span to overall depth ratio have been given for the slabs with various boundary conditions, aspect ratios, loading classes and spans. The final span to(overall)depth ratios recommended in this paper are slightly on the conservative side. Thus, with the adoption of these L/D values in the practical designs, the limits imposed by the code on deflection are automatically satisfied and no separate checks for deflection requirements need be made. Slab thickness obtained on the basis of these values shall be sufficient to carry the design loads.

2. LIMITATIONS IN THE CODE PROVISIONS FOR DEFLECTION CONTROL

The values of L/d recommended by IS : 456-1978[1] for controlling deflections are independent of the loading class and aspect ratio while in actual practice, permissible thickness d from deflection considerations depends upon these factors.

Computation of deflection at working loads is quite a tedious job as the RCC members develop cracking even during service loads. The extent of cracking varies along the span corresponding to the variation of bending moment. As such moment of inertia of cracked section becomes variable and to estimate its variation is a complicated task. To overcome this difficulty, IS code[1] prescribes an empirical expression for computing effective value of moment of inertia, I_{eff} which is assumed to be uniform all along the span. The expression given in the code is particularly suitable for beams and for one way slabs. Its use for two way slabs does not appear to be justified as the cracking is confined only in the limited width of slab depending upon the load distirbution along the two spans, while in the beam, whole width of beam is cracked.

Moreover, percentage of steel used in the two directions of slab is different due to which the behaviour of slab in the two directions is not indentical. The expression for I_{eff} fails to account for this difference and therefore, it does not represent the true behaviour of slab in deflection calculations.

3. BASIC APPROACH FOR DEFLECTION CALCULATIONS

In spite of all the limitations indicated above, code specifications are used as such for computing the deflections, which are divided into three categories as described below —

(i) Short Term Elastic Deflections

Short term elastic deflections are computed for the total working loads which include self weight of slab + weight of floor finishes + live load on the slab. Expressions given by Bares[5] have been used for computing the maximum elastic deflection of slab. Value of Poisson's ratio of concrete is taken as 0.15.

(ii) Long Term Deflections due to Shrinkage

(a) Coefficint K_3 for determining the deflection due to shrinkage is taken corresponding to the support conditions across the short span.

(b) Percentage of reinforcing steel P_t is taken between 0.25 and balanced percentage required for computing the value of K_4.

(c) The shrinkage strain is taken equal to 0.03 per cent[1]. At the time of laying of floor finishes i.e. after 2 months of the casting of the slab, 62.8 per cent of this strain would have already taken place[6].

(iii) Long Term Deflection due to Creep

It is assumed that the slab will carry its self weight after the removal of formwork completely i.e. after 28 days of casting and the weight due to floor finishes will come after completing the finishing works like plastering of roof and walls etc. i.e. after 2 months from the date of casting of slab. Corresponding values of creep coefficients are taken as 1.6 and 1.48 respectively[1].

4.1. Computational Procedure

For a given set of support conditions, value of short span, aspect ratio, loading class following sequence of computations has been adopted.

(i) Determine the limit state design moment Mu in the slab using the moment coefficients given in Table 22 of the code.

(ii) Determine the balanced thickness required for Mu.

(iii) Compute the corresponding area of reinforcement.

(iv) Compute short term elastic deflection by using the expression

$$\delta = KwL^4/(E_c\, I_{eff}) \qquad \ldots (1)$$

where, K is the deflection coefficient which depends upon boundary conditions and aspect ratio of slab, and is taken from the book by Bares[5].

and, $$I_{eff} = I_r / \left\{ 1.2 - \frac{Mr}{M} \cdot \frac{z}{d} \left(1 - \frac{x}{d} \right) \right\} \qquad \ldots (2)$$

while $I_r \leqslant I_{eff} \leqslant I_{gr}$

(v) Long term deflection due to shrinkage a_{es} is given by,

$$a_{cs}=K_3 \Psi_{cs} L^2 \quad \ldots (3)$$

where $$\Psi_{cs}=K_4 \cdot \frac{\varepsilon_{cs}}{D} \quad \ldots (4)$$

and $$K_4=0.72\sqrt{P_t} \quad \ldots (5)$$

(vi) Long term deflection due to creep $a_{cc(perm)}$ is obtained as,

$$a_{cc(perm)}=a_{i,cc(perm)}-a_{i(perm)} \quad \ldots (6)$$

where $a_{i,cc(perm)}$ is the initial plus creep deflection due to permanent loads and it is obtained by the expression for δ with the modified values of modulus of elasticity E_{cm} and modular ratio m_m.

