mpa British Precast Flooring Federation

Design Guide for Concrete Toppings to Beam & EPS Block Suspended Floors

September 2017

Cooperating organizations

BBA	Dr Morteza Aboutalebi
	Brian Chamberlain
	Seyed Tajallifar
BPF (British Plastics Federation)	John Thornberry
British Precast	Dr Nick Gorst
PFF	Dr John Cotton
BRMCA	Dr Chris Clear
Concrete Society	Dr Neil Crook
Grace Construction Products	Damian Thomas
HBF	Michael Black
	Dale Saunders
Low & Bonar	Mark Mitchell
	Richard Briers
	Mike Boggust
NHBC	Sally Boorer
	Andrew Jackson
	Graham Perrior
Propex Concrete Systems	Simon Evans
Tarmac	Glanville Norman
	Dharmesh Buch
	Peter Wood

September 2017 edition

Foreword

The aim of this design guide is to provide a central source of information relating to suspended beam and EPS flooring systems. It should be read in conjunction with the independent third party assessment relative to the floor system which is being considered.

Contents Page

1. Introduction

Suspended beam and block floors have been in regular use, particularly for low-rise residential buildings, for many years, originally incorporating load-bearing concrete blocks between the prestressed beams, but more recently incorporating insulating materials (EPS), which were first introduced to the UK market some 25 years ago. Since then they have evolved to adapt to ever changing regulations which have required increased levels of thermal performance.

2. History of insulated floors

This publication focuses on the use of non-resisting EPS blocks, but a similar approach may be used for non-load bearing concrete blocks for low-rise residential construction.

The first types of insulated floor systems incorporated T-shaped polystyrene infill blocks that sat in between the prestressed concrete T-beams and the tops of the infill blocks sat above the beams. Where necessary thin sheet material was cut to cover the top of the beams, allowing for different widths and multiples of beams (see Figure 1). These types of floors were dry finished with a floating timber floor but later versions use higher grade insulating material and are finished with a concrete topping.

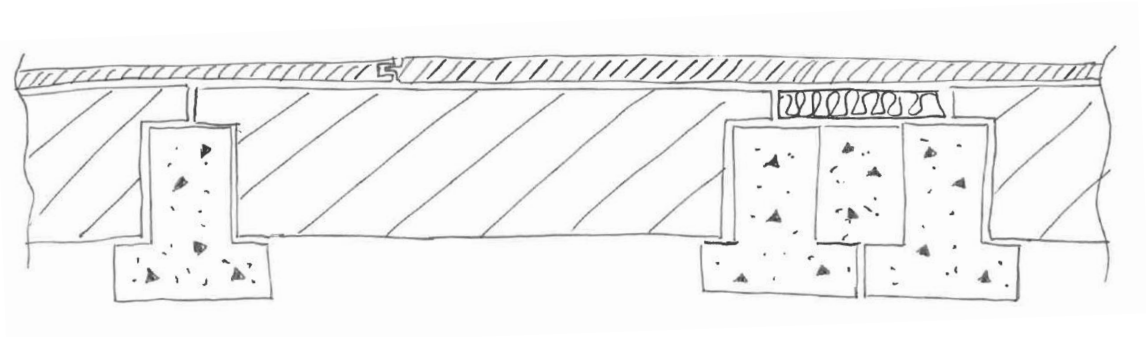

Figure 1

Subsequent versions used L-shaped polystyrene blocks that fitted between the beams with the toes extending under the beams. Sheet material was either cut and inserted to suit various beam widths and multiples, or toe lengths were manufactured for bespoke layouts. These floors are finished with a concrete topping (see Figure 2).

