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Code Criteria For Deflection Limitation In Reinforced Concrete Structures

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Synopsis: Code criteria for deflection limitation in reinforced concrete structures, from a number of countries, are reviewed and the two major methods used for deflection limitation are discussed. These methods are: limiting deflections to a fraction of the span length, and limiting the span-to-depth ratio.

Keywords: building codes; creep properties; deflection; flexural strength; loads (forces); reinforced concrete; shrinkage; span depth ratio; standards; stiffness.

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INTRODUCTION

The fact that so many prominent authors have contributed to this symposium indicates that deflection has become an important consideration in the design of reinforced concrete structures. Further evidence of its importance is that all of the codes of practice, either existing or proposed, and committee recommendations that were reviewed include some sort of provision for deflection limitation. In general, two methods are used to limit deflections; specifying maximum deflection as a fraction of the span length, and specifying the maximum span-to-depth ratio. Both methods will be discussed in this paper by citing examples of codes using each method. The examples will be taken from the documents reviewed and listed in the Bibliography.

ALLOWABLE DEFLECTIONS

If deflection is limited by the method of specifying allowable deflections, the designer is faced with two problems, determining the value of the limiting deflection and determining the method to be used for evaluation of the deflection of the structure. Before discussing these problems, it should be noted that analysis and design for deflection should be significantly different from analysis and design for strength. When a concrete member is designed for strength, inherent in the procedure are a number of assumptions, factors of safety for stress, factors of safety for load, and, in general, conservative estimates of all quantities involved. If the same approach is used to evaluate deflections or allowable span-to-depth ratios, unnecessarily conservative structures will result. Such computation should predict the true deformation of the structure as accurately as possible, with all factors of safety set equal to one.

Consider first the problem of the limiting deflection. There are a number of reasons, other than structural integrity, for setting limits on deflections. Some of these are: aesthetic, physiological, psychological, and the effect on non-structural elements. In addition, it is important to consider what component of the deflection should be limited. For example, if the effect on non-load bearing walls is being considered, the limitation should be placed on the deflection that will occur after the wall is constructed.

In 1968, ACI 435 (1) proposed the allowable or limiting deflection shown in Table 1. Table 2, taken from the Czech code Design of Concrete Structures (2) provides a second example. Both tables indicate the importance of considerations other than structural integrity, and the importance of incremental deflections.

Consider now the problem of calculating the deflection to be compared with the limiting deflection taken from, for example, Table 1 or Table 2. As 12 of the papers in this volume are concerned with this subject, a detailed discussion is not appropriate. However, a brief discussion of the important parameters involved in such calculation might be helpful. In a recent meeting of C. E. B., Dr. J. Brakel presented a comprehensive report on the calculation and limitation of deflections. The following is a summary of Dr. Brakel's comments on the parameters involved in deflection calculation.

1. Type of loading and support conditions
This can generally be taken into account by writing the deflection equation as

$$\delta = \beta \frac{M\ell^2}{EI}$$

where β is a correction factor for loading and support conditions which can be calculated from basic principles.

2. Variation in stiffness
Branson (3) and the ACI (4) code use an effective moment of inertia (I_e) to include the effect of stiffness variation caused by various amount of cracking along the length of the beam. I_e is a function of the cracking moment, maximum moment, the uncracked moment of inertia, and the cracked moment of inertia. Other methods utilize a simple deflection correction factor that depends on the moment distribution and cracking moment.

3. Creep curvature
The increase of curvature due to creep may be taken into account by multiplying the instantaneous curvature by a factor K, or by replacing the instantaneous modulus of elasticity by a reduced creep modulus.

4. Shrinkage curvature
Restrained shrinkage causes force in the steel which results in an additional bending moment, usually in the direction of the applied loads, thereby increasing deflection.

5. Other factors
Depending on the accuracy required, it is also possible to consider the contribution of other variables such as the uncracked concrete under the neutral axis, and compressive reinforcement.

LIMITING SPAN-TO-DEPTH RATIOS

From a design point of view, it is probably easier to satisfy a limiting span-to-depth ratio than it is to satisfy an allowable deflection. However, this approach will most likely result in a more conservative design because it is difficult to include all of the appropriate influences in a single span-to-depth ratio. Therefore such ratios tend to be set at conservative levels. Many of the codes reviewed use the concept of limiting depth or span-to-depth ratio but the most comprehensive treatment is that of the British Code of Practice for Reinforced Concrete (5). The allowable span-to-depth ratio is evaluated in terms of support conditions, percentage of reinforcement, the ratio of permanent to total load, and mix and environmental conditions. Thus it can be seen that this method attempts to take into account any of the important parameters involved in the calculation of deflection. The basic span-to-depth ratios are given for various span lengths and support conditions in Table 3. A member is assumed to be fully fixed if

$$\frac{\Sigma K_1 + \Sigma K_2}{K_\beta} > 4$$

and partially fixed if

$$\frac{\Sigma K_1 + \Sigma K_2}{K_\beta} > 2$$

Where K_β is the stiffness of the member considered and ΣK_1 and ΣK_2 are the sums of the stiffnesses of all other members framing into ends 1 and 2 of member β. These basic values (Table 3) are then modified by multipliers for reinforcement, long-term effects, and mix proportions and environment. The multipliers for reinforcement are given in Table 4 and Table 5 gives the multipliers for long-term effects. Note that the effect of compressive reinforcement has been included. Multipliers for mix proportions and environmental conditions are given in Table 6. Creep coefficient is defined as creep plus elastic strain divided by elastic strain.

