Evaluation of Design Provisions for One-Way Solid Slabs in SBC-304

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Abstract - *Building code's minimum thickness provisions for concrete members, are generally used in engineering practice to comply with the serviceability requirements without prediction of the expected deflection under service circumstances. However, concerns have been raised about the effect that the 50-year-old provisions in ACI 318 (American Concrete Institute) [1] and SBC 304 (Saudi Building Code) [2] have in controlling slab deflections within the allowable values, predicting the deflection serviceability of reinforced concrete members is fraught with uncertainties.*

This study aims to evaluate the effect of the parameters that affected on the design of one-way solid slab and not considered in the span to depth ratio provided in the SBC Code. These parameters are, live load, concrete modulus of elasticity (which is a function of concrete compressive strength) and reinforcing steel yield strength. A parametric study has been carried out to study the effect of the above-mentioned parameters on the effect of the span to depth ratio and the predicted deflection. On the bases of this parametric study a new modified span to depth ratio relation is recommended, in which all affecting parameters have been included. The proposed formula has been verified for a practical range of one-way slab design. Results of this verification show that the recommended formula gives more economic and safe design for both ultimate strength and serviceability limit states.

Key Words: one-way solid slabs, deflection, span to depth ratio, Saudi Building Code

1. INTRODUCTION

This Most current codes provide two approaches for deflection control. First approach recommends a maximum limit for span to depth ratio depending on element type and boundary conditions. While in the other approach, the designer may choose a different depth value and then check for deflection.

The SBC-304 Code provides minimum thickness values for one-way solid slabs (similar to ACI-318), under prescribed conditions, as a function of span length, boundary conditions, and steel yield strength as a basis for deflection control. Deflection of one-way solid slabs is a principal criterion in design, it governs thickness, which in turn has a large economic impact. Deflection is usually controlled by limiting the span to depth ratio. This research evaluates the history of the span-to-depth method of design in the one-way solid slab. Limits on deformation were set many decades ago. To justify the need to modify the Code provisions, and enable more sustainable and economic designs, knowledge of the background to current limits and of current performance is needed. Part of that is to review the resent studies carried out in the last years.

Young et al. (2010),[3] pointed out that these provisions have remained essentially unchanged since 1971 and are appealing due to their simplicity. Several authors have raised questions and criticism about the validity of the current provisions in ACI-318 and SBC-304 under certain design conditions (Grossman 1981[4]; Rangan 1982[5]; Gilbert 1985[6]; Hwang and Chang 1996[7]; Scanlon and Choi 1999[8]; Scanlon et al. 2001[9]; Bondy 2005[10]). Young et al. (2010) showed the effects of design parameters such as span length, support condition and value of applied load are evaluated. The results indicated that ACI-318 (SBC-304) provisions need to be revised to consider the range of design parameters that are prevalent in these days practices and the parametric study found that while these minimum thickness values are easy to apply, limitations need to be placed on the applicability of the current Codes. The results presented in Andrew et al. (1999),[11] study indicate that the minimum thickness values given in ACI 318 (SBC-304) are conservative for slabs not supporting nonstructural elements likely to be damaged by large deflections for span lengths usually found in building structures. Authors have arrived at this conclusion either by analyzing a few amounts of field data (Rangan and McMullen 1978),[12] or after conducting full parametric studies (Scanlon and Thompson 1990[13]; Lee and Scanlon 2010[14]). Moreover, some of them have proposed other provisions that include an allowance for the actual load levels, concrete properties, and deflection limits, reporting in the end that they give better results than code provisions for that same data. Elgohary et al. (2021),[15], carried out a comparison between ACI-318 (SCB-304) and Egyptian Code ECP-203. They concluded that the span to depth ratio in ACI-318 is more conservative and always gives overdesigned slab thickness. Using a larger value of the span to depth ratio as in ECP-203[16] leads to more efficient design with 10% saving in the overall self-weight of the building.