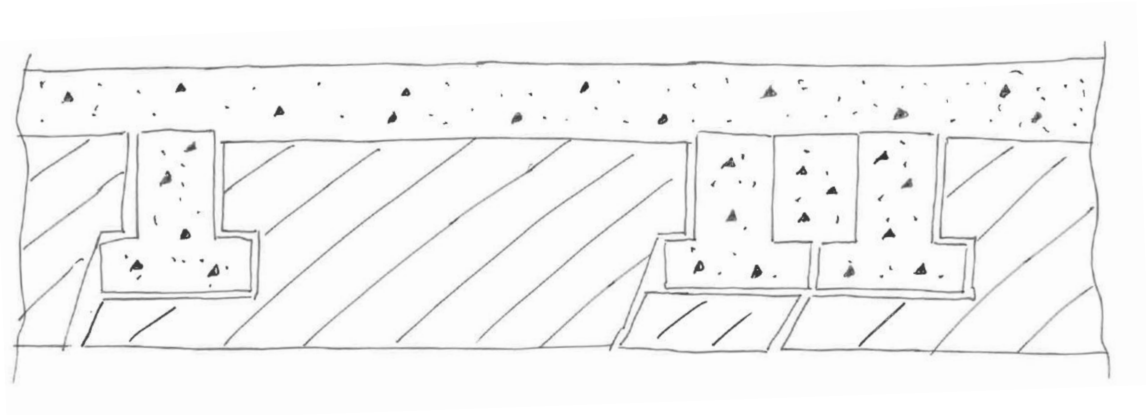

Figure 2

More recent variations use T-shaped blocks between the beams with separate sheet material placed over the entire floor (see Figure 3) or U-shaped channels centred over the beam and separate blocks between the beams. (see Figure 4).

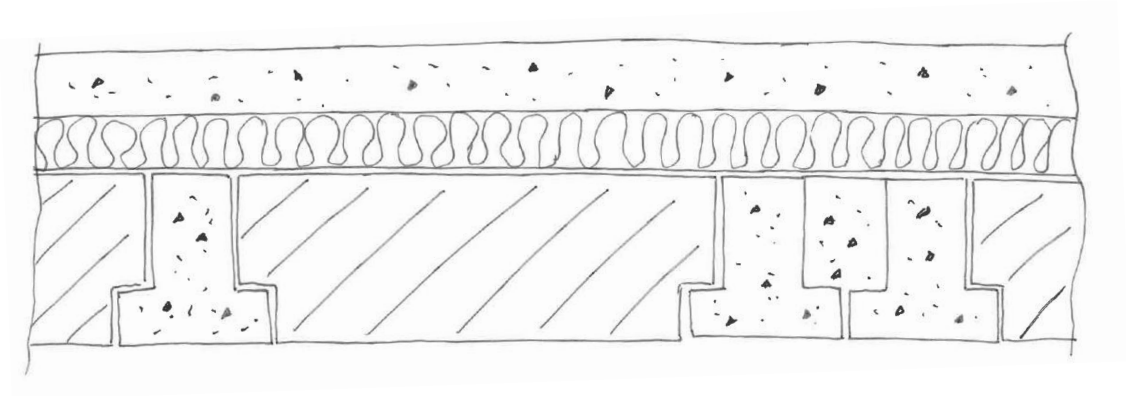

Figure 3

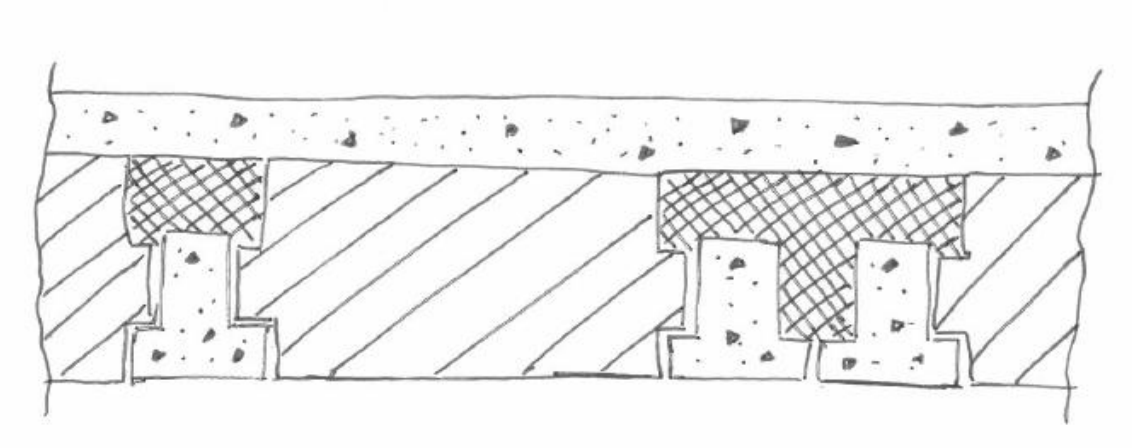

Figure 4

The main driver for the changes to the flooring systems is the increased level of thermal performance that is now required by Part L of the Building Regulations. Changes are also aimed at improving the efficiency on site by simplifying the installation.

