Design of Dowels and Fastenings in Concrete

Ian Feltham

Abstract
This Note discusses the position regarding advice on the design of steel dowels or fastenings in concrete. It concentrates on two documents originally published by the Comité Euro-International du Béton (CEB), one dealing with dowels, the other with fastenings.

Introduction

Neither *BS8110*[1] nor *EC2*[2] give guidance on the shear resistance of steel dowels or fastenings (anchors, studs, and lugs) in concrete. However advice is available from the CEB-FIP, which have now merged to form the International Federation for Structural Concrete (*fib*).

Dowels

The CEB-FIP Model Code 1990[3] *(MC90)* gives some rather restrictive guidance on the strength of dowels, which is based on the work of Rasmussen[4].

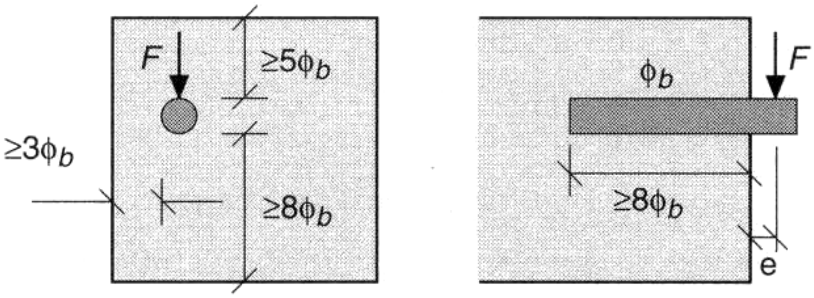

Fig. 1 Geometric conditions

The expression for the design shear resistance, F_{ud}, of a dowel with the geometric conditions given in Fig. 1, and adequately reinforced to prevent punching and splitting type failures, is:

$$F_{ud} = (1.3/\gamma_{Rd}) \times \phi_b^2 \times [\sqrt{\{1 + (1.3\varepsilon)^2\}} - 1.3\varepsilon] \times \sqrt{\{f_{cd}\, f_{yd} \times (1 - \zeta^2)\}}$$

but not greater than $A_s f_{yd}/\sqrt{3}$ (the shear resistance of the dowel)

with $\varepsilon = 3(e/\phi_b) \times \sqrt{\{f_{cd}/f_{yd}\}}$

where: ϕ_b denotes the diameter
A_s denotes the cross-sectional area of the dowel,
f_{cd} is the design value of the compressive strength of concrete, which is equivalent to $0.67f_{cu}/\gamma_m$ in *BS8110* terminology
f_{yd} is the design value of the steel yield stress, which is equivalent to f_y/γ_m in *BS8110* terminology
e is the load eccentricity
γ_{Rd} is a partial coefficient which may be taken equal to 1.3
ζ is σ_s/f_{yd} (where σ_s is the simultaneous axial stress (tensile or compressive) in the bar).

The expression applies only to dowels that are placed before casting of the concrete. The shear displacement along a concrete-to-concrete interface, which is needed for the mobilisation of F_{ud}, should be assumed to be $0.10\phi_b$, which is relatively large.

For: $f_{cd} = 0.45f_{cu}$
$f_{yd} = 400\text{MPa}$
$e = 0$
$\gamma_{Rd} = 1.3$
$\zeta = 0$

$F_{ud} = 13.4\phi_b^2\sqrt{f_{cu}}$ where F_{ud} is in N, ϕ_b is in mm and f_{cu} is in MPa.

For a typical dowel with ϕ_b = 12mm and f_{cu} = 35MPa, F_{ud} = 11.4kN and the displacement at ultimate load is 1.2mm.

Fastenings
The most comprehensive advice on the subject of fastenings is the CEB *Design guide*[5] on the design of fastenings in concrete, which covers the calculation of both shear and tensile resistances, although bearing failure is not covered explicitly. The European Committee for Standardization (CEN) is preparing a Technical Standard based on the CEB design method and some aspects of it are described in a paper in *the ACI Structural Journal*[6] by Fuchs, Eligehausen and Breen, where it is called the Concrete Capacity Design (CCD) Approach. This paper has been endorsed by the ACI Committee 318, which has included the approach as Appendix D its latest reinforced concrete code[7].

The CEB guide is in three parts. The first includes general provisions, scope, terminology and determination of action effects. The second part comprises the calculation of the ultimate limit states of resistance and fatigue and the serviceability limit state for fastenings with post-installed expansion and undercut anchors. Various modes of failure are considered including steel failure, pull-out, concrete cone, splitting and prying. The final part covers equivalent topics for fastenings with cast-in-place anchors

There are too many design formulae in the guide to summarise in this Note. However, as would be expected, the various expressions of ULS resistance related to steel failure are proportional to the sectional area of the fixing and steel strength, and those relating to concrete failure are proportional to the sectional area and the square root of the concrete strength (this being a measure of the concrete tensile strength). The constants of proportionality relate to the values of edge distances, spacing, member thickness and activated load-bearing length of the dowel, all normalised with respect to the fixing diameter, the reinforcement arrangement and whether the concrete is cracked or not.

Although the guide does not cover dowels, it is interesting to note that the shear resistance of an individual headed stud in a thick, cracked structural member with the geometric constraints given in Fig. 1 is $4.8\phi_b^2\sqrt{f_{cu}}$, only 35% of the resistance limited by bearing as calculated using *MC90*.

The detailed design method in Hilti's *Fastening Technology Manual*[8] follows the form of the CEB guide without considering bearing stress. For large edge distances, shear resistances greater than those for calculated for dowels using the expressions in the first part of this Note can be obtained. The edge distance, c, should therefore not be taken as greater than 8.5ϕ.

References
(1) BRITISH STANDARDS INSTITUTION. *BS8110: Part 1: 1997*. Structural use of concrete. Part 1. Code of practice for design and construction. BSI, 1997.
(2) BRITISH STANDARDS INSTITUTION. *DD ENV 1992-1-1: 1992*. Eurocode No. 2. Design of concrete structures. Part 1: General rules and rules for buildings. BSI, 1992.
(3) COMITÉ EURO-INTERNATIONAL DU BÉTON. CEB-FIP Model code 1990. Design code. Thomas Telford 1993.
(4) RASMUSSEN, B.H. The carrying capacity of transversely loaded bolts and dowels embedded in concrete. Bygningsstatiske Meddelser, 34(2), 1963.
(5) COMITÉ EURO-INTERNATIONAL DU BÉTON. Design of fastenings in concrete - design guide. Thomas Telford, 1997.
(6) FUCHS, W., ELIGEHAUSEN, R. *and* BREEN, J.E. Concrete capacity design (CCD) approach for fastenings to concrete. ACI Structural Journal, January-February 1995, pp.73-94.
(7) AMERICAN CONCRETE INSTITUTE. *ACI318-02*. Building code requirements for reinforced concrete. ACI, 2002.
(8) HILTI CORPORATION. Fastening technology manual. Hilti, 2002.

First published in October 1995 as NST53/4
Revised (a) February 2003 – references updated
Revised (b) January 2005 – clarification of failure types and reference to Hilti added