Once the span-to-depth ratio obtained by the above method is satisfied by design it may be assumed that the structure is adequate to withstand both long-term and short-term deflections.

SUMMARY AND CONCLUSION

It can be seen from the above discussion that codes of practice not only consider deflection control of reinforced concrete structures, but, in some cases, do so in a rather comprehensive manner. Either method, maximum deflections or maximum span depth ratios, can be used effectively to limit deflections if the following general procedures are followed in the analysis:

1. Evaluate as realistically as possible material properties, loading history and environmental conditions.

2. Set all factors of safety equal to 1.

3. Set all load factors equal to 1.

4. Consider the effects on deflection due to the following characteristics:

    a. Type of loading and support conditions

    b. Variation in stiffness

    c. Creep

    d. Shrinkage

    e. Other effects as necessary for the structure under consideration

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Table 1

Deflection Limitations from ACI 435

REASONS FOR LIMITING DEFLECTION	EXAMPLES	DEFLECTION LIMITATION	PORTION OF TOTAL DEFLECTION ON WHICH THE DEFLECTION LIMITATION IS BASED
1. Sensory acceptability			
1.1 Visual	Droopy cantilevers and sag in long span beams	By personal preference	Total deflection
1.2 Tactile	Vibrations of floors that can be felt Lateral building vibrations	L/360 No recommendation	Full live load Gust portion of wind
1.3 Auditory	Vibrations producing audible noise	Not permitted	
2. Serviceability of structure			
2.1 Surfaces which should drain water	Roofs, outdoor decks	L/240	Total deflection
2.2 Floors which should remain plane	Gymnasia and bowling alleys	L/360 + camber or L/600	Incremental deflections after floor is installed
2.3 Members supporting sensitive equipment	Printing presses and certain building mechanical equipment	Manufacturer's recommendations	Incremental deflections after equipment is leveled

Table 1

Deflection Limitations from ACI 435 (Continued)

REASONS FOR LIMITING DEFLECTION	EXAMPLES	DEFLECTION LIMITATION	PORTION OF TOTAL DEFLECTION ON WHICH THE DEFLECTION LIMITATION IS BASED
3. Effect on nonstructural elements			
3.1 Walls	3.1.1 masonry and plaster	L/600 or 0.30 in. (7.6 mm) max or φ = 0.00167 rad.	Incremental deflections after walls are constructed
	3.1.2 metal movable partitions and and other tempo-rary partitions	L/240 or 1 in. (25.4 mm) max	Incremental deflections after walls are constructed
	3.1.3 lateral building movement	0.15 in. (3.8 mm) offset per story 0.002 x (height)	Five min sustained wind load
	3.1.4 vertical thermal movement	L/300 or 0.60 (15.2 mm) max	Full temperature differential
3.2 Ceilings	3.2.1 plaster	L/360	Incremental deflection after ceiling is built
	3.3.3 unit ceilings such acoustic tile	L/180	

Table 1

Deflection Limitations from ACI 435 (Continued)

REASONS FOR LIMITING DEFLECTION	EXAMPLES	DEFLECTION LIMITATION	PORTION OF TOTAL DEFLECTION ON WHICH THE DEFLECTION LIMITATION IS BASED
3.3 Adjacent building elements supported by other members	Windows, walls and folding partitions on unyielding supported below the deflecting member	Absolute deflection limited by tolerances built into the element in question	Incremental deflection after building element in question is constructed
4. Effect on a structural elements			
4.1 Deflections causing instability of primary structure	Arches and shells Long columns	Effect of deflections on stresses and stability of the structure should be taken into account in the structural design of the element	
4.2 Deflection causing different force system or change in stresses in some other element	Beam bearing rotation on masonry wall	Effect of deflections on the stresses and stability of the structure should be taken into account in the structural design of the element	
4.3 Deflections causing dynamic effects	Resonant vibrations which increase static deflections and stresses such as those produced by wind, dancing, moving loads and machinery	Dynamic deflections should be added to static deflections and the total should be less than the limitations imposed for other reasons	

Table 2

Deflection Limitations from the Czechoslovak Code

LINE	STRUCTURAL ELEMENTS			LIMIT DEFORMATION: SLOPE OF DEFLECTION CURVE AT THE POINT OF LOAD	LIMIT DEFORMATION: DEFLECTION AT MIDSPAN	DEFORMATION CONSIDERED FOR THE CHECK
0	1	2	3	4	5	6
1	Beams of gantries for	hand cranes		0.0030	$\ell/500$	deformation after placing and leveling of rails
2		electrically powered with max. load	less than 50 t	0.0025	$\ell/600$	
3			over 50 t	0.0020	$\ell/750$	
4		suspended cranes		0.0040	$\ell/400$	
5	Beams of industrial floors	with railway traffic	regular	0.0025	$\ell/600$	
6			narrow gage	0.0040	$\ell/400$	
7		without railway traffic	girders	0.0040	$\ell/400$	deformation after leveling of floors
8			other beams	0.0060	$\ell/250$	
9	ceilings and walls with compact (for example covered by plaster) surfaces			0.0090	$\ell/350$	deformation after finishing the surface
10	ceiling and walls mountable surfaces (for example suspended ceilings)			0.0150	$\ell/200$	