3. Covering standards

BS EN 15037 'Precast concrete products. Beam and block floor systems', covers suspended beam and block floors. It is divided into five parts as follows:

- Part 1 – Beams
- Part 2 – Concrete Blocks
- Part 3 – Clay Blocks
- Part 4 – EPS Blocks
- Part 5 – Lightweight Blocks

The prestressed concrete beams that are used in the floors are covered by Part 1 of the standard. However, the more recent types of EPS blocks fall outside of the scope of Part 4 due to the shape of the block and how the applied load is transferred to the beams.

Part 4 categorises EPS blocks as either non-resisting (R1) or resisting (R2). If a block is type R1 then it has no mechanical function in the final floor system, but it has to be able to withstand a 1.5 kN point load to simulate foot traffic during the construction phase. Type R2 blocks contribute to the mechanical function of the floor and must be able to withstand a 2.0 kN point load. In either case the point load acts over a 100 mm x 300 mm footprint. In addition, Type R2 blocks must be minimum EPS200 grade material. The term EPS200 means that the EPS should have a compressive strength of 200 kPa (0.2 N/mm^2) at 10% strain deformation under short term static load. A limitation of BS EN 15037 is that it would appear it is intended to cover suspended beam and block floors, but it does not specifically include guidance on suitable toppings, be it a sand cement screed, timber floor or structural concrete topping.

The following documents are proposed for use in the design of structural concrete toppings:

- BS EN 1992-1-1 + UK NA
- BS EN 14651
- BS EN 14845
- TR34 – Concrete Industrial Ground Floors
- TR63 – Guidance for the Design of Steel-Fibre-Reinforced Concrete
- TR65 – Guidance on the use of Macro-Synthetic-Fibre-Reinforced Concrete

4. Structural behaviour of low-rise beam and block floors with structural concrete toppings

Beam and block floor systems using non-resisting EPS blocks all follow the same principle in that the applied loads are supported by the structural concrete topping which spans across the beams and transfers the load to the beams either by direct contact or by structural grade EPS. If structural grade EPS is used to transmit loads, then the designer will need to give due consideration to the layering and joint positions of the EPS components. The grade of the EPS will depend on the applied load, the width of the top of the beam(s) and whether single or multiple beams are used (see Figure 4). The EPS has to exhibit low creep characteristics for both short term and long term loading so that excessive compression of the material does not occur. For systems with a separate top sheet EPS130 grade is normally used for the topsheet, whereas systems using infill blocks that extend above the beams generally have a separate section of EPS250 grade material dovetailed to the main block. For non structural applications, i.e. the infill blocks, EPS90 grade is commonly used. The reader should note that beam and EPS block floor systems are not limited to the grades of EPS mentioned above.

It should be noted that as the T-beams are manufactured from prestressed concrete creep will occur within them and as such the deflection / camber will vary over time. The initial camber within the beam is reduced by 10 to 15mm by the weight of the concrete topping.

In current practice the range of T-beams used within the industry does not vary significantly. Typically there are three depths of beams used: 150 mm, 175 mm and 225 mm with a top width of 50 mm or 75 mm. When the various options for the infill blocks are combined with the beams the result is beam centres of between 590 mm and 610 mm. As such there is only a small variation between the various systems being supplied to the market in terms of beam centres and structural performance of the concrete topping.

When calculating the induced bending moment within the concrete topping a conservative approach is adopted in that it is assumed the concrete topping is simply supported between the beams. This approach will allow for a maximum moment to be used regardless of the spacing of the beams when the infill blocks are cut down or if narrow blocks are used. It also makes allowance for any expansion joints that may be in the topping.

Some concerns have been raised regarding the concrete exhibiting brittle failure under fatigue stress, but for a ground floor in a domestic application dynamic loads are not considered nor are transient vibrations from earthquakes.

The approach taken in this report for suspended beam and block floors is to minimise the risk of shrinkage and thereby the effect of shrinkage-induced stresses by careful attention to concrete mix design, floor detailing and construction. The reader's attention is drawn to the document '*Application guide for the specification and installation of concrete toppings to beam & EPS block suspended floors*'.

5. Design equations

5.1. Macro-fibres

The design approach for macro-fibres uses the values of f_{R1} and f_{R4} obtained from beam tests performed in accordance with BS EN 14651. This is not design by performance testing, but is design based on material properties, as outlined in Section 5.2 of TR63 and Section 5.1.2 of TR65. The advantage of this method is that any fibre and any dosage can be used provided that the required crack mouth opening displacement (CMOD) tests have been carried out and the values for f_{R1} and f_{R4} are available.