2. ONE-WAY SLAB PROVISIONS IN SBC-304

In SBC-304 the minimum thickness values are independent of applied loads and/or concrete modules of elasticity (concrete compressive strength). Modification factors are provided for steel yield strength fy and lightweight concrete. Span to depth ratio provided in the Code enables designers to initial estimate the slab thickness that will control deflection to be within the code limits. To show to which level these provisions are very conservative an initial study is performed. In this study, one-way simply supported solid slabs with practical range of span (from 2.0 to 5.2 m) and live load (from 2.0 to 5.0 KN/m2) according to Nadim, H., Al-Manaseer, A., (2015),[17] will be considered. Additional imposed dead load (weight of finishing floor materials) is taken 2.0 KN/m2. The concrete compressive strength is chosen 21 and 30 MPa, and steel yield strength equals 420 MPa. For all these slabs the instantaneous deflection due to live load and long-term deflection have been determined. Figures 1 and 2 represent the relationship between short span of the slab and instantaneous deflection due to live load, for the two cases of concrete strength, respectively. The code limit (L/360) is also shown in these figures. It's clear that the predicted deflection is too small compared to the code limit. For concrete strength fc'=21Mpa and span = 5.2 m, the code limit is 3.3 times the predicted deflection for the case of live load = 5 kN/m2, while it is 23.9 for the case of live load= 2 kN/m2. For concrete strength fc'=30 Mpa and span = 5.2 m, the code limit is 8.2 times the predicted deflection for the case of live load = 5 kN/m2, while it is 28.6 for the case of live load= 2 kN/m2.

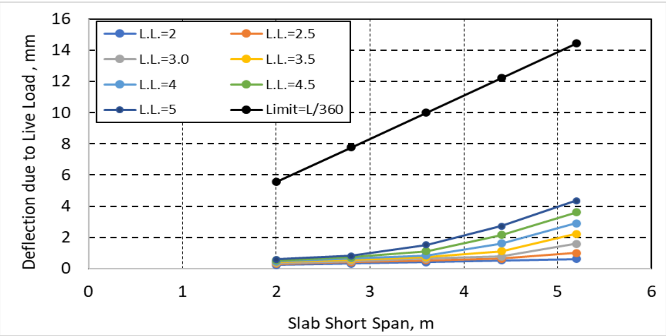

Chart -1: Slab Span-Instantaneous Deflection relationship for fc'=21 Mpa

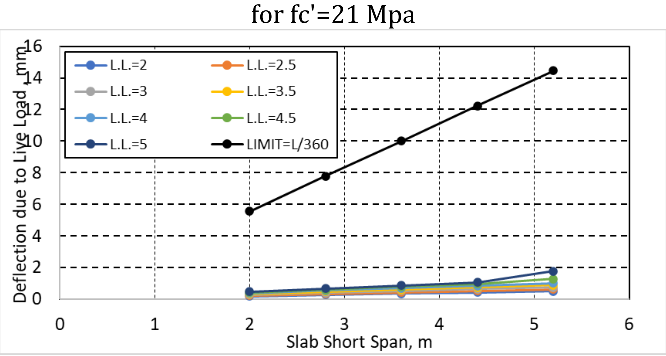

Chart -2: Slab Span-Instantaneous Deflection relationship for fc'= 30 Mpa

Charts 3 and 4 represent the same relationship for the case of concrete strength fc' = 21 and 30 MPa. The code limit (L/240) is also shown in these charts.