Modified modulus of elasticity, $$E_{cm}=\frac{E_c}{1+\theta} \quad \ldots (7)$$

Modified modular ratio $$m_m=200000/\{E_c/(1+\theta)\} \quad \ldots (8)$$

$a_{i(perm)}$ is the short term deflection due to permanent load and it is obtained by expression (1) using E_c.

(vii) Determine total deflection δ as

$$\delta_T=\delta+a_{cs}+a_{cc(perm)} \quad \ldots (9)$$

(viii) Calculate the long term deflection δ_L due to creep and shrinkage which will occur after 2 months of casting.

(ix) Check the values δ_T and δ_L against the permissible values of deflection as specified by the code[1]. If the limits are satisfied, go to step no. (xi). If the limits are not satisfied, go to the next step.

(x) Increase the thickness of slab by 5 mm. Modify the design loads and design moment Mu and compute the area of reinforcing steel. Compute deflections by repeating steps (iv) through (ix).

(ix) Determine the L/D ratio.

4. OBSERVATIONS AND DISCUSSION

4.1. From the computational results obtained for a wide range of spans, aspect ratios and loadings, it is observed that the condition of limiting the total long term deflection due to creep and shrinkage (after laying of floor finishes and erection of partition walls to span/350 or 20 mm whichever is less, does not govern the thickness of the slab anywhere.

4.2. The computed L/D ratios for slabs with simply supported edges upto 5 m span are nearly constant for a particular loading class. For square slabs, these values for the different loading classes are as given below;

Live load (in kN/m²)	2.0	3.0	5.0	7.0	9.0
L/D	36	34	32	30	29

These values will hence forth be termed as basic values of L/D and their variation is shown in Fig. 1. The basic value of L/D for a loading class gets

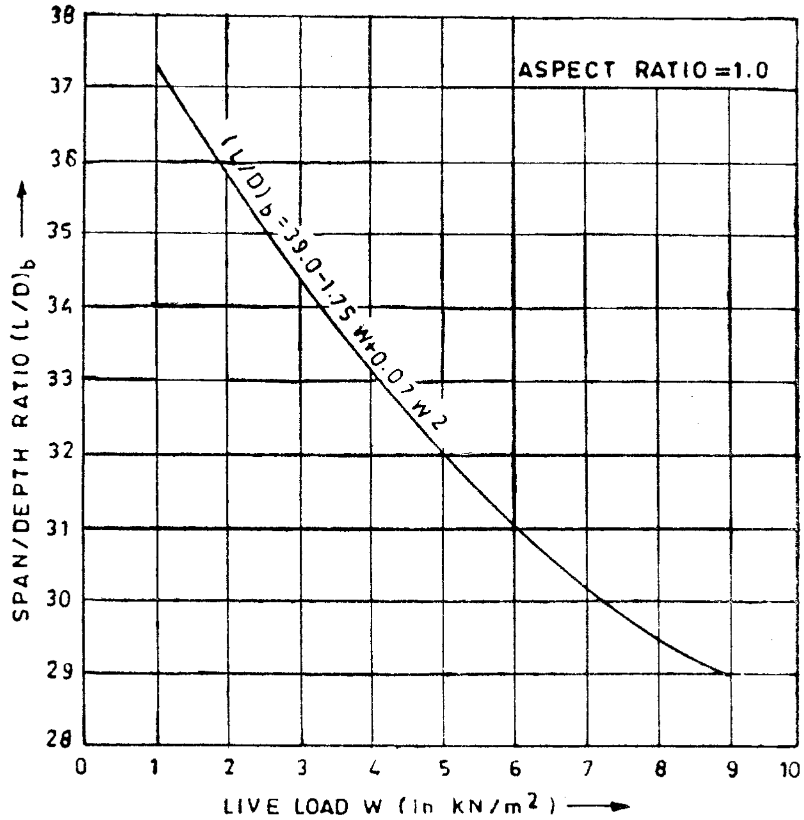

Fig. 1. Basic values of span/depth ratio $(L/D)_b$ for slabs with all edges simple supported

modified with aspect ratio and with changes in the boundary conditions as shown below:

(a) **Effect of Aspect Ratio**

Variation in the basic values of L/D for two way slabs with respect to aspect ratio is nonlinear, e.g., for 300 loading class it is given below:

Aspect ratio	1.0	1.2	1.5	1.8	2.0
L/D	34	31.5	28.0	26.5	26.0

This variation is true for other loading classes also and therefore effect of aspect ratio on basic value of L/D is independent of the value of live load on the slab. The above data has been approximated by a curve of second degree, shown in Fig. 2.

