The specialist team at LinkStudPSR Limited have created this comprehensive Design Manual, to assist Structural Engineers with a detailed explanation of the calculations and rules used to detail and specify the LinkStud PSR (Punching Shear Reinforcement) system.

This Manual deals exclusively with the correct use of the now withdrawn BS8110 design standard as at February 2010.

If you require any further detailed advice regarding the design and detailing of punching shear reinforcement to either the EC2 or BS8110 standards, please do not hesitate to contact our in-house team of experts.

LinkStudPSR Limited
Anson Court Business Centre
Dyson Way
Stafford
ST18 0GB

Tel / Fax: 08456 528 528
E-mail: technical@linkstudpsr.com
Web: www.linkstudpsr.com
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Introduction

The LinkStudPSR System offers customers a fast, easy and extremely cost effective method of providing Punching Shear Reinforcement around columns, and piles within flat slabs and post-tensioned slabs, at slab to shearwall junctions, beam to column junctions and within footings and foundation slabs.

The LinkStudPSR System comprises short lengths of carbon steel deformed bar reinforcement with end anchorages provided by enlarged, hot forged heads at both ends, giving a cross-sectional area ratio of 9:1. These stud heads anchor securely in the slab, eliminating slippage and providing greater resistance to punching shear. The double-headed LinkStud shear studs are welded to carrier / spacer rails to allow them to be located correctly and to be supported by the top flexural reinforcement.

LinkStudPSR is a technologically advanced and proven system, the first fully tested, fully accredited, fully traceable Punching Shear Reinforcement System approved by CARES for use in reinforced concrete slabs designed in accordance with both EC2 and BS8110 design standards.

Through our total focus on Punching Shear Reinforcement we have become experts in our field, with unparalleled experience in the design of PSR schemes and a thorough knowledge of the intricacies and complexities of the Eurocode 2 and BS8110 design standards. We are pleased to be able to offer you this expertise, as a cornerstone of the LinkStudPSR package.

From application advice and design guidance, through proposal drawings, calculations and quotations, to working drawings and site support, you can depend on LinkStudPSR for all your Punching Shear Reinforcement needs.

Kind Regards

Dariusz Nowik  MSc (Eng)
Senior Design Engineer
LinkStudPSR Limited
BS8110 Design Preface

Please note that the LinkStudPSR design and optimum pattern / layout details can be calculated very simply, by using the free LinkStudPSR design software (available later in 2010) with the minimum of input. This design manual simply explains the methods used to produce the design programme’s output, and although the BS8110 design standard is no longer officially supported, acts as an updatable guide to display some of the more complex layouts that may not be available within the LinkStudPSR Design Programme.

If in any doubt, LinkStudPSR’s specialist in-house Engineers can check and produce calculations and layouts for the Project Engineer’s approval. Although no longer current, our experienced Designers have access to specialist design programmes and calculations that can be used to achieve a quicker solution, than doing traditional long hand calculations and layouts.

To ensure clarity and conformity, this manual and related design procedures work strictly within the guidelines of the now withdrawn BS8110 part 1. An orthogonal pattern is used and the minimum required steel sectional area is calculated at each perimeter from the loaded area (column / pile) face.

Although further design procedures may be incorporated within the EC2 design standard at a later date as they become more widely accepted, LinkStudPSR Limited have, for now, focused primarily on improving the quality, traceability, conformity and certification of the LinkStudPSR system and its availability within the UK. This is so that the additional studs required to fully comply with the guidelines of the BS8110 standard can be used, without the increased costs, environmental impact and complications of importing from overseas.
Information required when designing to BS8110

If you would like the punching shear specialists at LinkStudPSR to produce an accurate calculation using the LinkStudPSR design programme, please copy and complete the pro-forma at the back of this manual and Fax to 08456 528 528 or forward it to technical@linkstudpsr.com.

We will need detailed information on:

- The dimensions and shape of the loaded area (e.g. square, rectangular or circular)
- The distance of the loaded area from the nearest edge(s) of the slab
- The diameter and spacing of the top reinforcement bars (bottom if a transfer slab)
- The depth of the slab
- The depth of the top and bottom reinforcement cover
- The characteristic compressive cube strength of the concrete ($f_{cu}$)
- The applied design shear load ($V$ or $V_{eff}$)
- Any design moments applied

Plus - where appropriate

- The dimensions and position in relation to the loaded area of any holes through the slab
- Any changes in slab depth, levels or movement joints within the live perimeter (a general layout drawing may be required)

Alternatively, you may prefer to gather the relevant data and produce a calculation and design layout yourself using the LinkStudPSR on-line design software (available later in 2010) or by using the long hand calculations to BS8110 that we have laid out later in this manual (pages 62 to 77).

NOTE: It is assumed that:

- Any loads given by the Project Engineer have been factored using the BS8110 load factors
- The concrete slab is not constructed using lightweight aggregate

IMPORTANT:

Make sure that loads given are only the slab loads and do not include the columns / loaded areas above.
BS8110 design and calculation introduction

So far in this BS8110 section of the manual we have explained the LinkStudPSR Ltd design principles and covered the main information required if you prefer to continue designing in the BS8110 design standard.

The following pages provide a description (below) of the symbols used within the punching shear calculations, an overview of the BS8110 design procedure, some general detailing rules, some examples of the most commonly used layouts to suit the most prevalent conditions and some installation information before displaying examples of the most common perimeter layouts for various standard conditions that you may encounter when designing punching shear reinforcement and an explanation of the long hand calculations used within the LinkStudPSR design programme, to enable qualified Engineers to quickly and easily check the workings of the software to satisfy themselves that the results are correct and the eventual structure will remain free from any punching shear problems.