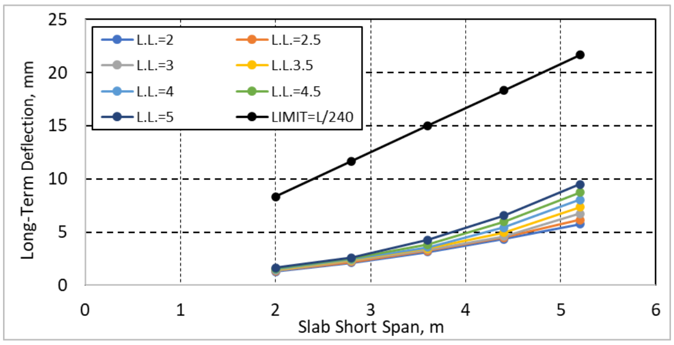

Chart -3: Slab Span-Long-term Deflection relationship for fc'=21 Mpa

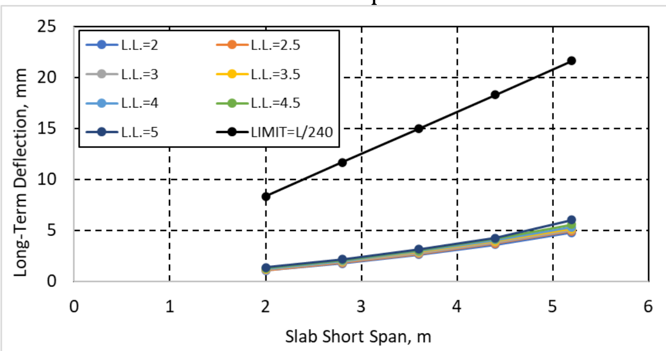

Chart -4: Slab Span-Long-term Deflection relationship for fc'=30 Mpa

For concrete strength fc'=21Mpa and span = 5.2 m, the code limit is 2.3 times the predicted deflection for the case of live load = 5 kN/m2, while it is 6.5 for the case of live load= 2 kN/m2. For concrete strength fc'=30 Mpa and span = 5.2 m, the code limit is 3.6 times the predicted deflection for the case of live load = 5 kN/m2, while it is 7.8 for the case of live load= 2 kN/m2.

The thickness of one-way slabs predicted using span to depth ratio provisions of SBC-304 lead to a very safe deflection. The large slab thickness obtained using code relations leads to a significant increase in dead loads of slab and consequently on the loads of supporting elements. It is essential to establish a modified span to depth ratio for one-way slab design and deflection control considering all affecting parameters for more efficient design.

3. PARAMETRIC STUDY

The objectives of the parametric study are to investigate the effect of all parameters affecting the deflection calculation and to determine modified span to depth ratio relation that will give more efficient design. The deflection of concrete elements depends on the applied live load, span, modulus of elasticity (concrete compressive strength) and the yielding strength of reinforcing steel. For the parametric study and to cover the practical range the following parameters have been considered as follows:

- Live load is chosen equals (L.L.) 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0 KN/m2
- Slab short span is taken (L) 2.0; 2.8; 3.6; 4.4; and 5.2 m
- Concrete compressive strength is chosen (fc') 21; 23; 25; 28; 30; 35 MPa
- Reinforcing steel yield strength (fy) is taken as 280 and 420 MPa
- Span to depth ratio is selected as 20; 22; 24; 26; 28; and 30

For these 2520 slab model, the instantaneous deflection due to live load and long-term deflection have been determined and compared with the code limit of (L/360) and (L/240), respectively. Selected results of the parametric study are shown in graphs presented in Charts 5 to 18.

3.1 Effect of Live Load

The effect of live load on the predicted deflection, for the boundary cases of the parametric study, is presented in Charts 5 to 12. The relationships between instantaneous deflection due to live load and the value of live load for different span to depth ratios are presented in Figures 5 to 8, while for long-term deflection in Charts 9 to 12. In general deflection is nonlinearly directly proportional with the value of live load. For most cases the predicted deflections are within the code limits, except for the cases of high values of span to depth ratio, live load, and span.