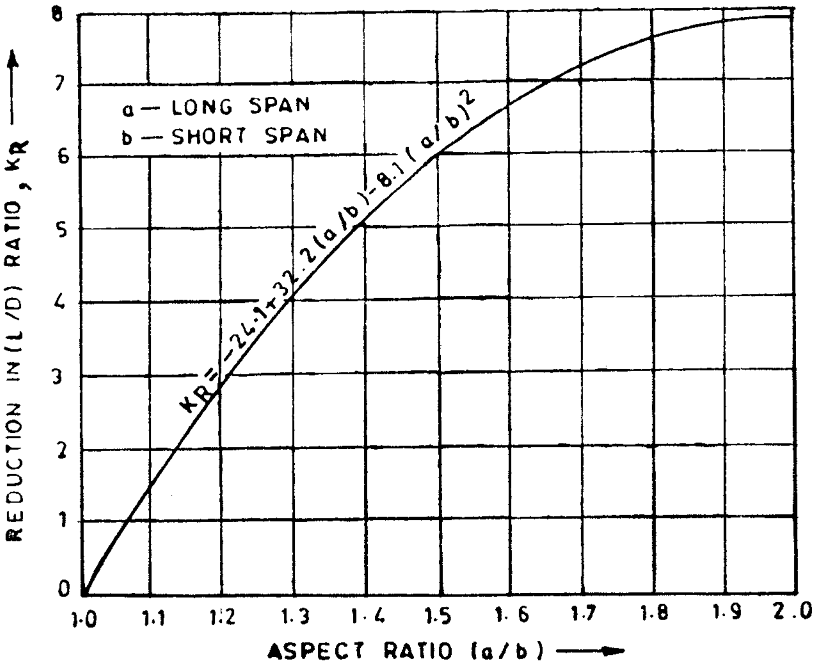

Fig. 2. Reduction in basic value of 'Span/depth' ratio with 'Aspect ratio'

(b) **Effect of Boundary Conditions**

Slabs with three different boundary conditions are dealt to demonstrate the effect of boundary conditions on the basic values of span/depth ratio.

(i) For simply supported slabs, L/D values remain constant for span upto 5.0 m and decrease linearly for higher spans. Upto 5 m span, for a particular loading class and aspect ratio, span to depth ratio could be taken as the corresponding basic value of L/D. The reduction for higher spans upto 10 m from the constant values could be represented by 0.8 (L-5) where L is short span in metres.

(ii) For slabs with three edges discontinuous and one short edge continuous, L/D values remain constant for span upto 5.0 m and decrease linearly for higher spans. However, these values happen to be approximately 1.5 times the L/D values for simply supported boundary conditions.

(iii) For interior panels (i.e. for slabs with all edges continuous) upto a span of 10.0 m, L/D ratio remains constant. Its value is approximately 1.5 times the L/D value for simply supported slabs with corresponding aspect ratio and span less than 5.0 m.

4.3. In cantilever slabs, *L/D* ratios reduce marginally with increase in cantilever span. This variation for different loading classes has been plotted in Fig. 3.

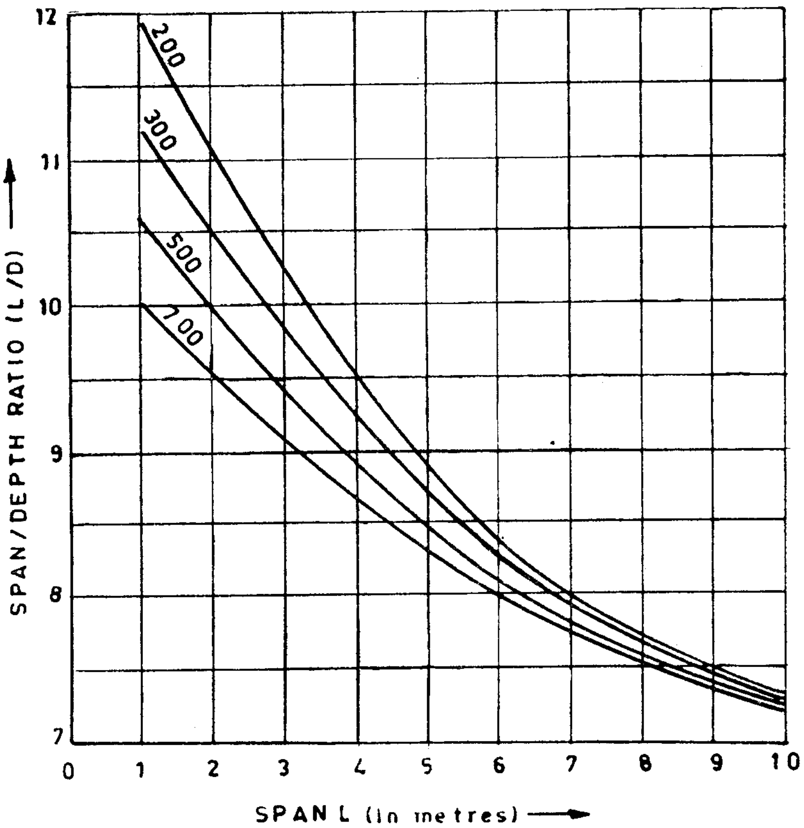

Fig. 3. Span/depth ratio for cantilever slabs
(Loading class as indicated on curves)