If you do have any questions regarding this design manual or the LinkStudPSR design programme, please contact the technical team direct at technical@linkstudpsr.com or on 08456 528 528.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>mm</td>
<td>Width of loaded area</td>
</tr>
<tr>
<td>A_{sv}</td>
<td>mm^2/m</td>
<td>Area of shear reinforcement</td>
</tr>
<tr>
<td>b</td>
<td>mm</td>
<td>Breadth of loaded area</td>
</tr>
<tr>
<td>c</td>
<td>mm</td>
<td>Dimension to edge of slab from face of loaded area (see diagrams)</td>
</tr>
<tr>
<td>d</td>
<td>mm</td>
<td>Effective depth of slab</td>
</tr>
<tr>
<td>h</td>
<td>mm</td>
<td>Overall slab depth</td>
</tr>
<tr>
<td>e</td>
<td>mm</td>
<td>Dimension to edge of slab from face of loaded area (see diagrams)</td>
</tr>
<tr>
<td>f_{cu}</td>
<td>N/mm^2</td>
<td>Characteristic compressive cube strength of concrete at 28 days</td>
</tr>
<tr>
<td>f_{sy}</td>
<td>N/mm^2</td>
<td>Characteristic strength of shear reinforcement. (not to be taken more than 500 N/mm^2)</td>
</tr>
<tr>
<td>M_l</td>
<td>kN/m</td>
<td>Design moment transferred between slab and loaded area at the connection</td>
</tr>
<tr>
<td>u_0</td>
<td>mm</td>
<td>Effective length of the loaded area perimeter</td>
</tr>
<tr>
<td>u_1, u_2,...</td>
<td>mm</td>
<td>Effective length of the design perimeters</td>
</tr>
<tr>
<td>u_p</td>
<td>mm</td>
<td>The effective perimeter where v ≤ v_c</td>
</tr>
<tr>
<td>v</td>
<td>N/mm^2</td>
<td>Design shear stress</td>
</tr>
<tr>
<td>v_c</td>
<td>N/mm^2</td>
<td>Design concrete shear stress</td>
</tr>
<tr>
<td>V_{eff}</td>
<td>kN</td>
<td>Design effective shear including allowance for moment transfer</td>
</tr>
<tr>
<td>V_l</td>
<td>kN</td>
<td>Design shear transferred to loaded area</td>
</tr>
<tr>
<td>X</td>
<td>mm</td>
<td>The length of the side of the perimeter considered parallel to the axis of bending</td>
</tr>
</tbody>
</table>

Note: X is always taken as the length of the side of u_1 at 1.5d from the loaded area face for each perimeter.

When calculating the direct shear with a moment at the loaded area face, X can be calculated as the length of the side of u_0 as a worst case, but it is normal practice to use 1.5d as stated.
Outline of the BS8110 design process

The design process for the now withdrawn BS8110 design standard works slightly differently to that used in the new EC2 (BS EN 1992-1-1:2004) standard, and so we have laid out a simple overview of the steps required so that a simple comparison can be made between the two standards.

**NOTE:** Please remember to take into account the size and position of any holes / penetrations through the slab within 6d of the loaded area (see page 79 for further information)

1. **Check if the punching shear stress at the loaded area face** ($v$) **exceeds**
   
   $$0.8 \sqrt{f_{cu}} \text{ or } 5 \text{ N} / \text{ mm}^2$$

   - **NO**
   - **YES**

   **FAILURE**

2. **Calculate** ($v_c$) **concrete shear capacity without reinforcement**

3. **n - current perimeter number**
   
   **n = 1**

4. **At $u_n$ (perimeter n) check if the punching shear stress is two times greater than the concrete shear capacity without reinforcement**

   - **Check if $v > 2v_c$**

   - **NO**
   - **YES**

   **FAILURE**

5. **At $u_n$ (perimeter n) check if the punching shear stress is less than the concrete shear capacity without reinforcement**

   - **Check if $v < v_c$**

   - **NO**
   - **YES**

6. **Calculate the required $A_{sw}$ (shear reinforcement) for n perimeter**

7. **Go to next perimeter**
   
   **n = n + 1**

8. **Is n > 1**
   
   - **NO**
   - **YES**

   **No shear reinforcement required**

   **Detail the position of the LinkStuds taking into account the calculated area of reinforcement, spacing rules, shape and position of the loaded area**
Design perimeters and steel areas

The LinkStudPSR design programme and the traditional BS8110 method, calculates the minimum required steel area needed at each perimeter from the loaded area (column / pile) face. The first perimeter \( u_1 \) is set at 1.5\( d \) from the face and subsequent perimeters are at 0.75\( d \) outwards \( u_2, u_3, \ldots \) until the slab and reinforcement properties are able to take the shear stresses \( (v_c > v) \).

Within the first perimeter \( (u_1) \) there are two boundaries of reinforcement (studs), with the first one at 0.5\( d \) from the face, which must provide at least 40% of the required steel area at \( u_1 \), and the second boundary at 1.25\( d \) (0.5\( d \) + 0.75\( d \)).

The first steel area is calculated using the reinforcement within the \( u_1 \) perimeter, using the studs on the perimeters at 0.5\( d \) and 1.25\( d \), with the second area using the studs at 1.25\( d \) and 2.0\( d \), and so on.

<table>
<thead>
<tr>
<th>Stud diameter (mm)</th>
<th>Stud area (mm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>78.54</td>
</tr>
<tr>
<td>12</td>
<td>113.09</td>
</tr>
<tr>
<td>14</td>
<td>153.93</td>
</tr>
<tr>
<td>16</td>
<td>201.06</td>
</tr>
<tr>
<td>20</td>
<td>314.16</td>
</tr>
</tbody>
</table>

For example:

\[
\begin{align*}
0.5d & \quad 8 \quad 8 \text{ studs} \\
\text{at} \ u_1 & \quad 8 + 16 = \quad 24 \text{ studs} \\
\text{at} \ u_2 & \quad 16 + 24 = \quad 40 \text{ studs} \\
\text{at} \ u_3 & \quad 24 + 32 = \quad 56 \text{ studs} \\
\text{at} \ u_4 & \quad \text{no studs required}
\end{align*}
\]
**LinkStudPSR BS8110 General detailing rules**

- The rail length is calculated so that the start of the rail is in line with the loaded area / column face
- The distance to the first and last studs on the rail must be at a maximum of 0.5d from the end of the rail
- Spacing between the studs along the rail must be at a maximum of 0.75d
- The forged ends of the studs must capture the top and bottom slab reinforcement
- The plan dimension between studs around the line of the perimeter must not exceed 1.5d
- Stud lengths and spacing should be rounded down to the nearest 10 mm
- Ideally layouts should be symmetrical (see plan details further on in this manual)
- LinkStuds have a minimum of two and a maximum of eight studs on a rail

Generally, using the above rules simplifies the amount of variation on site and during manufacture, reducing the need for complicated marking systems and the number of drawings required.

