Structures 5 (2016) 101–111

Contents lists available at ScienceDirect

Structures

journal homepage: http://www.elsevier.com/locate/structures

Partial safety factor for reinforcement

Andrew Beeby [a,1], Paul Jackson [b]

[a] Formerly University of Leeds, United Kingdom
[b] Ramboll UK, Carlton House, Ringwood Road, Woodlands, Southampton SO40 7HT, United Kingdom

ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form 7 September 2015
Accepted 7 September 2015
Available online 24 September 2015

Keywords:
Reinforced concrete
Safety factors
Reliability

ABSTRACT

In 1994 a proposal was published in the Structural Engineer [1] that the partial safety factor for reinforcement be reduced from 1.15 to 1.05. This was accepted and incorporated in BS8110 [2]. A change was subsequently made to the specified characteristic strength of reinforcement, changing it from 460 N/mm^2 to 500 N/mm^2. As a temporary measure until data was available on the characteristics of the new specification, the partial safety factor was changed back to 1.15. This study uses new, and very thorough, data obtained from CARES on current reinforcement properties to re-examine the requirements for a suitable partial safety factor for current reinforcement production.

The reliability approach is first considered using the previous data. The approach is then applied using the new data and a new factor is suggested. The practical implications and the alternative of deriving factors from experience are then considered.

The quantitative study is carried out on sections subjected to pure flexure although implications for other aspects are also considered. It is concluded that the partial safety factor of 1.15 is unnecessarily high and the value of 1.05 is justified.

The paper was first drafted by Professor Beeby who died shortly afterwards and before responding to comments by the second author. Because a change in the basis of reinforcement standards discussed below was not considered in the first draft, most of the analysis reported was by the second author.

1. Introduction

In 1994, a note was published in the Structural Engineer [1] which investigated the values chosen for the partial safety factor for reinforcement. The value in the codes current at that time for the partial factor was 1.15 (for example, BS8110 [2] and ENV 1992 the predecessor to EN 1992 [3]). The note proposed a reduction of this value to 1.05. This was accepted and the modified value was introduced into BS 8110 by Amendment No.2 (December 1989); it will be seen that the note in the Structural Engineer post-dates the actual modification in the partial factor by some time. The factor in BS 5400 Part 4 (the code for concrete bridges) was not reduced at the same time. This was because it was felt that relying on actual steel data, rather than specified, was dubious when the code could be used with reinforcement from a different statistical population from that for which the gamma factor was derived, as when it is used overseas with steel from other very different suppliers. Whilst this argument may have some merit, it appears that all reliability based calibration of codes of practice necessarily depends on actual distributions so this argument implies other gamma factors in codes should also ideally be restricted in application to the populations they are based on. The current study specifically relates to steel produced to BS 4449 [4] by CARES approved suppliers and it is only intended to apply its findings to that.

In 2005, the standards for reinforcement were changed with the specified characteristic yield strength being increased from 460 N/mm^2 to 500 N/mm^2. This required changes in the manufacturing processes and it became unclear whether the value of 1.05 remained appropriate for the modified specification. It was also understood that some of the steel sold as 460 grade to BS 4449 was identical to steel sold as 500 grade elsewhere and could have been included in the steel population considered in earlier work. For these reasons, as a temporary measure, the partial safety factor was changed back to 1.15 where 500 N/mm^2 reinforcement was used (BS 8110 Amendment 16016 Nov. 2005). This meant that, while the specified characteristic yield strength was increased from 460 to 500, the design strength (equal to characteristic strength/safety factor) remained almost unchanged.

Changes to the partial factor on the reinforcement do not only affect the clauses in codes dealing with the ultimate limit state. Any change to the partial factor leads to a change in the stresses in the reinforcement under serviceability loads and consequently could require changes to the provisions for deflection and crack width control where these are not calculated explicitly.

The objective of this paper is to look at the test information from quality control measurements on current (500 N/mm^2) reinforcement to try to establish what value should most logically be chosen for the partial

E-mail address: Paul.Jackson@Ramboll.co.uk (P. Jackson).

[1] The late.

http://dx.doi.org/10.1016/j.istruc.2015.09.002
2352-0124/

safety factor for the currently available reinforcement. The information on the variability in strength of reinforcement is supplied by CARES and relates to steel manufactured to CARES standards and to BS 4449.

Some of the steel quantities in structures will be decided by serviceability issues or by practical fixing issues. However, it seems reasonable to estimate that at least half of it is decided by ultimate strength. Based on current estimates of reinforcement production and price, the difference between a factor of safety of 1.05 and 1.15 represents a saving of some seven million pounds a year in the UK alone.

2. Methods for establishing the partial safety factor for reinforcement

The methods used here are based on the provisions of Annex C (informative); "Basis for partial factor design and reliability analysis" in BS EN1990: "Eurocode — Basis of structural design" [5]. The approach and the target values used have been developed over a number of years. The target reliability values used for structural codes were originally derived by back analysis of structures designed to previous codes [6] and therefore represent what had been found to be satisfactory. However, the approach gives a more rational basis for comparison and it is hoped that codes will gradually evolve to give more consistent reliability.