The following equations are used to calculate the moment capacity of macro-fibre concrete.

Example 1 calculation.

Parameters:

- Imposed variable action = 1.5 kN/m^2
- Alternative point load = 2 kN on 50 mm square
- Beam centres = 610 mm
- Topping thickness, h = 65 mm (nominal 70mm with 5mm allowance for camber)
- Material partial factor for concrete, γ_c = 1.5
- Variable action partial factor = 1.5
- Permanent action partial factor = 1.35
- Concrete unit weight (unreinforced) = 24 kN/m^3
- Concrete characteristic strength, f_{ck} = 25 MPa
- Macro-fibre dosage = 5 kg/m^3
- f_{R1} = 1.5 MPa
- f_{R4} = 1.7 MPa

BENDING

EC2 Applied moment M_{ED} = $P.L/4 + W.L^2/8$
= $(1.5 \times 2 \times 0.61/4) + (1.35 \times 0.065 \times 24 \times 0.61^2 / 8)$
= 0.56 kNm/m

TR34 $\sigma_{r1} = 0.45\, f_{R1}$
= 0.45×1.5
= 0.675 MPa

TR34 $\sigma_{r4} = 0.37\, f_{R4}$
= 0.37×1.7
= 0.629 MPa

Eq 6 $M_u = h^2 / \gamma_c \times (0.29\, \sigma_{r4} + 0.16\, \sigma_{r1})$
= $0.065^2 / 1.5 \times (0.29 \times 0.629 + 0.16 \times 0.675) \times 10^3$
= 0.82 kNm/m

Check $M_u > M_{ED}$ **OK in bending**

PUNCHING SHEAR

Shear at the face of the loaded area

	d	$= 0.75 \times h$ $= 0.75 \times 65$ $= 49$ mm
Eq 6.49	v_{Ed}	$= (1.5 \times P) / (u \times d)$ $= (1.5 \times 2 \times 1000) / (4 \times 50 \times 49)$ $= 0.306$ MPa
Eq 6.6N	v	$= 0.6 \times (1 - f_{ck}/250)$ $= 0.6 \times (1 - 25/250)$ $= 0.54$
UK NA	$\alpha_{cc,pl}$	$= 0.6$
	$f_{cd,pl}$	$= \alpha_{cc,pl} \times f_{ck} / \gamma_c$ $= 0.6 \times 25 / 1.5$ $= 10.0$ MPa
UK NA 6.4.5(3)	$v_{Rd,max}$	$= 0.5\ v\ f_{cd,pl}$ $= 0.5 \times 0.54 \times 10$ $= 2.7$ MPa

Check $v_{Rd,max} > v_{Ed}$ **OK for punching shear at the face of the loaded area**

Shear on the critical perimeter (at distance 2d from the loaded area)

Fig 6.13	Perimeter	$= 4 \times 50 + 2 \times \pi \times (2 \times 49)$ $= 816$ mm
Eq 6.49	v_{Ed}	$= (1.5 \times P) / (u \times d)$ $= (1.5 \times 2 \times 1000) / (816 \times 49)$ $= 0.075$ MPa
Eq 6.2b	k	$= 1 + \sqrt{(200 / d)} \leq 2.0$ $= 1 + \sqrt{(200 / 49)}$ $= 3.02$ $= 2.0$
Eq 6.3N	v_{min}	$= 0.035 \times k^{3/2} \times f_{ck}^{\ 1/2}$ $= 0.035 \times 2.0^{3/2} \times 25^{\ ½}$ $= 0.49$ MPa
Eq 6.2b	Taking $\sigma_{cp} = 0$, then $v_{Rd,c} = v_{min}$ $= 0.49$ MPa	

Check $v_{Rd,c} > v_{Ed}$ **OK for punching shear on the critical perimeter**

The values of f_{R1} and f_{R4} can be used in one of two ways to design a topping with a new macro-fibre for a flooring system that has previously undergone full-scale testing.

Approach 1 - Equivalence

This approach relies on testing fibre-reinforced concrete samples in accordance with the European Notched Beam Test methodology specified in BS EN 14651. The purpose of the testing is to demonstrate the equivalence between:

- a specified concrete mix (reference concrete), which is reinforced with fibres of a known type and dosage that featured in a full-scale load test, and
- a reference concrete reinforced with an alternative fibre type and dosage.

