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Detailing of Reinforced Concrete Structures

Détails de construction de structures en béton armé

Konstruieren von Stahlbetontragwerken

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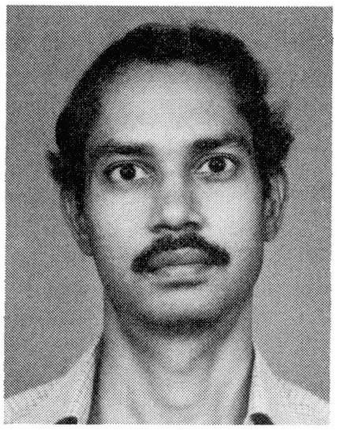

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SUMMARY

Codes of practice play a significant role in developing safe and economical structures. However, a design practice that is satisfactory in one country may appear unsafe according to the code of another country. Some of the inconsistencies between the codes of a few countries are discussed in this article. Actual construction practice and the practicability of some of the aspects of concrete structures are also discussed. The need for consistent specifications along with tolerances, and some of the aspects to be incorporated in the codes are indicated.

RÉSUMÉ

Les codes pratiques de construction jouent un rôle significatif dans le développement sûr et économique des structures. Cependant, une norme de dimensionnement satisfaisante dans un pays peut être paraître peu sûre selon le code d'un autre. Quelques unes de ces contradictions entre les codes de certains pays sont discutées dans cet article. La façon de construire actuelle, ainsi que la validité de quelques aspects de structures en béton sont également discutés. La nécessité de spécifications cohérentes sur les tolérances est présentée conjointement aux différents aspects qui doivent être intégrés dans des normes.

ZUSAMMENFASSUNG

Normen spielen eine wichtige Rolle, um sichere und wirtschaftliche Bauwerke zu erstellen. Die zufriedenstellende Entwurfspraxis eines Landes kann jedoch nach der Norm eines anderen Landes unsicher sein. In diesem Artikel werden einige solcher Unsicherheiten zwischen den verschiedenen Normen einiger Länder diskutiert. Weiterhin werden auch die Ausführungspraxis und Fragen der Ausführbarkeit diskutiert. Es werden die Notwendigkeit konsistenter Regeln zusammen mit Toleranzangaben sowie andere notwendige Gesichtspunkte angedeutet.

1. INTRODUCTION

Codes of practice are formulated to provide guidelines on various aspects of analysis and design, and to set minimum standards of safety that are consistent with economy. Considerable efforts go into the preparation of codes of practice, which are often expected to be followed meticulously. The codes of practice of any country are not prepared in isolation, but tend to incorporate the developments reported from other countries as well. Nevertheless, it is surprising to note the differences between the codes of practice pertaining to various countries, and more so when the codes of practice of the same country differ from each other. In addition, construction practices may sometimes differ from the specifications. Some of these may be termed trivial and ignored, but some of the parameters may have a direct bearing on the safety and economy.

Some of the mundane aspects of detailing, such as diameter of hooks, anchorage length, concrete cover and corner reinforcement in slabs, are discussed in this article with reference to the codes of a few countries [1-5]. The actual construction practice and its influence on the performance of structures is also discussed. Some of the aspects to be included in the codes are suggested.

2. DETAILING OF REINFORCEMENT

A practice that is satisfactory in one country may be unsafe by the standards of another country. Local factors should be certainly taken into consideration in developing the codes of practice. However, there is less room for such inconsistencies in the present era of fast communications and exchange of information between the investigators of various countries. There is a need to narrow down these differences, which may appear to be illogical on one hand, and to reduce the chasm between the specified recommendations and construction practice on the other. A few aspects of such glaring examples are discussed briefly here.

2.1 Diameter of hooks and cogs

The specified diameters of hooks and cogs vary over a wide range. Hooks and cogs have a significant role in anchoring reinforcement, and the need for proper specifications can never be over-emphasised. However, a look at Table 1 indicates that the specifications of Indian codes require much larger diameter than DIN 1045 or AS 3600. The parameters of Table 1 are expressed in terms of the bar diameter Φ.