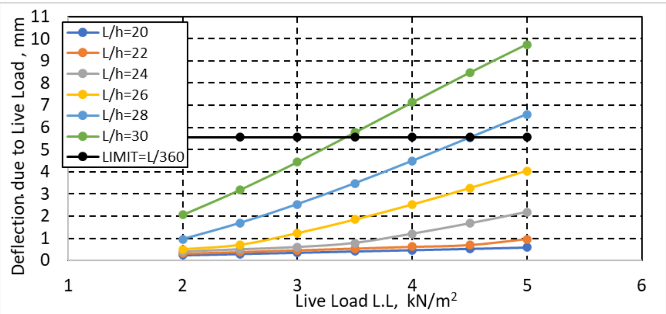

Chart -5: Immediate Deflection-Live Load Relationship for Concrete Compressive Strength= 21Mpa and span= 2m

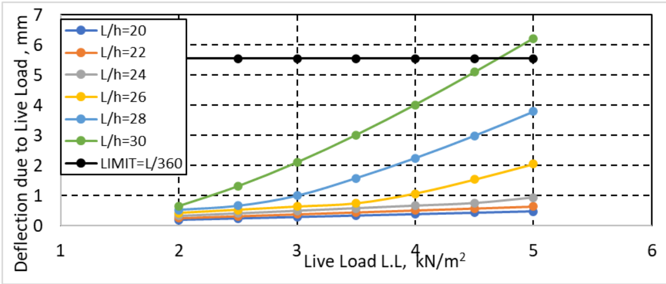

Chart -6: Immediate Deflection-Live Load Relationship for Concrete Compressive Strength= 30Mpa and span= 2m

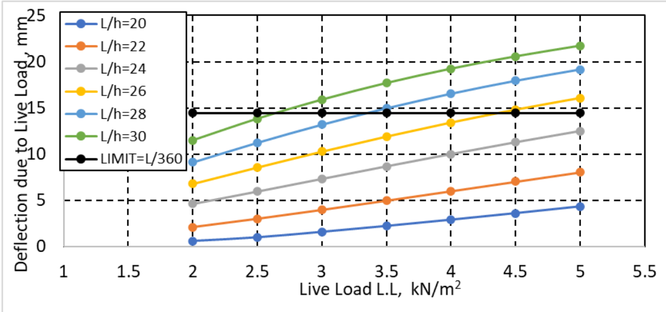

Chart -7: Immediate Deflection-Live Load Relationship for Concrete Compressive Strength= 21Mpa and span= 5.2m

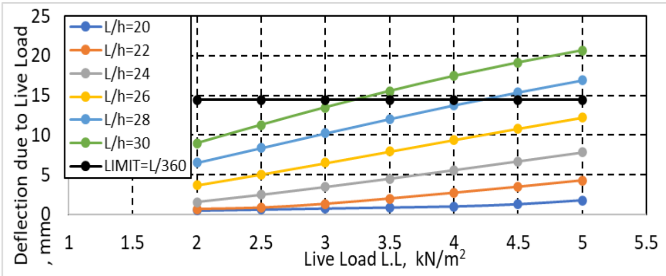

Chart -8: Immediate Deflection-Live Load Relationship for Concrete Compressive Strength= 30 Mpa and span= 5.2m

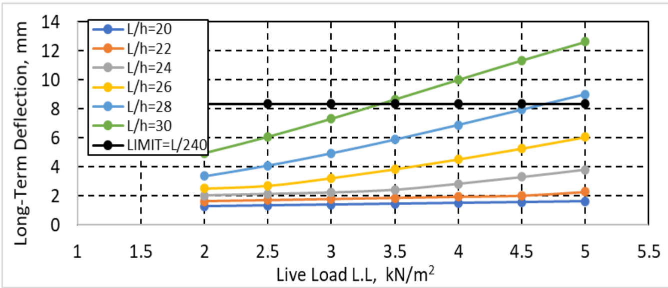

Chart -9: Long-Term Deflection-Live Load Relationship for Concrete Compressive Strength= 21Mpa and span= 2m

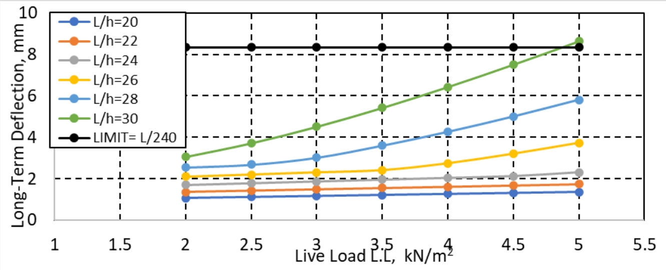

Chart -10*:* Long-Term Deflection-Live Load Relationship for Concrete Compressive Strength= 30Mpa and span= 2m

