Achieving robustness of precast concrete stairs using proprietary cast-in inserts

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Introduction

Precast concrete stair flights and landings are a common form of construction. As individual elements they are inherently robust, and as the spans of such elements are relatively small, flexural or shear failures are very rare. In the event of an occurrence such as fire or the failure of lifts, stairs often provide the only practical means of escape for the occupants of a building. It is vital therefore, that stairs remain available and useable under extreme conditions without suffering progressive collapse. One method through which this can be achieved is the anchoring of the individual elements into the structure.

Background

It would appear that no current British Standards have any requirement for dealing with the robustness of stairs. However, Building Regulation Approved Document A3[1] requires that '*in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause*'. It then states that this requirement '*will be met by an appropriate choice of measures to reduce the sensitivity of a building to disproportionate collapse should an accident occur*', and refers to various Standards including BS 8110-1:1997[2]. Until recently, this was the relevant design Standard for precast stair elements. However, this is now superseded and was withdrawn by BSI on 16 April 2010. It has been replaced by BS EN 1992-1-1:2004, *Eurocode 2: Design of concrete structures*, commonly called 'EC2'[3]. Whilst BS 8110 might still be used, its adoption will become increasingly irrelevant. BS 8110 (clause 5.1.8.3) did however have a requirement that '*...precast floor, stair or roof members...should be effectively anchored...to that part of the structure containing the ties*'. EC2 has no equivalent requirement, and a bridging document was deemed necessary by BSI.

Figure 1
Support method: Steel angles bolted to wall

Currently, in the UK, the relevant guidance document is PD 6687-1:2010 *Background paper to the National Annexes to BS EN 1992-1 and BS EN 1992-3*[4]. Clause 2.26.2 states:

'BS EN 1992-1-1:2004 does not cover anchorage of precast floor and roof units and stair members explicitly and the following recommendations should be followed:
a) All precast floor, roof and stair members should be effectively anchored whether or not such members are used to provide other ties required in BS EN 1992-1-1:2004, 9.10.2.
b) The anchorage described in a) should be capable of carrying the dead weight of the member to that part of the structure that contains the ties.

These recommendations apply to precast units and stairs incorporated into concrete construction. Where they are incorporated into other forms of construction (e.g. masonry, structural steel or timber) the recommendations of the relevant Eurocode and its National Annex should be followed.'

This effectively reinstates the BS 8110 requirement to anchor all elements, including precast stairs in almost all buildings. When considering precast stairs in a concrete stairwell, it is considered that the stairwell wall is '*that part of the structure that contains the ties'*.

It should be noted that the requirements are carefully worded to avoid any reference to 'connection' or 'tying' of stair elements to the structure. This does not, however, preclude other methods utilising physical connection or tying.

The alternative methods of achieving a tie include 'pull-out' reinforcement cast into the *in situ* walls. However, this has to be accurately positioned in order to coincide

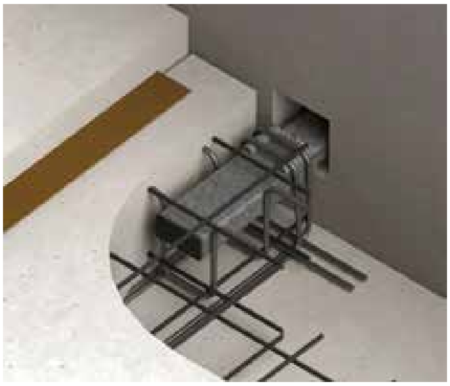


Figure 2
Support method: Proprietary support inserts

with relatively thin toppings on landings. Due to this accuracy requirement, these reinforcement systems cause problems when cores are slip-formed, as the box containing the pull-out bars can be dragged upwards by the formwork.

This article is intended for engineers dealing with the requirements for precast stair elements to be anchored into the structure, achieving the anchorage using proprietary cast-in inserts. It is limited to the use of precast concrete stair flights and landings contained within an *in situ* or precast concrete stair well.

Material and load factors

In the absence of guidance, a partial factor $\gamma_g = 1.0$ is suggested.

The regulations give no guidance on material stress levels or partial factors. It is suggested that for the steel inserts, a plastic design approach is taken. This would seem appropriate since the inserts should be fully grouted with the hollow section filled, minimising any possibility of buckling of the sides of the hollow sections. The stress is limited to the ultimate yield strength. PD 6687 does not require variable actions to be considered when checking robustness. For actions, the regulations merely require that the anchorage should carry '*the dead weight of the member*'. It is, however, recommended from a practical viewpoint, that this dead weight should include permanent finishes, and for a given element should also include the dead weight imposed on it by supported members. Thus, when considering a landing, the figure would include the self-weight of any flights carried by it. No limits are given as to the amount of cracking or deformation allowed.

Flight to landing connection

The connection between flights and landing is not covered here as there are many different solutions available, and the solution is a matter of personal choice. The same overall anchorage requirements still apply however.