If the results of the European Notched Beam Test for the alternative fibre when used in the reference concrete are equal to or greater than the results for the existing fibre when used in the reference concrete, then the alternative fibre should perform satisfactorily in the flooring system provided that the concrete used in the topping is otherwise unchanged.

Approach 2 – Reverse engineering

In this approach the design equations are used to back-calculate the values of f_{R1} and f_{R4} that are required to carry the loads and then a dosage of fibres is determined to provide that level of performance. European Notched Beam Test (BS EN1 4651) results are also needed to calibrate the engineered solution against a reference concrete. The designer must be satisfied that the fibre reinforced concrete will ultimately still exhibit the behaviour of a typical fibre reinforced concrete.

5.2. Steel reinforcement

This design approach is familiar with all practicing engineers and is covered within BS EN 1992-1-1.

Example 2 calculation using the same data as in Example 1.

Parameters:

- Assume 25 mm cover to the reinforcement and A142 mesh with longitudinal bars in the bottom layer
- Material safety factor for steel γ_s = 1.15

BENDING		
EC2	f_{yk}	= 500 MPa
Cl 3.1.6(1)P	α_{cc}	= 0.85
	d	= 65 - 25 - 6/2 = 37 mm
Eq 3.20	λ	= 0.8 - max (0,fck - 50)/400 = 0.8

BENDING (continued)

Cl 3.1.7(3)	x	$= [d - \surd(d^2 - 2000 / \alpha_{cc} \times M_{ED} \times \gamma_c / f_{ck})] / \lambda$ $= [37 - \surd(37^2 - 2000/0.85 \times 0.66 \times 1.5/25)] / 0.8$ = 1.6 mm
CL 5.5(4)	x/d	= 1.6 / 37 = 0.043 < 0.6 **OK**
	z	$= d - \lambda/2 . x$ = 37 - 0.4 x 1.6 = 36.4 > 0.95d = 35.2mm
	A_s	$= M_{ED} / f_{yk} / z \times \gamma_s$ = 0.66 / 500 / 35.2 x 1.15 $= 43 \text{ mm}^2/\text{m}$
Cl 9.2.1.1(1)	$A_{s,min}$	= 1.33 x d = 1.33 x 37 $= 49 \text{ mm}^2/\text{m}$
	A142 mesh	$= 142 \text{ mm}^2/\text{m}$ **OK in bending**

5.3. Micro-fibres

Micro-fibres have long been used within the concrete topping of EPS beam and block floors. They are suitable for incorporation into finishing screeds used in non-structural situations, e.g., as a levelling finish to prestressed concrete beam and resisting EPS block floor systems. The inclusion of micro-fibres within the mix is intended to control plastic shrinkage and settlement cracking when used in accordance with manufacturers' instructions and the '*Application guide for the specification and installation of concrete toppings to beam & EPS block suspended floors*'.

Historically, micro-fibre toppings have also been used in structural situations, when a flooring system comprises prestressed concrete beams and non-resisting EPS blocks. The basic principle is that the bending stress developed due to the uniformly distributed load and / or point load is within the concrete's tensile capacity. As such the concrete is then designed as plain concrete using Section 12 of BS EN 1992-1-1.

Appendix A contains an example calculation of how a plain concrete topping could be designed.

<u>This approach may only be used if the building warranty provider permits the use of micro-fibre or plain concrete as a structural topping.</u>

APPENDIX A

With regards to BS EN 1992-1-1, Section 12 does not stipulate that plain concrete must be mass concrete or in compression. Clause 12.3.1 (1) acknowledges the less ductile properties of plain concrete and so reduces design values through the use of partial factors. Clause 12.6.1 discusses design resistance to bending and axial force, and so flexure is considered in Section 12. Additionally, Clause 12.6.3(3) states that a concrete member may be considered to be uncracked in the ultimate limit state if either it remains completely under compression or if the absolute value of the principal concrete tensile stress σ_{ct1} does not exceed $f_{ctd, pl}$. It is therefore permissible for tension to be generated in plain concrete designed in accordance with EC2.

The method does not make allowance for stress induced by shrinkage as TR34 states that realistic assessment of the combined effects of load-induced stresses and shrinkage is problematical and could produce conservative designs without significantly reducing the risk of cracking.