Critical Study of Recommendations of Codes[1 and 7]

In general day to day practice, span of slab and loading class seldom exceed 5.0 m and 3.0 kN/m^2 respectively. It is therefore, of interest to compare the span to depth ratios as obtained from this study with the values given in IS:456-1978 & those given in IS:456-1964. These values are listed below for having an overall comparative idea.

Boundary Conditions of slab	*IS:456-1978 L/D*	**IS:456-1964 L/D*	*Present study L/D*
Simply supported	28	35	34
Continuous	32	40	51
Cantilever	7	12	9.5

*Since the recommendations of IS:456-1978 are based on the effective depth, the values given above will further decrease if determined on the basis of overall depth. It is evident from above that these recommendations for L/d are too conservative and they will lead to uneconomical slab design.

Recommendations given by IS:456-1964 are closer to the L/D values determined by actual deflection calculations based on specification of new code[1]. Consequently, the approach adopted in the old code for limiting deflections of slabs seems to be more rational and justified. Although the values in the old code are higher than those calculated (except for continuous slabs), they are not questionable since they have stood the test of time since 1964 and produced no problems in various structures designed on this basis. However, in the light of above study, recommendations given in this paper should be adopted for a rational and economical design of slabs. The provisions in IS:456-1978 needs drastic modification in the light of the above study.

Relationship between Short Term and Long Term Deflection

In all, 2550 slabs having different spans, aspect ratios and boundry conditions have been analysed. As observed from the analytical values for deflection obtained here a definite relationship between the short term elastic deflection and long term deflection is apparent which is summarised below.

The total long term deflection due to shrinkage and creep varies from 40 to 70 per cent of the short term elastic deflection, the lower percentage being true for the higher loading class of 9.0 kN/m^2 and the higher percentage for the slabs carrying low intensity of live load (nearly 2.0 kN/m^2). For slabs with exteremely small spans (2.0 $\times$ 2.0m) carrying the live load of low intensity (2.0 kN/m^2), the total long term deflection is almost equal to short term elastic deflection.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. On the basis of the preceding observations, following recommendations are made for L/D ratios to satisfy the limit state of deflection while giving an economical design.

Span to (overall) depth ratios for simply supported square slabs for spans $\leqslant$ 5.0 m adopted as basic values of L/D and henceforth, they will be denoted by the symbol $(L/D)_b$. For different loading classes, $(L/D)_b$ values are as given below:

Live load (kN/m^2)	2	3	5	7	9
$(L/D)_b$	36	34	32	30	29

Figure 1 may be used for intermediate values of live loads.

(i) For simple-supported square slabs (i.e. for slabs with aspect ratio=1), span to depth ratio is given by

$$(L/D)_s = (L/D)_b \text{ for } L \leqslant 5 \text{ m} \quad \dots (10)$$

$(L/D)_s = (L/D)_b - 0.8\,(L-5)$ for $5\text{m} \leqslant L \leqslant 10\text{m}$ ... (11)

(ii) For slabs with three edges discontinuous (one short edge continuous), span to depth ratio is given by

$(L/D)_s = 1.15 \times (L/D)_b$ for $L \leqslant 5\text{m}$ ... (12)

$(L/D)_s = 1.15 \times (L/D)_b - 0.92\,(L-5)$ for $5\text{m} \leqslant L \leqslant 10\text{m}$ ... (13)

(iii) For slabs dealt in (i) & (ii) above with aspect ratio > 1, span to depth ratio is given by

$L/D = (L/D)_s - K_R$ ... (14)

K_R is obtained from Fig. 2.

(iv) For interior panels (i.e. slab with all edges continuous) with spans upto 10 m,

$L/D = 1.5 \times (L/D)_b - 1.5\,K_R$ ... (15)

(v) For cantilever slabs,

$L/D = 9.0$ if $L \leqslant 3.5$ m and live load $\leqslant 7.0$ kN/m²

$= 8.0$ if $3.5\text{ m} < L \leqslant 5.5$ m and live load $> 3.0\text{ kN/m}^2 \leqslant 7.0\text{ kN/m}^2$

For more precise values of L/D, figure 3 may be directly used.

5.2. From the observations given in para 3, it can be safely concluded that the total deflection can be arrived at in a much easier way just by multiplying the short term elastic deflection by a suitable factor which can be conservatively taken as 2.0.

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