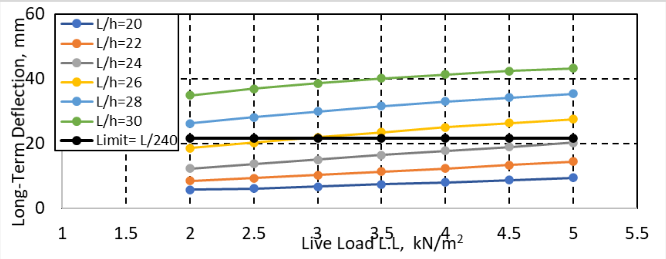

Chart -11*:* Long-Term Deflection-Live Load Relationship for Concrete Compressive Strength= 21Mpa and span= 5.2m

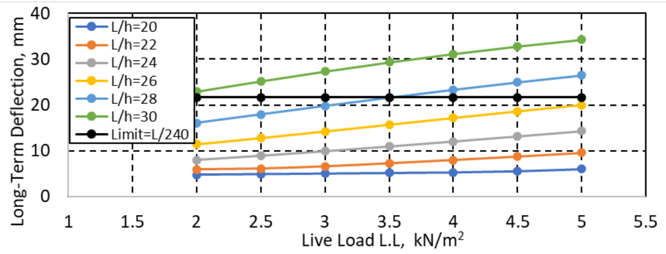

Chart -12*:* Long-Term Deflection-Live Load Relationship for Concrete Compressive Strength= 30Mpa and span= 5.2m

3.2 Effect of Slab Short Span

The effect of slab short span on the predicted deflection is presented in Charts 13 and 14. It is encountered that deflection is nonlinearly directly proportional to slab short span. Similarly, for most cases the predicted deflections are within the code limits, except for the cases of high values of span to depth ratio, live load, and span.

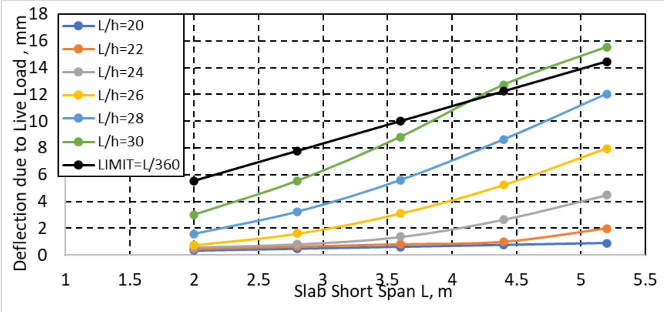

Chart -13: Immediate Deflection-Slab Short Span Relationship for Concrete Compressive Strength= 30Mpa and span= 3.5m

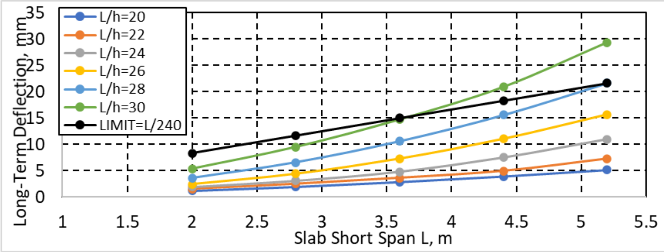

Chart -14: Long-Term Deflection-Slab Short Span Relationship for Concrete Compressive Strength= 30Mpa and span= 3.5m

3.3 Effect of Concrete Compressive Strength

The effect of concrete compressive strength on the predicted deflection is presented in Charts 15 and 16. It is clear that, deflection is nonlinearly inversely proportional to slab short span. For most cases the predicted deflections are within the code limits, except for the cases of high values of span to depth ratio, live load, and span.