Table 1 Minimum diameter of bend and length beyond hooks and cogs in terms of bar diameter Φ

S. No.	Code of practice	Min. diameter	Min. length beyond bend: Hook	Min. length beyond bend: Cog
1	IS 456	8 Φ	4 Φ	4 Φ
2	IRC 21	6 Φ	5 Φ	10 Φ
3	DIN 1045	4 Φ*	5 Φ	5 Φ
4	AS 3600	5 Φ	4 Φ $\geq$ 70 mm	@

* upto $\Phi < 20$ mm; and 7 Φ for $20 < \Phi < 28$ mm
@ total length should be the same as that for hook of same diameter

The values of Table 1 pertain to high strength steel (characteristic strength > 400 MPa). It is inexplicable that a diameter of 4 Φ is adequate as per DIN 1045, but IS 456 requires double that value for the same bar. Again, IRC 21 pertaining to the same country as IS 456, recommends a smaller value for the diameter of bend but a larger value for the length beyond hooks and cogs.

A recent survey at construction site revealed that the diameter of bend was between 3 Φ and 5 Φ in 86 percent of the hooks measured as against 8 Φ specified by IS 456 [6]. No cracking or any distress was found on the hooks of high strength deformed bars, indicating that the specified diameter of 8 Φ may be too conservative or impracticable.

2.2 Anchorage length

Anchorage and lap lengths differ significantly as per various codes of practice. Figure 1 and 2 indicate the basic lengths of anchorage in terms of bar diameter (ld/Φ) for tension and compression respectively. Some codes provide the anchorage length directly (DIN 1045 and IRC 21), while others recommend ld as a function of several parameters, such as the strength of steel and concrete, and bar diameter. The values of Figure 1 and 2 are applicable for deformed bars of 415 MPa characteristic strength. The cylinder strength of concrete was converted to cube strength using a factor of 0.8 for the specifications of ACI 318. Further, the value of ld depends upon the cross-sectional area as per ACI 318 and AS 3600, whereas it is a function of bar diameter in the other cases. The values of ld even in the former cases are expressed as a function of Φ for specific bar sizes (12 mm and 35 mm) for comparison. In the case of AS 3600, ld was computed for minimum concrete cover (20 mm or Φ, whichever larger).

IRC 21 yields the most conservative values generally, follwed by IS 456, AS 3600 and DIN 1045. ACI 318 yields the lowest values for bar sizes 9.5 to 16 mm, and the largest values for bar sizes greater than 35 mm. Only AS 3600 considers the influence of concrete cover; the larger the cover, the smaller the value of ld. Significant reduction in ld for bars in compression is recommended by IS