Variations should then be limited to only the diameter and number of LinkStuds on a rail.

Mark number “12-4-250-910” = stud diameter – number of studs – length of studs – length of rail

![Diagram of rail spacing and stud placement](image)

The above ‘mark number’ is sufficient information to manufacture and identify the LinkStudPSR system.

Each LinkStudPSR rail is manufactured with the correct number of studs required to achieve the design layout, normally providing one rail type per column / pile head and hence no complicated assembly is needed on site.

Calculating the rail spacing required can be done without difficulty from the mark number given:

i.e. from the above rail “12-4-250-910” : length of rail = 910 mm & number of studs = 4

Effective slab depth \( d = \frac{\text{length of rail}}{(\text{number of studs} - 1) \times 0.75 + 1} \)

for example = 910 / ((4 - 1) \times 0.75 + 1) = 280 mm effective slab depth

**Edge spacing** = 0.5d = 0.5 \times 280 = 140 mm

**Stud spacing** = 0.75d = 0.75 \times 280 = 210 mm
Typical LinkStudPSR BS8110 layouts

<table>
<thead>
<tr>
<th>Condition</th>
<th>Square loaded area</th>
<th>Rectangular loaded area</th>
<th>Circular loaded area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal condition</strong></td>
<td><img src="image1" alt="Square loaded area" /></td>
<td><img src="image2" alt="Rectangular loaded area" /></td>
<td><img src="image3" alt="Circular loaded area" /></td>
</tr>
<tr>
<td><strong>Edge condition</strong></td>
<td><img src="image4" alt="Square loaded area" /></td>
<td><img src="image5" alt="Rectangular loaded area" /></td>
<td><img src="image6" alt="Circular loaded area" /></td>
</tr>
<tr>
<td><strong>External corner condition</strong></td>
<td><img src="image7" alt="Square loaded area" /></td>
<td><img src="image8" alt="Rectangular loaded area" /></td>
<td><img src="image9" alt="Circular loaded area" /></td>
</tr>
<tr>
<td><strong>Internal corner condition</strong></td>
<td><img src="image10" alt="Square loaded area" /></td>
<td><img src="image11" alt="Rectangular loaded area" /></td>
<td><img src="image12" alt="Circular loaded area" /></td>
</tr>
</tbody>
</table>
LinkStudPSR can be installed either with studs down (top down) or up (bottom up) in the concrete slab. In either condition the flat ends of the forged heads must sit level with the outer top and bottom slab reinforcement to work correctly. In split level or 'cranked' slabs the studs must extend into the slab reinforcement or an additional level of reinforcement should be added, this is easy to achieve using the square (orthogonal) layout pattern of BS8110.

'Studs down' or 'top down' –

The most common and quickest method of fixing; the rails sit directly on the top reinforcement. Care must be taken to fix the rails (usually with wire) so that the studs don't rotate as the concrete is poured, and also that the forged head remains at the correct level with the bottom reinforcement.

'Studs up' or 'bottom up' –

Place the carrier rails on concrete spacers and nail between the rails into the formwork. The bottom reinforcement sits on, and is supported on, the carrier rail, hence the heads of the stud will remain at the correct level with the bottom reinforcement and the top heads can be seen to be in the correct position.
Laying out the LinkStudPSR system to BS8110

To simplify the system layout the LinkStudPSR system uses only one ‘symmetrical’ rail type. In the BS8110 standard the layout patterns are the same for square and circular loaded areas alike. Large columns may require additional side rails to maintain the maximum distance between the studs of 1.5d.

The carrier / spacer rails are non-structural and can therefore be placed on the top or under the bottom reinforcement. The LinkStudPSR system rails are manufactured so that they are symmetrical and therefore cannot be installed the wrong way around.

The forged ends (heads) of the studs must remain level with the top and bottom reinforcement layers.

**Internal condition layout – installation / pattern creation.**

Place the side rails first with the end of the rails touching the loaded area face. The first stud along the rail should be no more than 0.5d from the loaded area face.

Line up the ends of the outer rails with the loaded area face and the outer stud of the side rails. Then place the inner rails inline with each stud on the side rails, automatically giving the relevant designed spacing.

Place the remaining two rails in line with the centre of the column at equal spacing from the two inner rails to complete the pattern, and making sure that the distance to the studs on the inner rails does not exceed 1.5d.
As a quick reference guide to the now withdrawn BS8110 design standard, and to help with a like for like comparison with the new EC2 standard, we have produced a series of layout drawings and associated long hand calculations for each of the main column types and the most common positions (conditions) that they are likely to be used in.

We hope that this will help to accelerate the calculation and design process for the most frequently used conditions.

The following section provides information on designing punching shear reinforcement based strictly on the orthogonal pattern layout of BS8110. For additional information (not included in this design manual) on designing using this layout style, please contact the LinkStudPSR technical team.

If you have any questions regarding these calculations or their associated layouts, please do not hesitate to contact our technical team on 08456 528 528 or by e-mail at technical@linkstudpsr.com.