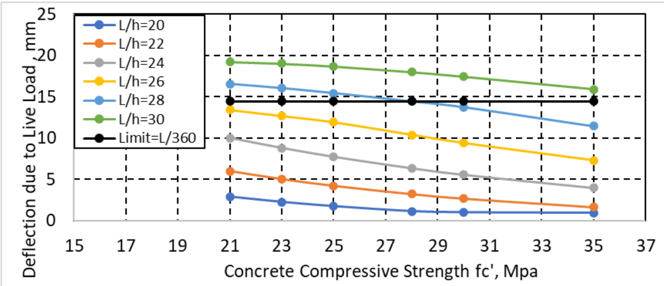

Chart -15*:* Immediate Deflection-Concrete Compressive Strength Relationship for Live Load= 4 kN/m² and span= 5.2m

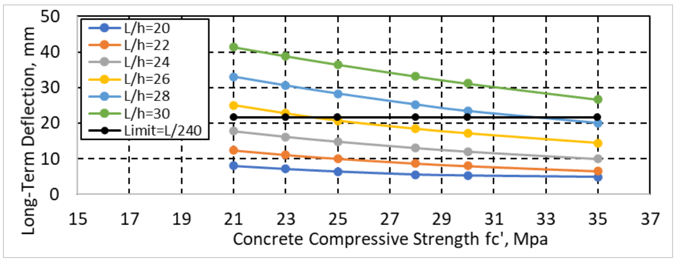

Chart -16: Long-Term Deflection-Concrete Compressive Strength Relationship for Live Load= 4 kN/m² and span= 5.2m

3.4 Effect of The Reinforcing Steel Yielding Strength

The effect of yield strength of reinforcing steel on the predicted instantaneous and long-term deflection is shown in Charts 17 and 18, respectively. These relations show that the yield strength has insignificant effect on the deflection.

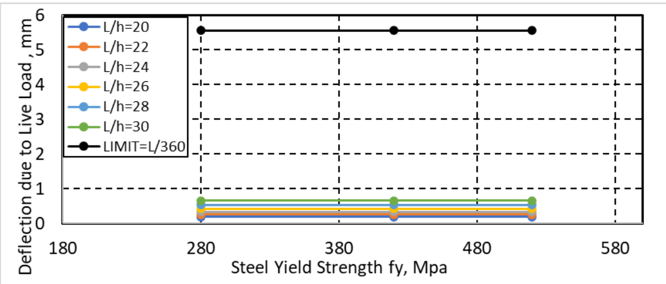

Chart -17: Immediate Deflection-Steel Yield Strength Relationship for Live Load= 2 kN/m² and span= 2m

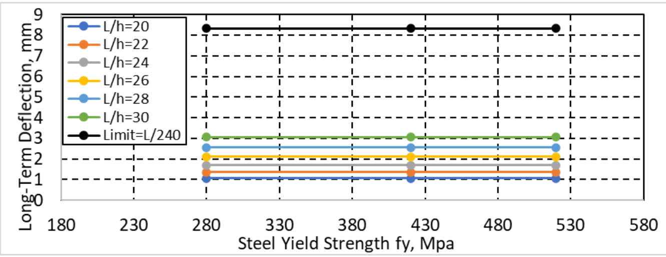

Chart -18: Long-Term Deflection-Steel Yield Strength Relationship for Live Load= 2 kN/m² and span= 2m

4. MODIFIED SPAN TO DEPTH RATIO

In this section analysis has been conducted to the results of 2780 models to figure out enhanced span to depth formulae for more economic and efficient design for the one-way solid slabs. Obtaining the intersection between code limits and results of the values of parameter studied gives the exact span to depth ratio.

Relations between the exact span to depth ratio L/h and the parameter studied (Live Load LL, span Length L and concrete compressive strength fc') are presented in Charts 19 to 21.