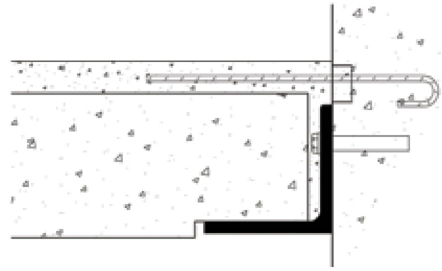
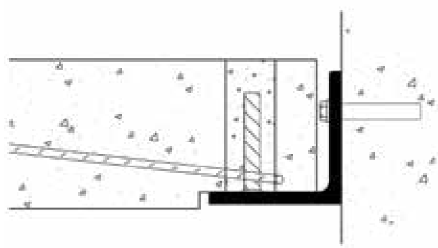


Figure 3
Steel angle anchorage: 'pull-out' continuity bars into topping

Figure 4
Steel angle anchorage alternative: welded dowel



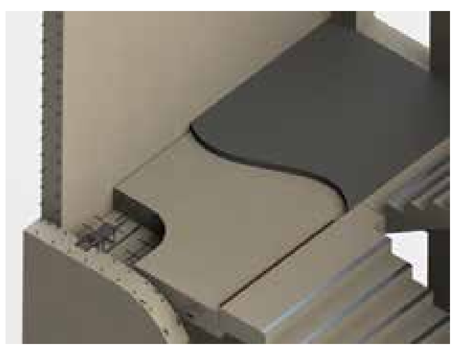


Figure 5
Insert cast into end of landing

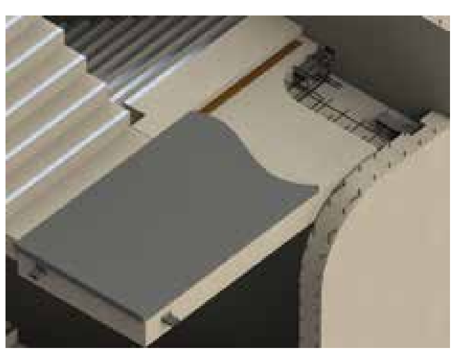


Figure 6
Two inserts repositioned to rear wall

Landing to wall connection

The detail employed at this interface depends largely on the method of support. There are two principal methods used in the UK: steel angles bolted to the wall (Figure 1), or proprietary support inserts (Figure 2). For steel angles, the anchorage is normally provided either by 'pull-out' continuity bars into a topping (Figure 3) or a welded dowel on the angle (Figure 4). If continuity systems are used, then the topping must be of a structural grade and reinforced. Calculation of bond length should be based on an assumption of 'poor' bond condition. Measures must be taken to ensure that separation of precast and topping does not occur. For a dowel, the main connection items to be checked are the fixings into the wall, the dowel welding and the dowel capacity in the precast concrete. Local reinforcement must be provided around dowels to prevent burst-out. The guidance provided here is primarily applicable to proprietary inserts.

Support by proprietary inserts

The inserts should first be designed to ensure that they will carry the variable action of the landings, stairs and any imposed loads in normal conditions. This is carried out by a simple design check against published capacities, or the insert supplier will normally provide a free design service. As an example, consider a landing spanning end-to-end in a stairwell, with two flights supported on one edge (Figure 5). Normally, inserts would be cast into the ends of the landing as shown, and this would still be the case even if alternative anchorage (e.g. continuity bars) is provided.

Robustness using inserts

If the inserts are being used to provide robustness anchorage, then two of the inserts are repositioned. By moving two of the inserts to the rear wall (Figure 6), the landing is physically anchored in both horizontal axes, since the inserts offer horizontal resistance via transverse shear and bending capacities. By default, the inserts will have already been checked for adequacy in the vertical axis, so all three orthogonal axes are dealt with.

The inserts have vertical bending and shear capacity which is given in published data such as a European Technical Approval (ETA). These can be used to check the capacity under 'normal' actions. They also have horizontal/transverse capacities which are usually greater than the vertical capacity due to the rectangular profile, although these are not usually published and need to be calculated (Table 1).

In the 'robustness' situation, capacities are calculated using the plastic section properties and the ultimate yield strength. Thus, an insert has:

a vertical shear capacity $V_{pl,Rd,V}$
a vertical moment capacity $M_{pl,Rd,V}$
a horizontal shear capacity $V_{pl,Rd,H}$
a horizontal moment capacity $M_{pl,Rd,H}$

These capacities can be found in Table 2.