The following pages supply designs and calculations for:

- Square / circular loaded areas - Internal condition ...................... p.62-63
- Square / circular loaded areas - Edge condition ............................ p.64-65
- Square / circular loaded areas - External corner condition .............. p.66-67
- Square / circular loaded areas - Internal corner condition .............. p.68-69
- Rectangular loaded areas - Internal condition ............................. p.70-71
- Rectangular loaded areas - Edge condition ................................. p.72-73
- Rectangular loaded areas - External corner condition .................. p.74-75
- Rectangular loaded areas - Internal corner condition ................... p.76-77
Square loaded area - Internal condition

Circular loaded area - Internal condition
### Square / Circular loaded areas - INTERNAL

**Reference to BS8110 part 1**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d = h - \text{top cover} - \frac{T1 \text{Bars size}}{2} - \frac{T2 \text{Bars size}}{2} ) (average in both directions)</td>
<td>Figure 3.14</td>
</tr>
<tr>
<td>( x = a + (2 \times 1.5d) ) (required only when there is a moment in the slab)</td>
<td>3.7.7.2</td>
</tr>
<tr>
<td>( u_0 = 4a ) (Square loaded area) or ( aT ) (Circular loaded area)</td>
<td>Figure 3.15</td>
</tr>
<tr>
<td>( V_{\text{eff}} = 1.15V_t ) (direct shear) or ( V_{\text{eff}} = V_t \left(1 + 1.5M_t / (V_t \times X)\right) ) (moment present)</td>
<td>Design at face</td>
</tr>
<tr>
<td>( v = \frac{V_{\text{eff}}}{u_0 \times d} )</td>
<td>Equation 27</td>
</tr>
</tbody>
</table>

Check ‘\( v \)’ is not greater than \( 0.8 \times \sqrt{f_{\text{cu}}} \) or \( 5 \text{ N/mm}^2 \)

\( f_{\text{cu}} \) should not to be taken greater than \( 40 \text{ N/mm}^2 \)

**Design at face**

**Equation 28**

\( v = \frac{V_{\text{eff}}}{u_1 \times d} \)

\( v < v_c \) - No Shear reinforcement is required

\( v > 2v_c \) - Redesign using: deeper slab, increased grade or top reinforcement.

\( v \leq 1.6v_c \) - \( A_{sv} = (v - v_c) u_1 \frac{d}{(0.87f_{sy})} \) Note: Sin 90º = 1 for vertical bars

\( 1.6v_c < v \leq 2v_c \) - \( A_{sv} = 5(0.7v - v_c) u_1 \frac{d}{(0.87f_{sy})} \) Note: Sin 90º = 1 for vertical bars

Check against minimum steel = \( 0.4u_1 \frac{d}{(0.87f_{sy})} \) .... (altering \( u_1 \) to \( u_2 \), etc... accordingly)

Note: \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of \( 0.75d \) centres.

The first perimeter of studs located at \( 0.5d \) should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat ‘design at perimeters’... until \( v < v_c \) hence no more reinforcement is required.

**Design at perimeters**

**3.7.7.4**

\( v < v_c \) - No Shear reinforcement is required

\( v > 2v_c \) - Redesign using: deeper slab, increased grade or top reinforcement.

\( v \leq 1.6v_c \) - \( A_{sv} = (v - v_c) u_1 \frac{d}{(0.87f_{sy})} \) Note: Sin 90º = 1 for vertical bars

\( 1.6v_c < v \leq 2v_c \) - \( A_{sv} = 5(0.7v - v_c) u_1 \frac{d}{(0.87f_{sy})} \) Note: Sin 90º = 1 for vertical bars

Check against minimum steel = \( 0.4u_1 \frac{d}{(0.87f_{sy})} \) .... (altering \( u_1 \) to \( u_2 \), etc... accordingly)

Note: \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of \( 0.75d \) centres.

The first perimeter of studs located at \( 0.5d \) should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat ‘design at perimeters’... until \( v < v_c \) hence no more reinforcement is required.
Square loaded area - Edge condition

Circular loaded area - Edge condition

Square loaded area - Edge condition

Circular loaded area - Edge condition
Cantilever edges (c) are restricted to a maximum of 3d. Lengths greater than 3d are ignored.

\[ d = h - \text{top cover} - T1 \text{ Bars size} / 2 - T2 \text{ Bars size} / 2 \] (average in both directions)

Square loaded area: \( u_0 = 4a \) or \( u_0 = 3a + 2c \) whichever is the smallest.

Circular loaded area: \( u_0 = a \times \pi \) or \( u_0 = a \pi / 2 + a + 2c \) whichever is the smallest.

\[ X_{xy} = a + c + 1.5d \quad \text{or} \quad X_{x} = a + (2 \times 1.5d) \quad \text{required only when there is a moment in the slab} \]

\[ V_{\text{eff}} = 1.4V_t \quad \text{or} \quad 1.25V_t \quad \text{direct shear} \quad \text{or} \quad V_{\text{eff}} = V_t \left(1.25 + 1.5M_t / (V_t \times X)\right) \quad \text{moment present} \]

\[ v = V_{\text{eff}} / (u_1 \times d) \]

- Check 'v' is not greater than \( 0.8 \times f_{\text{cu}} / \ \text{or} \ 5 \text{N/mm}^2 \)
- \( f_{\text{cu}} \) should not be taken greater than 40 N/mm²

**Design at face**

Equation 27

3.7.6.4 & 3.7.7.2

**Design at perimeters**

3.7.7.2

Table 3.8

Design each perimeter \( u_1, u_2, \ldots, u_n \) - starting 1.5d from the loaded area face and at 0.75d thereafter until \( v_c \) is greater than or equal to \( v \).

\[ u_1 = (1.5d \times 4) + 3a + 2c \quad u_2 = (2.25d \times 4) + 3a + 2c \quad u_3 = (3d \times 2) \times 4 + 3a + 2c \ldots \& \text{so on} \]

\[ v_c = 0.79 \times \left( \left( \frac{100A_s}{(1000 \times d)} \right)^{1/3} \times \left( \frac{400}{d} \right)^{1/4} \right) / 1.25 \times \left( \frac{f_{\text{cu}}}{25} \right)^{1/3} \]

Where:

\[ \frac{100A_s}{(1000 \times d)} \leq 3 \]

\[ \frac{400}{d} \geq 1 \]

\[ v = V_{\text{eff}} / (u_1 \times d) \]

**No Shear reinforcement is required**

**Redesign using: deeper slab, increased grade or top reinforcement.**

**Design against minimum steel = (0.4 \( u_t, d \) / (0.87v_{\text{fv}})) \ldots (altering \( u_t, \text{to} \ u_2, \text{etc... accordingly})**

Note: \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of 0.75d centres.