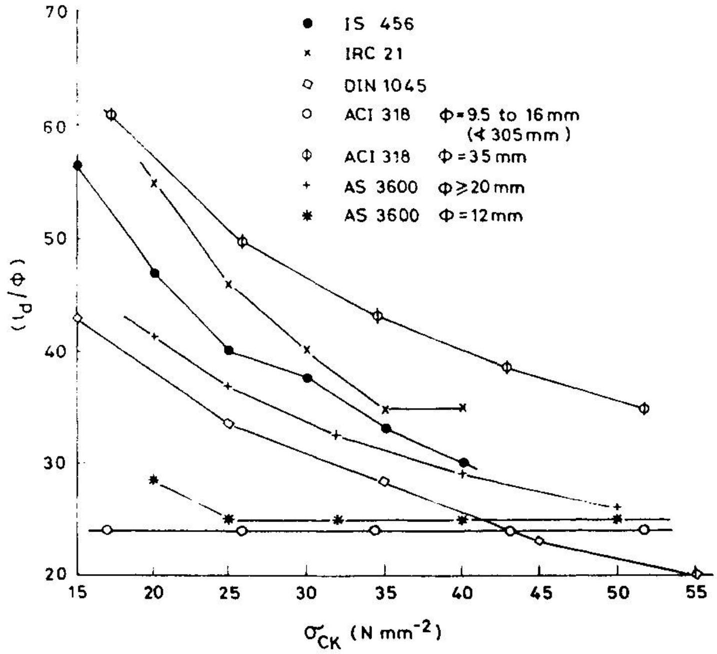


Fig. 1 (ld/Φ) for tension bars

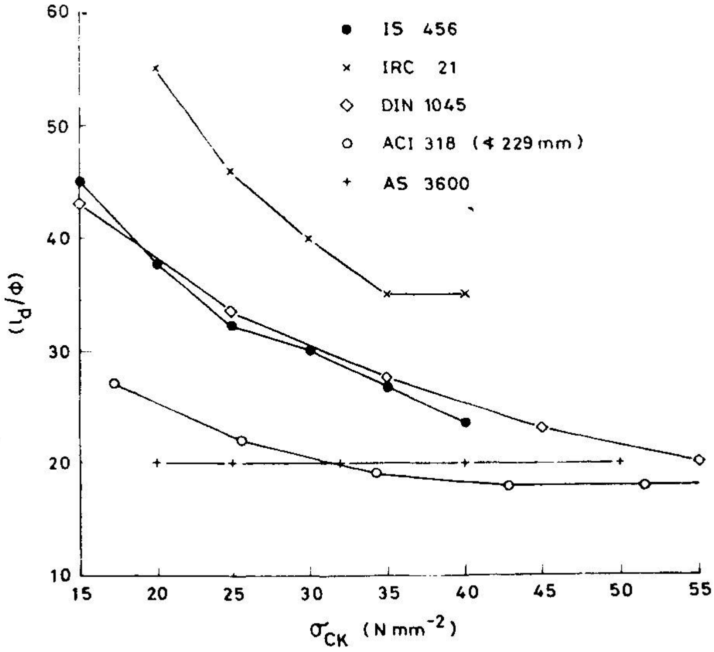


Fig. 2 (ld/Φ) for compression bars

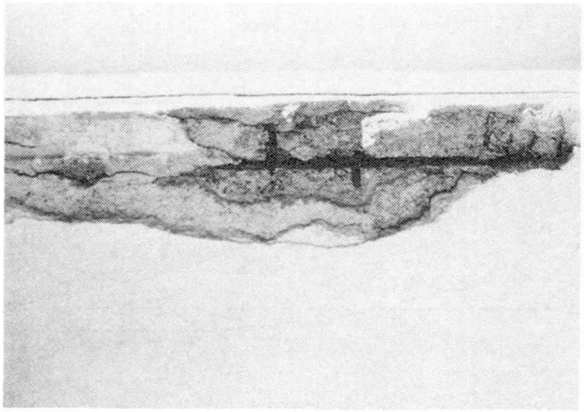
456, ACI 318 and AS 3600, while IRC 21 and DIN 1045 do not recommend any such reduction. While most of the codes recommend a reduction in ld for steel area in excess of the required value at the section, IS 456 does not include any such provision.

2.3 Concrete cover

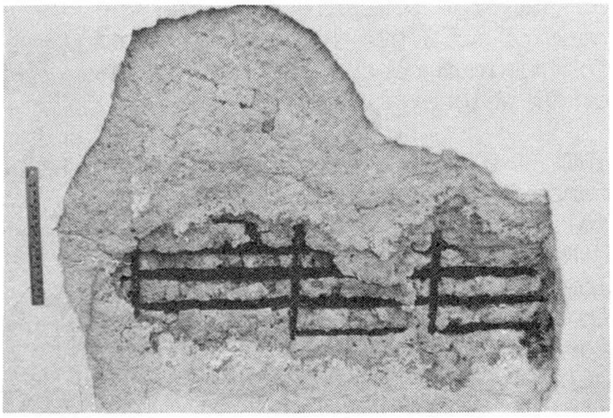
It is interesting to note that the codes of practice differ in their recommendations for concrete cover as well. While some codes do not distinguish between the requirements of cover for slabs, beams and columns, others do. The differences are all the more glaring between IS 456 and IRC 21 in this regard. The former recommends a minimum concrete cover of 15 mm for slabs and 25 mm for beams subject to a minimum of one bar diameter for mild exposure conditions; IRC 21, on the other hand, recommends a minimum value of 25 mm for slabs less than 150 mm thick, and 30 mm in other cases for concrete strengths upto 30 MPa.

The values of cover specified are generally the nominal values, and tolerances are also recommended sometimes. It may be of interest to note that the conclusions of site surveys on these aspects are not very encouraging [6,7]. Particularly the site measurements on common residential structures indicate the pre-pour cover to be too large, while the post-pour conditions reveal the lack of adequate cover [6]. While IS 456 recommends a minimum cover of 40 mm to the main bars of columns larger than 200 mm, site surveys indicated the maximum cover to be less than 20 mm in about 70 percent of the cases. The specified cover of about 40 mm was provided by mistake rather than by design in all the cases of residential and commercial structures surveyed; cover on the opposite face of the column was barely 5 mm in such cases.