Table 1: Section properties used to calculate horizontal/transverse bending and shear capacities

Published capacity	Section size	Area	Shear area A_v [1]		Plastic section moduli W_{pl}	
			$A_{v,V}$ [2]	$A_{v,H}$ [3]	$W_{pl,V}$ [4]	$W_{pl,H}$ [5]
40kN	70 x 40 x 4	7.75cm²	2.82cm²	4.93cm²	11.8cm³	17.8cm³
100kN	100 x 50 x 6	15.6cm²	5.20cm²	10.40cm²	28.5cm³	46.9cm³

[1] **Calculated in accordance with EN 1993-1-1 clause 6.26(3)**
[2] **Shear area for vertical actions**
[3] **Shear area for horizontal actions**
[4] **Plastic modulus for vertical actions**
[5] **Plastic modulus for horizontal actions**

Orientation in use

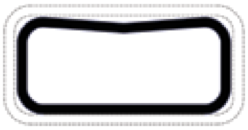


Table 2: Capacities using plastic section properties and ultimate yield strength

Published capacity	Vertical shear capacity $V_{pl,Rd,V}$	Vertical moment capacity $M_{pl,Rd,V}$	Horizontal shear capacity $V_{pl,Rd,H}$	Vertical moment capacity $M_{pl,Rd,H}$
40kN	76.52kN	5.55kNm	133.78kN	8.37kNm
100kN	141.10kN	13.39kNM	282.21kN	22.04kNm

Horizontal actions result from the anchorage forces derived in Figure 7, where:

F1 = Self-weight of flight split (50% to each end of flight)
F2 = Self-weight of landing split (50% to each end, plus F1, taken by inserts at 'A')
F3 = Self-weight of landing split (50% to each end, taken by inserts at 'B')

Vertical loads are calculated by a simple analysis, taking into account the position of the front inserts and the point of application of the loads from the flights.

To calculate bending moments in the inserts, a suitable lever arm is required. ETA figures typically use a figure of 75mm from the centre of support to the precast, so this figure is taken unless actual conditions dictate otherwise. In practice, this is a generous figure since the stiff insert tends to rotate about the front of the bearing, reducing the lever arm significantly. The same lever arm is used for both vertical and horizontal actions. If a shorter lever arm is assumed, then spalling effects should be considered.

The vertical shear, vertical moment, horizontal shear and horizontal moment for each insert may thus be calculated and denoted as $V_{Ed,V}$, $M_{Ed,V}$, $V_{Ed,H}$ and $M_{Ed,H}$ respectively. The applied actions are then checked against the calculated plastic resistances in Tables 1 and 2.

For multiple applied actions, guidance is scarce, but following the principles of EN 1993-1-1 clause 6.2.9.1 (6)[5], for each insert, a check against unity is made, i.e. $(V_{Ed,V} / V_{pl,Rd,V}) + (M_{Ed,V} / M_{pl,Rd,V}) + (V_{Ed,H} / V_{pl,Rd,H}) + (M_{Ed,H} / M_{pl,Rd,H}) \leq 1$

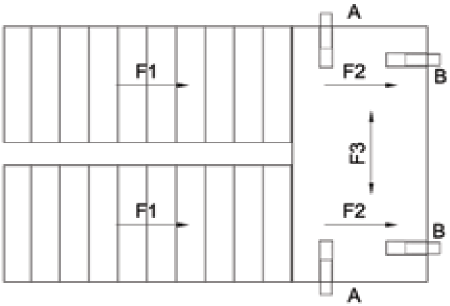
Where:
$V_{Ed,V}$ = Applied shear – vertical
$V_{Ed,H}$ = Applied shear – horizontal
$M_{Ed,V}$ = Applied bending moment – vertical
$M_{Ed,H}$ = Applied bending moment – horizontal
$V_{pl,Rd,V}$ = Plastic shear resistance – vertical
$V_{pl,Rd,H}$ = Plastic shear resistance – horizontal
$M_{pl,Rd,V}$ = Plastic moment resistance – vertical
$M_{pl,Rd,H}$ = Plastic moment resistance – horizontal

If this check against unity is satisfied, then the inserts are deemed to offer anchorage in the three local axes and hence give the anchorage required by PD 6687. Other checks such as bearing stresses in the wall should be carried out as normal.

The technique described will not be the optimal solution in every situation, and there will be instances where a more direct 'tying' approach is preferable. In all cases, sound engineering judgment is required to address this safety-critical requirement.

This guidance is based on RVK and TSS inserts as supplied by J&P Building Systems Ltd, together with the associated local reinforcement. Other inserts may not behave in the same manner. It is strongly recommended that any inserts used have full European Technical Approval and are CE compliant as required by the Construction Products Regulation.

Figure 7
Derivation of anchorage forces



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► 2 British Standards Institution (1997) *BS 8110-1:1997, Structural use of concrete. Code of practice for design and construction* London: BSI

► 3 British Standards Institution (2004) *BS EN 1992-1-1:2004: Eurocode 2: Design of concrete structures,* London: BSI

► 4 British Standards Institution (2010) *PD 6687-1:2010: Background paper to the National Annexes to BS EN 1992-1 and BS EN 1992-3,* London: BSI

► 5 British Standards Institution (2005) *EN 1993-1-1:2005 Design of steel structures – General rules and rules for buildings,* London: BSI

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