The first perimeter of studs located at 0.5d should contain at least 40% of the calculated area of the reinforcement required in \( u_t \).

Repeat 'design at perimeters'... until \( v < v_c \) hence no more reinforcement is required.

Figure 3.14

Figure 3.15

Figure 3.17
Square loaded area - External corner

Circular loaded area - External corner

Square loaded area - External corner

Circular loaded area - External corner
Cantilever edges \((c,d)\) are restricted to a maximum of \(3d\). Lengths greater than \(3d\) are ignored.

\[
d = h - \text{top cover} - T1 \text{ Bars size} / 2 - T2 \text{ Bars size} / 2 \quad \text{(average in both directions)}
\]

\[
X_y = a + c + 1.5d \quad \text{or} \quad X_x = a + e + 1.5d \quad \text{(required only when there is a moment in the slab)}
\]

Square loaded area: \(u_0 = 4a\) or \(u_0 = 2a + c + e\) or \(u_0 = 3a + 2c\) or \(u_0 = 3a + 2e\) whichever is the smallest.

Circular loaded area: \(u_0 = a \times \pi\) or \(u_0 = a \pi / 4 + a + c + e\) whichever is the smallest.

\[
X_y = a + c + 1.5d \quad \text{or} \quad X_x = a + e + 1.5d \quad \text{(required only when there is a moment in the slab)}
\]

\[
V_{\text{eff}} = 1.25V_t \quad \text{(direct shear)} \quad \text{or} \quad V_{\text{eff}} = V_t \left( 1.25 + 1.5M_t / (V_t \times X) \right) \quad \text{(moment present)}
\]

\[
v = V_{\text{eff}} / (u_0 \times d)
\]

Check \(v\) is not greater than \(0.8 \times \sqrt{\pi f'_{cu}}\) or \(5 \text{ N/mm}^2\)

\(f_{cu}\) should not to be taken greater than \(40 \text{ N/mm}^2\)

Design each perimeter \(u_1, u_2, \ldots u_n\) - starting \(1.5d\) from the loaded area face and at \(0.75d\) thereafter until \(v_c\) is greater than or equal to \(v\).

\[
u_1 = (1.5d \times 2) + 2a + c + e \ldots u_2 = (2.25d \times 2) + 2a + c + e \ldots u_3 = (3d \times 2) + 2a + c + e \ldots \& \text{so on}
\]

\[
v_c = 0.79 \times \left( (100 A_s / (1000 \times d))^{1/3} \times (400 / d)^{1/4} \times 1.25 \times (f_{cu} / 25)^{1/3} \right)
\]

Where:

\[
100 A_s / (1000 \times d) \leq 3
\]

\[
400 / d \geq 1
\]

\[
v = V_{\text{eff}} / (u_1 \times d)
\]

\(v < v_c\) ■ No Shear reinforcement is required

\(v > 2v_c\) ■ Redesign using: deeper slab, increased grade or top reinforcement.

\(v \leq 1.6v_c\) ■ \(A_{sv} = (v - v_c) u_t \times d / (0.87 f_{cy})\) Note: Sin 90º = 1 for vertical bars

\(1.6v_c < v \leq 2v_c\) ■ \(A_{sv} = 5 \times (0.7v - v_c) u_t \times d / (0.87 f_{cy})\) Note: Sin 90º = 1 for vertical bars

Check against minimum steel = \((0.4 u_t \times d) / (0.87 f_{cy})\) .... (altering \(u_t\) to \(u_2\), etc… accordingly)

Note: \(A_{sv}\) is for TWO perimeters of studs / links at a maximum of \(0.75d\) centres.

The first perimeter of studs located at \(0.5d\) should contain at least 40% of the calculated area of the reinforcement required in \(u_1\).

Repeat ‘design at perimeters’… until \(v < v_c\) hence no more reinforcement is required.
Square loaded area - Internal corner

Circular loaded area - Internal corner

Circular loaded area - Internal corner

Square loaded area - Internal corner
### Square / Circular loaded areas - INTERNAL CORNER

#### Cantilever edges (c,e) are restricted to a maximum of 1.5d. Lengths greater than 1.5d are ignored.

\[ d = \text{h} - \text{top cover} - T1 \text{ Bars size} / 2 - T2 \text{ Bars size} / 2 \] (average in both directions)

\[ Xy = a + 3d \text{ or } Xx = a + 3d \] (required only when there is a moment in the slab)

Square loaded area: \( u_0 = 4a \) or \( u_0 = 4a + c + e \) whichever is the smallest.

Circular loaded area: \( u_0 = \pi a \) or \( u_0 = \pi a / 3 + a + c + e \) whichever is the smallest.

Use X as Xx or Xy as appropriate

#### Design each perimeter \( u_1, u_2, \ldots, u_n \) - starting 1.5d from the loaded area face and at 0.75d thereafter until \( v_c \) is greater than or equal to \( v \).

\[ u_1 = (1.5d \times 6) + 4a + c + e \ldots u_2 = (2.25d \times 6) + 4a + c + e \ldots u_3 = (3d \times 6) + 4a + c + e \ldots & \text{so on} \]

Check \( u_1, u_2, \text{etc.} \). Against a complete enclosed perimeter i.e. \( u_1 = (1.5d \times 2) + a \) \( \times 4 \)

\[ v_c = 0.79 \times (100A_s / (1000 \times d) )^{1/3} \times (400 / d)^{1/4} / 1.25 \times (f_{cu} / 25)^{1/3} \]

Where:

\[ 100A_s / (1000 \times d) \leq 3 \]

\[ 400 / d \geq 1 \]

\[ v = V_{\text{eff}} / (u_1 \times d) \]

\[ v < v_c \] — No Shear reinforcement is required

\[ v > 2v_c \] — Redesign using: deeper slab, increased grade or top reinforcement.

\[ v \leq 1.6v_c \]

\[ A_{sv} = (v - v_c) u_1 d / (0.87f_{vy}) \]

Note: Sin 90º = 1 for vertical bars

\[ 1.6v_c < v \leq 2v_c \]

\[ A_{sv} = 5(0.7v - v_c) u_1 d / (0.87f_{vy}) \]

Note: Sin 90º = 1 for vertical bars

Check against minimum steel = (0.4 \( u_1 \) \( d \) / (0.87f_{vy}) \(...) (altering \( u_1 \) to \( u_2 \), etc..., accordingly)

Note: \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of 0.75d centres.