In almost all the cases, too small cover was the result of inadequate or misplaced bar supports [6,7]. The surveys reported from Australia suggest the need for specifications for bar supports and practicable tolerances [8]. Lack of adequate cover is the most common reason for deterioration of concrete than any other cause. Figure 3 (a) and (b) indicate spalled concrete and corroded steel due to lack of adequate cover (less than 10 mm) coupled with porous concrete. The 1.0 m wide cantilever slab of Figure 3 (a) was about 23 years old, and the portico slab of Figure 3 (a) was about 15 years old when concrete spalled; both the structures are located in mild environments away from any major industry. Figure 3 (a) indicates the hooks at the ends of the plain bars are missing for several bars; further, the reinforcement lies at the bottom of the cantilever. The problem of concrete cover appears to be lot more serious in labour intensive construction than in mechanised construction.



(a) Cantilever slab



(b) Portico slab

Fig. 3 Corrosion of steel and spalling of concrete due to inadequate cover

2.4 Corner reinforcement in rectangular slabs

The requirements of reinforcement in the corner regions of rectangular slabs for torsional moments differ considerably as per various codes. DIN 1045 recommends orthogonal reinforcement equal to the maximum bottom reinforcement of the slab over 0.3 times the smaller span. However, IS 456 and AS 3600 recommend reinforcement equal to 0.75 times the maximum bottom steel area per metre length over 0.2 times the smaller span.

Obviously, it is much simpler to provide the corner reinforcement the same way as the mid-span bottom bars from practical considerations, rather than reduce it to 75 percent. However, the length factors of 0.3 and 0.2 cannot be explained away; either the value of 0.3 is conservative or 0.2 is inadequate.

The author was embarrassed more than once by the queries of the students regarding the corner reinforcement during site visits. The corner reinforcement was not provided at several sites visited by the author, with no apparent distress to the structures. The reasons could be conservative assumptions regarding material strength and loads or the support conditions.

2.5 Shear reinforcement

Specifications pertaining to shear reinforcement are possibly more elaborate in DIN 1045 than any other code. Not many codes take cognizance of various shear zones in specifying the maximum spacings of stirrups like DIN 1045; AS 3600 takes into account various shear zones by specifying the shear capacity of the section with minimum shear reinforcement. AS 3600 and DIN 1045 do not specify any limit to the angle of inclined reinforcement, while IS 456 and IRC 21 limit the inclination of longitudinal bars to 45 degrees, and ACI 318 to 30 degrees.

It does not appear rational to ignore the bars inclined at less than 45 degrees as per IS 456 or IRC 21, while other codes consider them to be effective.

2.6 Other factors

Similar differences exist regarding the maximum spacings of stirrups, interaction of torsion and flexure, and splices to mention a few. It is difficult to estimate the influence of these parameters on structural performance. However, these specifications are also to be examined to bring more uniformity between various codes.

3 THERMAL STRESSES

It can be said that all the codes of practice deal inadequately with the problem of thermal stresses. Temperature variations through structural depth induce in plane as well as flexural stresses in concrete structures, and the neglect of these stresses leads to inevitable cracking. Cracking of long slabs in transverse direction through the depth due to inadequate distribution reinforcement is a well known problem [6]. The minimum distribution steel recommended by the codes may not be adequate to resist tensile stresses due to temperature variations.

Similarly, cracking of bridges due to temperature effects has led to considerable research on these aspects. However, the codes are yet to incorporate rational specifications regarding design temperature distributions for various structures; the current specifications induce soffit tensile stresses that are higher than actual values for beams of depths less than about 2.0 m, and lower values for larger beam depths [9].

4. CONCLUSIONS

Codes of practice of various countries differ from each other significantly on several aspects. Thus a design practice that may be satisfactory in one country may be unsafe as per the code of another country. Some of these aspects are discussed in some detail along with actual construction practice and the influence on structural performance. There is a need to bring consistency and uniformity between the codes of practice of various countries on one hand, and rationalise the specifications to make them practicable on the other. Further, rational design specifications on temperature effects are still lacking despite the evidence of distress to structures when these aspects are ignored.

It would appear that the design specifications are not always translated into construction practice, particularly those pertaining to concrete cover. Lack of adequate cover is perhaps the most common cause of early deterioration of concrete structures. Thus the need for proper cover specifications and tolerances, and for their implementation can never be over-emphasised. There is a need to formulate specifications for bar supports as well, in order to ensure the required concrete cover.

Consistent specifications that also suggest acceptable tolerances, and extension of the codes of practice to include the aspects discussed in this article should go a long way in developing unambiguous and rational guidelines to help evolve economical and creative designs.

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