The notation used is:

- R_m mean resistance
- $R_{d.}$ design resistance
- E_m mean load effect
- E_d design load effect
- α_R sensitivity factor for resistance, defining the proportion of the safety ascribed to the resistance. This is specified in EN1990 Annex C as 0.8.
- α_E sensitivity factor for load effects, defining the proportion of the safety ascribed to the loading. This is specified in EN1990 Annex C as 0.7.
- $\beta required$ safety index, given in EN1990 Annex C as 3.8 for 50 year design life.
- σ_R standard deviation of the resistance distribution.
- σ_E standard deviation of the distribution of load effects

Clearly, for a satisfactory design, the design resistance must be equal to, or greater than, the design load effect. However, for the purposes of establishing the partial safety factors, the load effect and resistance parts of the problem can be separated and we can write, for the resistance:

$$Rd \geq R_m - 3.04\sigma_R$$

Or:

$$(R_m - R_d)/\sigma_R \geq 3.04$$

The factor 3.04 arises because Annex C of EN 1990 recommends for normal cases that α_R (the sensitivity of resistance) can be considered to be 0.8 and thus that 0.8 times 3.8 = 3.04 standard deviations are considered. It can be shown that use of 3.04 for concrete structures normally leads to a calculated overall safety index β which is greater than the target 3.8 but this aspect will not be considered here.

The design resistance, $R_{d.}$, is calculated according to the appropriate Code provisions and is a function of (for a reinforced concrete section) f_{yk}/γ_S, f_{ck}/γ_C and the geometry of the section. In this study, the objective is to find a suitable value for γ_S but the calculation is made more complex by the presence of the partial factor on the concrete. In fact, if the problem being considered is the strength of a section subjected dominantly to flexure, the effect of the variability in the concrete strength is relatively small and it will be satisfactory to assume the value for γ_C currently used in the Code. This is 1.5. If a more complex study was being carried out, it might be reasonable to find a value for γ_S on this basis then repeat the study using the value obtained for γ_S to establish an improved value for γ_C. This will not be done here as there is no intention to consider any change to the value for γ_C from that currently used. γ_C will therefore be taken as 1.5 throughout. It is also noted that the use of an α_{cc} of 0.85 in the UK National Annex means that this would be equivalent to using a γ_C of 1.76 with the recommended α_{cc} of 1.0 in EN 1992-1-1, although the effect of this change is still small.

In the above:

- f_{ck} the characteristic strength of the concrete
- f_{yk} the characteristic strength of the reinforcement
- γ_C the partial safety factor for concrete
- γ_S the partial safety factor for the reinforcement.

Note that in accordance with EN 1990 and EN 1992 notation, γ_C and γ_S (equivalent to γ_{mc} and γ_{ms} in BS 8110 and therefore in Ref [1]) with upper case suffices are used indicating that allowance for model uncertainty and dimensional errors which affect resistance are covered by these factors.

Information can be obtained from surveys on the variability of concrete strength, section breadth and section depth. As already mentioned, information supplied by CARES will be used for the strength of reinforcement.

A variation in the bar diameter occurs because of wear in the rollers which causes a small increase in the diameter with time. Bar diameter was therefore considered as a separate variable in the previous work, just as plate thickness is considered in equivalent work for structural steelwork. However, since then, BS 4449 has been changed to bring it into line with EN 10080 and it now requires yield and ultimate stress to be calculated from nominal rather than actual area. The true yield strength of the bars is therefore directly proportional to calculated yield stress and including variability of diameter would be incorrectly double-counting the effect of variation in diameter. The previous paper assumed a 1.07% standard deviation in diameter. It also used a mean diameter 1.75% below nominal which represents a more significant difference and is on its own equivalent to a 3.6% change in required safety factor.

What remains to be considered is a suitable method for calculating the section strength as a function of the variables mentioned above. In principle, the derivation of an equation is very straightforward but will be set out below for the record. For simplicity, the derivation will be done for a singly reinforced rectangular section.

It is assumed that the reinforcement will have yielded at failure and, in carrying out analyses, care will be taken to ensure that this is so. The analysis used was able to estimate the reliability of over-reinforced beams where the reinforcement does not yield but this is independent of steel partial safety factor so cannot be used to determine that. It is noted that reducing the partial safety factor for reinforcement makes beams which previously appeared under-reinforced appear over-reinforced in design calculations so heavily reinforced beams cannot be included in the study. It will be seen later that the more heavily reinforced sections are not critical for deriving the required safety factor.

The area of the reinforcement is given by: $A_s = n\pi\phi^2/4$ where n is the number of bars and ϕ the nominal bar diameter. From the equilibrium of longitudinal forces, we can write:

$$f_y n\pi\phi^2/4 = bxk_1 f_c$$

where

- f_y yield strength of reinforcement
- f_c compressive strength of concrete
- b breadth of section
- x depth of compression zone at failure, measured from most compressed face.
- k_1 coefficient relating the average concrete stress to the concrete strength.