The first perimeter of studs located at 0.5d should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat ‘design at perimeters’... until \( v < v_c \) hence no more reinforcement is required.

---

**Figure 3.14**

**Figure 3.15**

**Design at face**

Equation 27

**Design at perimeters**

Equation 28

**Design at perimeters**

Equation 29a

**Design at perimeters**

Equation 29b

**Design at perimeters**

Figure 3.17

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Reference to BS8110 part 1
Rectangular loaded area - Internal condition
## Rectangular loaded areas - INTERNAL

For rectangular loaded areas with a length exceeding four times its thickness, should be considered as a wall receiving localised punching shear at its ends. See section on Wall / Blade column.

\[ d = h - \text{top cover} - T1 \text{ Bars size} / 2 - T2 \text{ Bars size} / 2 \]  
(average in both directions)

\[ X_y = b + (2 \times 1.5d) \text{ or } X_x = a + (2 \times 1.5d) \]  
(required only when there is a moment in the slab)

\[ u_0 = 2a + 2b \]

use \( X \) as \( X_x \) or \( X_y \) as appropriate

\[ V_{eff} = 1.15V_t \]  
(direct shear)

\[ V_{eff} = V_t \left(1 + \frac{1.5M_t}{V_t X}\right) \]  
(moment present)

\[ v = \frac{V_{eff}}{(u_0 \times d)} \]

Check ‘\( v \)’ is not greater than \( 0.8 \times \sqrt{f_{cu}} \) or 5 N/mm²

\( f_{cu} \) should not be taken greater than 40 N/mm²

\[ \nu_c = 0.79 \times \left(\frac{100A_s}{1000 \times d}\right)^{1/3} \times \left(\frac{400}{d}\right)^{1/4} \times \frac{1.25}{f_{cu}/25} \]

Where:

\[ \frac{100A_s}{1000 \times d} \leq 3 \]

\[ \frac{400}{d} \geq 1 \]

\[ v = \frac{V_{eff}}{(u_1 \times d)} \]

\( v < \nu_c \) — No Shear reinforcement is required

\( v > 2\nu_c \) — Redesign using: deeper slab, increased grade or top reinforcement.

\( v \leq 1.6\nu_c \) — \( A_{sv} = (\nu - \nu_c) u_1 d / (0.87f_{fy}) \)  
Note: Sin 90º = 1 for vertical bars

\( 1.6\nu_c < v \leq 2\nu_c \) — \( A_{sv} = 5(0.7 \nu - \nu_c) u_1 d / (0.87f_{fy}) \)  
Note: Sin 90º = 1 for vertical bars

Check against minimum steel = \( (0.4 \times u_1 \times d) / (0.87f_{fy}) \) .... (altering \( u_1 \) to \( u_2 \), etc... accordingly)

\[ A_{sv} \] is for TWO perimeters of studs / links at a maximum of 0.75d centres. The first perimeter of studs located at 0.5d should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat ‘design at perimeters’... until \( v < \nu_c \) hence no more reinforcement is required.
Rectangular loaded area - Edge condition

Rectangular loaded area - Edge condition
Rectangular loaded areas - EDGE

Cantilever edges (c) are restricted to a maximum of 3d. Lengths greater than 3d are ignored.

\[ d = h - \text{top cover} - T1 \text{ Bars size } / 2 - T2 \text{ Bars size } / 2 \] (average in both directions)

\[ X_y = b + c + 1.5d \quad \text{or} \quad X_x = a + (2 \times 1.5d) \] (required only when there is a moment in the slab)

\[ u_0 = 2a + 2b \quad \text{or} \quad u_0 = a + 2b + 2c \] whichever is the smallest.

Use X as Xx or Xy as appropriate

\[ V_{eff} = 1.4V_i \quad \text{or} \quad 1.25V_i \] (direct shear) or

\[ V_{eff} = V_i \left( 1.25 + 1.5M_i / (V_i \times X) \right) \] (moment present)

\[ v = V_{eff} / (u_0 \times d) \]

Check 'v' is not greater than \( 0.8 \times \sqrt{\pi f'\text{cu}} \) or 5 N/mm²

\( f_{cu} \) should not to be taken greater than 40 N/mm²

Design each perimeter \( u_1, u_2, \ldots u_n \) - starting 1.5d from the loaded area face and at 0.75d thereafter until \( v_c \) is greater than or equal to \( v \).

\[ u_1 = (1.5d \times 4) + a + 2b + 2c \quad \ldots u_2 = (2.25d \times 4) + a + 2b + 2c \quad \ldots u_3 = (3d \times 2) \times 4 + a + 2b + 2c \quad \ldots & \text{so on} \]

\[ v_c = 0.79 \times ( ( ( 100A_s / (1000 \times d) ) )^{1/3} \times (400 / d)^{1/4} ) / 1.25 \times (f_{cu}/25)^{1/3} \]

Where:

\[ 100A_s / (1000 \times d) \leq 3 \]

\[ 400 / d \geq 1 \]

\[ v = V_{eff} / (u_1 \times d) \]

\[ v < v_c \quad \text{■ No Shear reinforcement is required} \]

\[ v > 2v_c \quad \text{■ Redesign using: deeper slab, increased grade or top reinforcement.} \]

\[ v \leq 1.6v_c \quad A_{sv} = (v - v_c) u_1 d / (0.87f_{yv}) \quad \text{Note: Sin 90º = 1 for vertical bars} \]

\[ 1.6v_c < v \leq 2v_c \quad A_{sv} = 5 (0.7v - v_c) u_1 d / (0.87f_{yv}) \quad \text{Note: Sin 90º = 1 for vertical bars} \]

Check against minimum steel = \( (0.4 u_1 \times d) / (0.87f_{yv}) \) .... (altering \( u_1 \) to \( u_2 \), etc… accordingly)

Note: \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of 0.75d centres.

