Macro Synthetic Fibre Reinforced Ground Slabs

A Guide to the Design and Construction of

Macro Synthetic Fibre Reinforced Ground Supported Slabs

- Industrial Concrete Floors and Pavements

Revision 3: April 2018

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This document is provided by BarChip Inc. for the purposes of education and guidance in the methodology behind designing ground supported slabs in accordance with the UK Concrete Society's Technical Report 34 (TR34) 4th Edition 2013. As such BarChip recommends that upon receiving this copy that you take the time to register your details with your local BarChip representative. This will enable BarChip to provide you with updates/revisions to the document as they arise, which will maintain the accuracy and usability of this manual.

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Symbols

f_{ck}	MPa	=	characteristic compressive cylinder strength
f_{cm}	MPa	=	mean compressive cylinder strength
$f_{ctk,fl}$	MPa	=	characteristic flexural tensile strength
$f_{ctd,fl}$	MPa	=	design flexural tensile strength
f_{ctm}	MPa	=	mean axial tensile strength
γ_m	[-]	=	partial safety factor for materials
γ	[-]	=	partial safety factor for loads
a	mm	=	equivalent radius of contact area of the load
b	mm	=	width of standard notched beam (150 mm, as per EN 14651)
d	mm	=	racking leg width or width of vertical member carrying concentrated load.
d^*	mm	=	effective depth of slab
		=	0.75 h for fibre reinforced concrete
h	mm	=	slab thickness
h_{sp}	mm	=	depth of standard notched beam (125 mm)
I	mm^4	=	moment of inertia
l	mm	=	radius of relative stiffness
l	mm	=	span of standard notched beam (500 mm)
P_u	N	=	ultimate capacity under concentrated load
P^*	N	=	ultimate design concentrated load
P^*_{lin}	kN/m	=	ultimate design line load
P^*_{UDL}	kN/m^2	=	ultimate design uniformly distributed load
u_0	mm	=	length of the perimeter of the loaded area
u_1	mm	=	length of the critical perimeter
y	mm	=	neutral axis depth of hsp section
F_R	[-]	=	the applied load at stage R

Glossary of Terms and Abbreviations

Strain Compatibility	Refers to concrete section under bending, where the concrete reaches its limiting compressive strain simultaneously with the fibre concrete reaching its limiting tensile strain.
Strain Softening	Reduction in tensile stress in the fibre concrete as strain increases.

1. Introduction

The benefits of providing tensile reinforcement in concrete have been recognised for many years. Steel is strong in tension, and it has been used as tensile reinforcement to compensate for the weak tensile strength of concrete to achieve desirable structural performance. However, steel reinforcement in concrete has many associated drawbacks.

From economic and social perspectives, traditional steel reinforcement (bars or welded mesh) is expensive to purchase, transport and store. Steel fixing requires significant time and costs as it is particularly labour intensive. It is a potentially risky exercise at difficult and dangerous locations. Additionally, steel is highly corrosive in nature. The high alkalinity of concrete (pH>12) can passivate steel reinforcement depending on the amount of intact concrete cover. However, chloride ions and other chemicals can diffuse through the concrete to further corrode steel over time.

Industrial concrete slabs often experience cracking, mainly due to plastic shrinkage at earlier stages in the design life, and due to temperature, drying shrinkage or settlements at the later stage of the element's design life. This significantly reduces the effectiveness of steel passivation and in conjunction with carbonation of the concrete cover can significantly reduce the design life of reinforced concrete structures. Due to these reasons, there has been a growing interest in options to reduce the quantity of steel in concrete works, whilst maintaining or optimizing the structural performance of traditional steel reinforced concrete.

Fibres have been incorporated in concrete since ancient times, to reduce cracking and improve toughness and strength of brittle building materials. Some examples are straw in clay bricks and hair in plaster (Muller et al., 2012). The first modern alternative was the use of asbestos fibres in the early 1900's, and the need to replace asbestos gave rise to steel fibres. Steel fibres are used in a wide range of structural applications such as industrial pavements, precast structural elements, tunnel linings etc. Despite the economic, social and some structural advantages of steel fibres over traditional steel in concrete in certain applications, steel corrosion in concrete remains an issue.