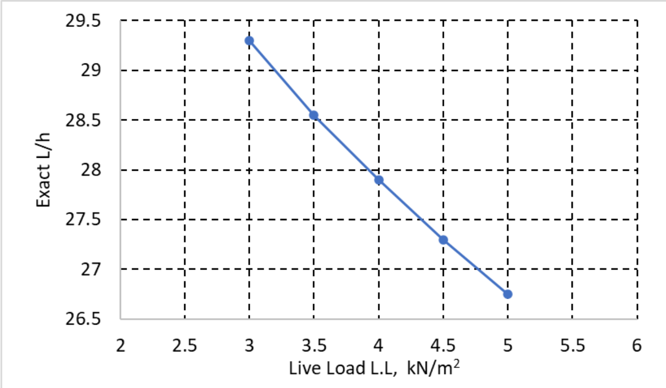

Chart -19: Relation between exact L/h and Live Load, kN/m2

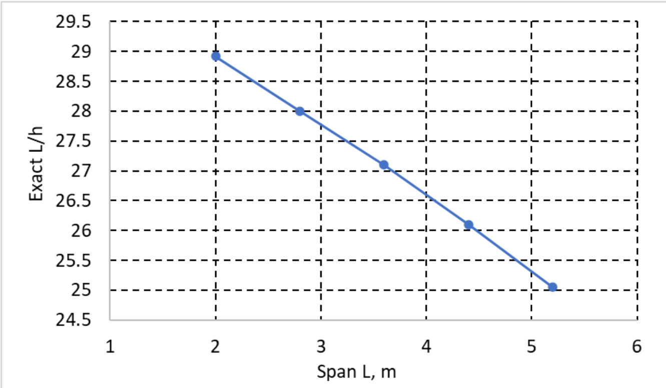

Chart -20: Relation between exact L/h and Short Span, m

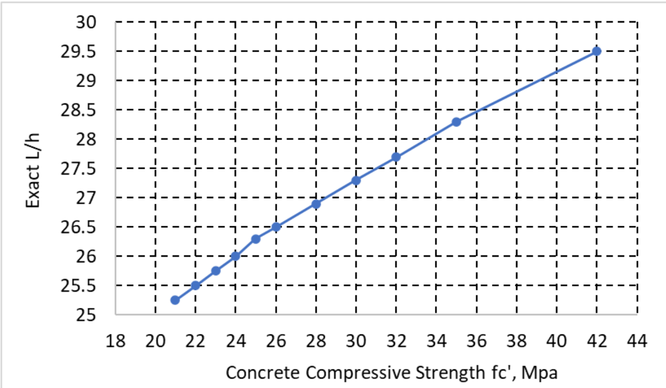

Chart -21: Relation between exact L/h and concrete compressive strength, fc', Mpa

As shown from the previous charts the relation is:

- Relation between L/h and LL is inverse nonlinearly proportion.
- Relation between L/h and L is inverse nonlinearly proportion.
- Relation between L/h and fc' is direct nonlinearly proportion.

From the previous relations of span to depth ratio and different parameters the equation format should be:

$$\frac{L}{h} = \frac{c_1\,(fc')^{c_2}}{L^{c_3}\,LL^{c_4}} \qquad (1)$$

where,

L/h Span to depth ratio

C1, C2, C3 and C4 Constant values

fc' Concrete compressive strength, Mpa

L Span length. m

LL Live load, kN/m2

Applying nonlinear regression analysis (IBM SPSS Statistics-26, (2019),[18] on the obtained results relating the exact values of the span to depth ratio, to the parameters the following equation for yield strength of 420Mpa will has the form:

$$\frac{L}{h} = \frac{19.513\,fc'^{0.225}}{L^{0.144}\,LL^{0.133}} \qquad (2)$$

For the case of steel yield strength 280 MPa, will have the form:

$$\frac{L}{h} = \frac{19.411\,fc'^{0.213}}{L^{0.121}\,LL^{0.105}} \qquad (3)$$

For different values of yield strength fy a modified equation should be created. For this purpose, the effect of fy has to be understood using the previous equations. The following equation is the ratio of equation (3) to equation (2):

$$\frac{\left(\frac{L}{h}\right)_{280}}{\left(\frac{L}{h}\right)_{420}} = \frac{0.995\,fc'^{-0.012}}{L^{-0.023}\,LL^{-0.028}} \qquad (4)$$