The first perimeter of studs located at 0.5d should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat 'design at perimeters’… until \( v < v_c \) hence no more reinforcement is required.

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Reference to BS8110 part 1

Design at face

Equation 27

3.7.6.4 & 3.7.7.2

Design at perimeters

Equation 28

3.7.7.3

Table 3.8

Equation 29a

3.7.7.4

Equation 29b

3.7.7.5
Rectangular loaded area - External corner

Rectangular loaded area - External corner
### Cantilever edges (c) are restricted to a maximum of 3d. Lengths greater than 3d are ignored.

\[ d = h – \text{top cover} – T1 \text{ Bars size} / 2 – T2 \text{ Bars size} / 2 \] (average in both directions)

\[ X_y = b + c + 1.5d \quad \text{or} \quad X_x = a + e + 1.5d \] (required only when there is a moment in the slab)

\[ u_0 = 2a + 2b \quad \text{or} \quad u_0 = a + b + c + e \quad \text{or} \quad u_0 = a + 2b + 2c \quad \text{or} \quad u_0 = 2a + b + 2e \]

whichever is the smallest.

Use \( X \) as \( X_x \) or \( X_y \) as appropriate

\[ V_{\text{eff}} = 1.25V_t \] (direct shear) \quad or \quad \[ V_{\text{eff}} = V_t (1.25 + 1.5M_t / (V_t x X)) \] (moment present)

\[ v = V_{\text{eff}} / (u_0 x d) \]

Check ‘v’ is not greater than \( 0.8 x \sqrt{f_{cu}} \) or 5 N/mm\(^2\)

\( f_{cu} \) should not to be taken greater than 40 N/mm\(^2\)

### Design at face

- Equation 27

### Design at perimeters

- 3.7.6.4 & 3.7.7.2

### Table 3.8

### Reference to BS8110 part 1

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### Design at perimeters

- 3.7.7.3

- 3.7.7.4

### Table 3.8

### Design at face

- Equation 27

### Design at perimeters

- 3.7.6.4 & 3.7.7.2

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### Check against minimum steel = (0.4 \( u_1 \) d) / (0.87f_{pv}) .... (altering \( u_1 \) to \( u_2 \), etc... accordingly)

### Note:

- \( A_{sv} \) is for TWO perimeters of studs / links at a maximum of 0.75d centres.
- The first perimeter of studs located at 0.5d should contain at least 40% of the calculated area of the reinforcement required in \( u_1 \).

Repeat ‘design at perimeters’... until \( v < v_c \) hence no more reinforcement is required.
Rectangular loaded area - Internal corner
### Cantilever edges (c,e)

Cantilever edges (c,e) are restricted to a maximum of 1.5d. Lengths greater than 1.5d are ignored.

\[ d = h - \text{top cover} - T_1 \text{ Bars size} / 2 - T_2 \text{ Bars size} / 2 \] (average in both directions)

\[ X_y = b + 3d \text{ or } X_x = a + 3d \] (required only when there is a moment in the slab)

\[ u_0 = 2a + 2b \text{ or } u_0 = a + b + c + e \] whichever is the smallest.

Use \( X \) as \( X_x \) or \( X_y \) as appropriate.

\[ V_{\text{eff}} = 1.25V_t \] (direct shear) or \[ V_{\text{eff}} = V_t \left( 1.25 + 1.5M_t / (V_t \times X) \right) \] (moment present)

\[ v = V_{\text{eff}} / (u_0 \times d) \]

Check \( v \) is not greater than 0.8 \( \sqrt{f_{\text{cu}}} \) or 5 N/mm²

\( f_{\text{cu}} \) should not be taken greater than 40 N/mm²

---

### Design at face

Equation 27

#### Design at perimeters

- Design each perimeter \( u_1, u_2, \ldots u_n \) - starting 1.5d from the loaded area face and at 0.75d thereafter until \( v \) is greater than or equal to \( v_c \).

\[ u_1 = (1.5d \times 6) + 2a + 2b + c + e \ldots u_2 = (2.25d \times 6) + 2a + 2b + c + e \ldots u_3 = (3d \times 6) + 2a + 2b + c + e \ldots \& \text{ so on} \]

Check \( u_1, u_2, \ldots \). Against a complete enclosed perimeter i.e. \( u_1 = ( (1.5d \times 2) \times 4 + 2a + 2b) \)

\[ v_c = 0.79 \times ( ( (100A_s / (1000 \times d))^{1/3} \times (400 / d)^{1/4}) / 1.25 \times (f_{\text{cu}} / 25)^{1/3} ) \]

Where:

- \( 100A_s / (1000 \times d) \leq 3 \)
- \( 400 / d \geq 1 \)

\[ v = V_{\text{eff}} / (u_1 \times d) \]

---

#### Design at perimeters

- \( v < v_c \) - No Shear reinforcement is required
- \( v > 2v_c \) - Redesign using: deeper slab, increased grade or top reinforcement.
- \( v \leq 1.6v_c \) - \( A_{sv} = (v - v_c) u_1 / (0.87f_{\text{yw}}) \) Note: \( \sin 90^\circ = 1 \) for vertical bars
- \( 1.6v_c < v \leq 2v_c \) - \( A_{sv} = 5(0.7v - v_c) u_1 / (0.87f_{\text{yw}}) \) Note: \( \sin 90^\circ = 1 \) for vertical bars

Check against minimum steel = \( (0.4 \ u_1 \ d) / (0.87f_{\text{yw}}) \) .... (altering \( u_1 \) to \( u_2 \), etc... accordingly)

### Reference to BS8110 part 1

- Figure 3.14
- Figure 3.15
- Table 3.8
- Equation 28
- Equation 29a
- Equation 29b
- Figure 3.17
Design guidance for large columns or walls

**BS8110 part 1 1997 1.3.4.1**

A vertical load bearing member whose length exceeds four times its thickness.