The following equations are used to calculate the moment capacity of plain concrete.

<u>Parameters:</u>

- Imposed variable action = 1.5 kN/m^2
- Alternative point load = 2 kN on 50 mm square
- Beam centres = 610 mm
- Topping thickness, h = 65 mm
- Material partial factor for concrete, γ_c = 1.5
- Variable action partial factor = 1.5
- Permanent action partial factor = 1.35
- Concrete unit weight = 24 kN/m^3
- Concrete characteristic strength, f_{ck} = 25 MPa

BENDING		
EC2	Applied moment M_{ED}	$= P.L/4 + W.L^2/8$ $=(1.5 \times 2 \times 0.61/4) + (1.35 \times 0.065 \times 24 \times 0.61^2 / 8)$ $= 0.56$ kNm/m
UK NA	$\alpha_{ct,pl}$	$= 0.8$
Table 3.1	$f_{ctk,0.05}$	$= 1.8$ MPa
Eq 12.1	$f_{ctd,pl}$	$= \alpha_{ct,pl} \times f_{ctk,0.05} / \gamma_c$ $= 0.8 \times 1.8 / 1.5$ $= 0.96$ MPa
	Moment capacity M_{RD}	$= f_{ctd,pl} \times h^2/6$ $= 0.96 \times 1000 \times 0.075^2 / 6$ $= 0.68$ kNm/m
	Check $M_{RD} > M_{ED}$ **OK in bending**	

GENERAL SHEAR

EC2	Applied shear V_{ED}	$= P/2 + W.L/2$
		$= (1.5 \times 2 / 2) + (1.35 \times 0.065 \times 24) \times 0.61 / 2$
		$= 2.14$ kN/m
Eq 12.4	τ_{cp}	$= k \times V_{ED} / A_{cc}$
		$= 1.5 \times 2.14 \times 1000 / (65 \times 1000)$
		$= 0.049$ MPa
Eq 12.5	Taking $\sigma_{cp} = 0$, then f_{cvd}	$= f_{ctd,pl}$
		$= 0.96$ MPa
	Check $f_{cvd} > \tau_{cp}$ **OK in shear**	

PUNCHING SHEAR

<u>Shear at the face of the loaded area</u>

	d	$= 0.75 \times h$
		$= 0.75 \times 65$
		$= 49$ mm
Eq 6.49	v_{Ed}	$= (1.5 \times P) / (u \times d)$
		$= (1.5 \times 2 \times 1000) / (4 \times 50 \times 49)$
		$= 0.306$ MPa
Eq 6.6N	v	$= 0.6 \times (1 - f_{ck}/250)$
		$= 0.6 \times (1 - 25/250)$
		$= 0.54$
UK NA	$\alpha_{cc,pl}$	$= 0.6$
	$f_{cd,pl}$	$= \alpha_{cc,pl} \times f_{ck} / \gamma_c$
		$= 0.6 \times 25 / 1.5$
		$= 10.0$ MPa
UK NA 6.4.5(3)	$v_{Rd,max}$	$= 0.5\ v\ f_{cd,pl}$
		$= 0.5 \times 0.54 \times 10$
		$= 2.7$ MPa
	Check $v_{Rd,max} > v_{Ed}$ **OK for punching shear at the face of the loaded area**	

PUNCHING SHEAR (continued)

Shear on the critical perimeter (at distance 2d from the loaded area)

Fig 6.13 Perimeter $= 4 \times 50 + 2 \times \pi \times (2 \times 49)$
$= 816$ mm

Eq 6.49 v_{Ed} $= (1.5 \times P) / (u \times d)$

$= (1.5 \times 2 \times 1000) / (816 \times 49)$

$= 0.075$ MPa

Eq 6.2b k $= 1 + \sqrt{(200 / d)} \leq 2.0$
$= 1 + \sqrt{(200 / 49)}$
$= 3.02$
$= 2.0$

Eq 6.3N v_{min} $= 0.035 \times k^{3/2} \times f_{ck}^{1/2}$
$= 0.035 \times 2.0^{3/2} \times 25^{½}$
$= 0.49$ MPa

Eq 6.2b Taking $\sigma_{cp} = 0$, then $v_{Rd,c} = v_{min}$
$= 0.49$ MPa

Check $v_{Rd,c} > v_{Ed}$ **OK for punching shear on the critical perimeter**