Applying the ratio equation (4) for lower bounds of the practical (span L=2 m, live load LL=2 kN/m2) and for the upper bound (span L=5 m and live load LL=5 kN/m2) gives the graph shown in Chart 22. The ratio for both boundaries, is around the unity. The steel yield strength has insignificant effect on the span to depth ratio for one-way solid slabs. The modifier for steel yield strength provided in SBC-3.4, needs to be revised. Equation (2) is applicable for different values of yield strength.

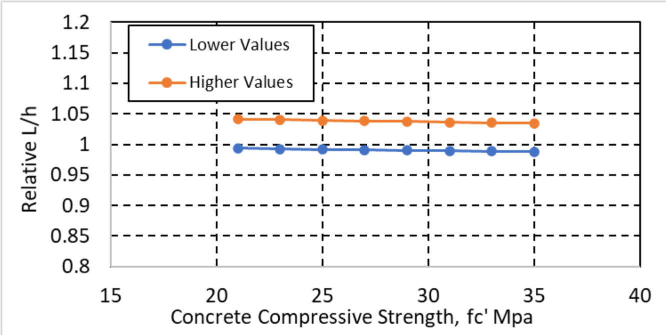

Chart -22: Effect of fy on lower and higher values of the practical rang

5. VERIFICATION OF THE RESULTS

To verify the result of the proposed equation, five slab models have been designed using the proposed equation and the SBC-304 equation. Results are shown in Table-1 for the case of steel yield strength 420 MPa. For all models, predicted deflections are within the code limit. The slab thickness reduces by 38.9 % for models 1 and 2; and by 25% for models 3 and 4. The same results obtained and presented in Table 2 for the case of steel yield strength 280 MPa, using equation (2) (equation for fy=420 MPa).

Table-1: Comparison between proposed equation and the code's equation of fy=420Mpa

Model	Span, m	L.L. KN/m2	Proposed equation				Code equation			Code Limit	
			L/h	h	δ_{LL}	δ_{LT}	h	δ_{LL}	δ_{LT}	LL Limit	LT Limit
1	5	2	29.87	180	5.042	13.122	250	0.50261	4.6492	13.9	20.8
2	5	3	28.30	180	8.584	16.664	250	0.75392	4.9005	13.9	20.8
3	5	4	27.24	200	6.4927	12.873	250	1.00522	5.1518	13.9	20.8
4	5	5	26.44	200	9.0437	15.424	250	1.89368	6.0402	13.9	20.8

Table-2: Comparison between proposed equation and the code's equation of fy=280 Mpa

Span, m	L.L. KN/m2	Proposed equation				Code equation			Code Limit	
		L/h	h	δ_{LL}	δ_{LT}	h	δ_{LL}	δ_{LT}	LL Limit	LT Limit
5	2	29.87	180	4.5731	12.6526	250	0.50261	4.64916	13.9	20.8
5	3	28.3	180	7.454	15.5335	250	0.75392	4.90047	13.9	20.8
5	4	27.24	200	5.7844	12.1652	250	1.00522	5.15178	13.9	20.8
5	5	26.44	200	7.7717	14.1525	250	1.8361	5.98265	13.9	20.8

6. CONCLUSIONS

Span to depth ratio provisions for one-way solid slab design, presented in SBC-304 (ACI-318) always give very conservative values of slab thickness.

Using SBC-304 provisions to determine the slab thickness leads to larger values of thickness and consequently increase the own weight of the slab and loads on all supporting elements.

A modified proposed equation for the span to depth ratio is recommended for more efficient design of one-way solid slab.

The results of the design using the proposed equation show more economical design with safe deflection.

The current study proves that the reinforcing steel yielding has insignificant effect on the span to depth ratio in one-way solid slab design and can be neglected.

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