Loaded areas with a length greater than four times its thickness are considered to be a wall and as such localised punching will occur at the ends or corners. This subject is not covered by BS8110 part 1 1997. Therefore, to conform to the code, it could be assumed that the perimeters could be returned around the ends by two times the thickness \((2 \times 'a')\).

i.e. a loaded area 800 x 200 in size would be treated as a normal punching shear situation, whereas a 1000 x 200 loaded area would retain the same perimeter size as the 800 x 200 example (the shear force may be reduced due to direct shear taken across the middle part of the loaded area / wall). The Project Engineer should be consulted first as to if and how this can be achieved.

This topic is however also covered by the Eurocode in more depth for edge and corner conditions adopting the smaller dimension of \(< 1.5d\) or \(< 0.5c1\), where \(c1\) can be taken as half the loaded area / wall length.

The final decision should rest with the Project Engineer who is fully aware of the whole structure.

It would therefore be easier to separate each end of the loaded area / wall and calculate it as an edge condition with the respective loaded area width ‘a’ and the return dimension ‘R’ being considered as the smaller of 2a, 1.5d or 0.5c1.

Still retaining the factor of \(V_{eff} = 1.25V_t\) for the edge condition and half the loading unless otherwise specified. Large loaded area corners or wall corners can be addressed in a similar manner, returning each side by 1.5d and calculated as a corner condition (as indicated below).
BS8110 part 1 1997 3.7.7.6  Modification of effective perimeter to allow for holes.

When a hole or holes are within $6d$ from the face of the loaded area, part of the perimeter that is enclosed by the radial projections (dead zone) from the centre of the loaded area to the edges of the hole(s) are considered ineffective.

Each perimeter ($u_0, u_1$, etc..) must be reduced accordingly and any studs / reinforcement ignored when calculating the area of steel required / used. Care should be taken when repositioning rails to miss holes that it has not moved into another perimeter without adjusting the calculation likewise.

A single hole can be ignored if its largest width is less than the smaller of:
1. One quarter of the side of the loaded area
2. Half the slab depth

It may be desirable or quicker to consider a worst case design, ignoring the part of the slab with the hole(s) and design as an edge or corner condition, supplying additional rails to the disregarded area of slab that will be receiving load from the slab.

Alternatively, a percentage reduction of the perimeters can be used, but care must be taken, as the percentage will vary due to the position around the loaded area and with the distance between the loaded area and the hole.
Option 1
Design as a 250 mm deep slab, in an edge condition (worst case), and arrange the layout of rails/studs to give similar stud lengths on each rail where possible.
Bottom reinforcement must be provided for any short stud lengths within the deeper slab zone.
Maintain stud spacing for the 250 mm deep slab in the 350 mm slab, but increase the stud length to suit the deeper slab.

Option 2
Design as a 350 mm deep slab in a corner condition.
Stud spacing and length are as standard for the 350 mm slab depth.
This assumes that most of the load is being applied from the deeper slab, the stud arrangement will stiffen the slab locally to the loaded area and aid transferring of the load from the thinner slab.
If desired additional rails can be added in the 250 mm slab, but the stud spacing rules for the thinner slab should be applied. (see option 3 below).

Option 3
Design as a 350 mm deep slab in a corner condition. Stud spacing and length are as standard for the 350 mm slab depth.
The perimeters can be increased to allow for the additional connecting part of the 250 mm deep slab.
The distance along the connecting face will need to be converted to an equivalent length of the thinner slab by $d_1 / d_2$: i.e. $U_1 = 1155 \times \frac{190}{290} = 756.72$ mm.
Once the new lengths are calculated it can be added to the perimeter in the design programme by using the 'Perimeter Reduction' function and entering it as a negative value.

If desired, additional rails can be added in the 250 mm slab, but the stud spacing rules for the thinner slab should be applied.
Design guidance for split level slabs - Internal condition

Internal condition with slab depth change within the loaded area zone.

Option 1
Design as an ‘Internal Condition’ using the smaller slab depth (worst case), arrange the layout of rails / studs to give similar stud lengths on each rail where possible.

Bottom reinforcement must be provided for any short stud lengths within the deeper slab zone.

Maintain stud spacing for the 250 mm slab within the 350 mm slab, but increase the stud length to suit the deeper slab.

Option 2
Design as an ‘Edge Condition’ using the deeper slab depth.

The perimeters can be increased to allow for the additional connecting part of the 250 mm deep slab.

The distance along the connecting face will need to be converted to an equivalent length of the thinner slab by $d_1 / d_2$.

Once the new lengths are calculated it can be added to the perimeter in the design programme by using the ‘Perimeter Reduction’ function and entering it as a negative value.

If desired additional rails can be added in the 250 mm slab, but the stud spacing rules for the thinner slab should be applied.

Option 3
Determine the loads on each side of the loaded area and design as two separate edge conditions:

- 350 mm deep edge slab
- 250 mm deep edge slab

Stud spacing and length will vary either side of the loaded area.

Note: the $V_{\text{eff}}$ factor should be calculated as an ‘Edge Condition’ on each side.
Design guidance for split level slabs - Internal condition

Internal condition with slab depth change outside the loaded area zone.

**Option 1**
Design as an ‘Internal Condition’ using the smaller slab depth (worst case), arrange the layout of rails / studs to give similar stud lengths on each rail where possible.

Bottom reinforcement must be provided for any short stud lengths within the deeper slab zone.

Maintain stud spacing for the 250 mm slab within the 350 mm slab, but increase the stud length to suit the deeper slab.

**Option 2**
Design as a ‘Cantilever Edge Condition’ using the deeper slab depth.

Stud length and spacing to suit the 350 mm deep slab.

**Option 3**
Design as a ‘Cantilever Edge Condition’ using the deeper slab depth.

The perimeters can be increased to allow for the additional connecting part of the 250 mm deep slab.

The distance along the connecting face will need to be converted to an equivalent length of the thinner slab by \( \frac{d1}{d2} \).

Once the new lengths are calculated it can be added to the perimeter in the design programme by using the ‘Perimeter Reduction’ function and entering it as a negative value.