To counteract corrosion problems, macro synthetic fibres made of high strength polymers, such as BarChip fibre, can be specified to replace steel in concrete.

There are numerous applications of synthetic fibres. Examples include slabs on ground, precast elements and sprayed concrete. Macro synthetic fibres are typically 30 to 65 mm long and are used for structural performance. In contrast, micro synthetic fibres, with diameters between 18 and 34 microns, are typically 6 to 20 mm long and are used mainly for crack control in young concrete (plastic shrinkage).

The most common advantages of using macro synthetic fibres are:

Increases concrete ductility / toughness

- Provides post crack flexural capacity equivalent to SL82 mesh at regular dose rates

Eliminates corrosion

- Removing the risk of concrete cancer and ensuring long term durability

70% reduction in carbon footprint compared to steel alternatives

Reduces crack propagation

Eliminates set-up of steel mesh

- Increased construction speeds
- Lower labour cost
- Reduction in workplace health and safety risks

Reduced maintenance costs

Safer and lighter to handle than traditional steel reinforcement

Improves shrinkage and temperature crack control

Retains performance with age

This guide aims to provide guidance on the design and construction of BarChip macro synthetic fibre reinforced concrete floors, based on best practice design guidelines and construction practices. The design guidance provided in this document is in accordance with the UK Concrete Society's Technical Report 34 (TR34) 4th Edition (The Concrete Society, 2013). The appendix contains a worked design example using BarChip fibre reinforcement

2. Synthetic Fibres in Concrete

2.1 General

The introduction of high performance macro synthetic fibres by BarChip made of virgin polypropylene (BarChip range) or polymer bi-components (MQ58) with a tensile strength of over 600 MPa has shared the attention of steel fibres as concrete reinforcement in non-free standing structural elements. Macro synthetic fibres are non-corrosive in nature, which enhances concrete durability. This is exemplified through their use in marine works to "eliminate corrosion risk under exposure to seawater" (Bernard, 2004). BarChip macro synthetic fibre is environmentally friendly and drastically reduces the carbon footprint of concrete reinforcement.

2.2 Strength Performance

Like steel fibres, high performance macro synthetic fibres improve concrete's post cracking behaviour, such as toughness, ductility and residual strength.

- "The ability of steel and synthetic fibres to absorb energy has long been recognized as one of the most important benefits of incorporating fibres into plain concrete…" (Gopalaratnam and Gettu, 1995)
- Fibre concrete performance is "controlled by the volume of fibres, the physical properties of fibres and the matrix, and the bond between the two" (The Concrete Society, 2007)
- Ductility is a characteristic dependent on fibre type, tensile strength, and anchorage mechanism (Soutsos et al., 2012).

One of the common fibre concrete strength indicators is the measure of toughness, which can be defined as energy absorption or the area under the load deflection curve. The load deflection (or stress/ strain) curve of a bending test illustrates the way in which this is measured. What is notable, is that the fibres substantially increase the ability of concrete to sustain load at deflections or strains beyond the appearance of first crack. The decrease in flexural resistance with the increase in deflection is known as 'strain softening'. This behaviour is different from the traditional steel reinforced concrete where the design aims at increasing flexural resistance after the concrete cracks ('strain hardening' or 'tension stiffening').

When the concrete cracks in the tension zone under flexural stress, the fibres in the concrete matrix create a 'bridging' effect at the cracked region, which continue to hold the concrete together until fibre pullout occurs. The pullout of fibres only occurs if the fibres are sufficiently stiff; otherwise, the fibres might rupture before fibre pullout and failure can be brittle and catastrophic. It is the fibre pullout or de-bonding that allows fibre concrete to be 'ductile'.

BarChip fibres are high performance macro synthetic fibres that are engineered for structural performance, having an elastic modulus (Young's

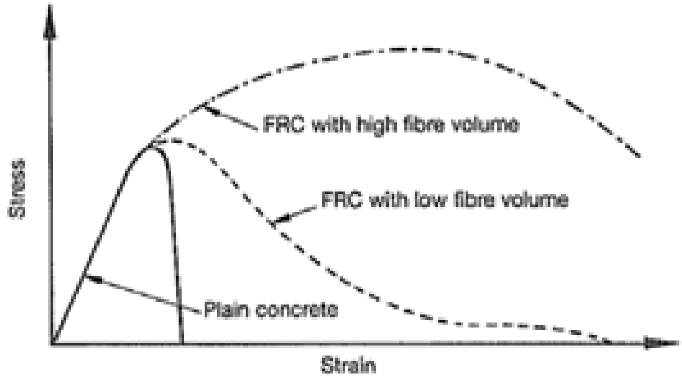

Figure 2-1: Toughness performance of fibre reinforced concrete

Figure 2-2: Crack bridging by fibres in a beam test

modulus) of 8 – 14 GPa and a tensile strength of 600 – 700 MPa. Whereas other synthetic fibres such as Collated Fibrillated Polypropylene (CFP) or mono-filament micro synthetic fibres have typical elastic moduli of 3.5 – 4.8 GPa and tensile strength of 300 – 400 MPa only.

BarChip macro synthetic fibres also increase concrete's abrasion, impact and spalling resistance. In regards to stress-strain behaviour in the elastic zone (uncracked concrete), there is no significant contribution from either steel or synthetic fibres and the compression and flexural designs should be treated as plain concrete. The benefit of using macro synthetic fibres is predominantly to improve the post cracking properties of hardened concrete for structural elements.

2.2.1 Compressive Strength

Figure 2-3 shows the up shift of the stress stain curve in compression with increasing fibre dosage rate relative to plain concrete. This implies that post peak toughness and ductility are both positively related to fibre dosage. The graph illustrates consistent results with previous studies showing fibres' effectiveness in the post crack region. However, the design of concrete should be treated as plain as the increase in fibre dosage has no effect in the elastic region.

With regards to the relative performance of macro synthetic fibres and steel fibres in concrete compressive strength, Buratti, et al. (2011) found that the macro synthetic (MS) fibres with lower dosages show similar compressive strength to steel fibre (SF).

Polyolefin MS1 (copolymer with fibrillated polystyrene), polystyrene MS2 and polymeric mix MS3 were tested with different dosages as indicated behind the symbols (i.e., MS2_5 = polystyrene fibres at 5 kg/m^3). With MS1_2 excluded, the effect of compressive strength increase with the increase in fibre dosage is more significant with synthetic fibres than steel fibres. The results also show synthetic fibres at higher dosages have compressive strength exceeding steel fibres.

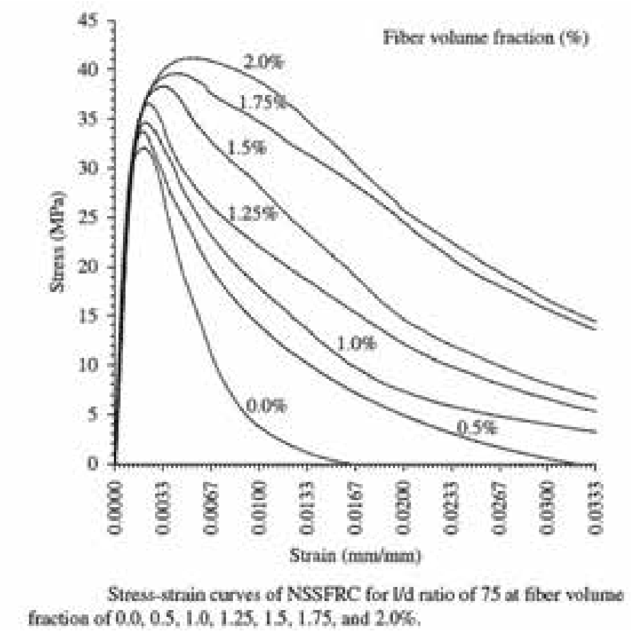

Figure 2-3: Influence of fibre dosage in concrete compressive strength.

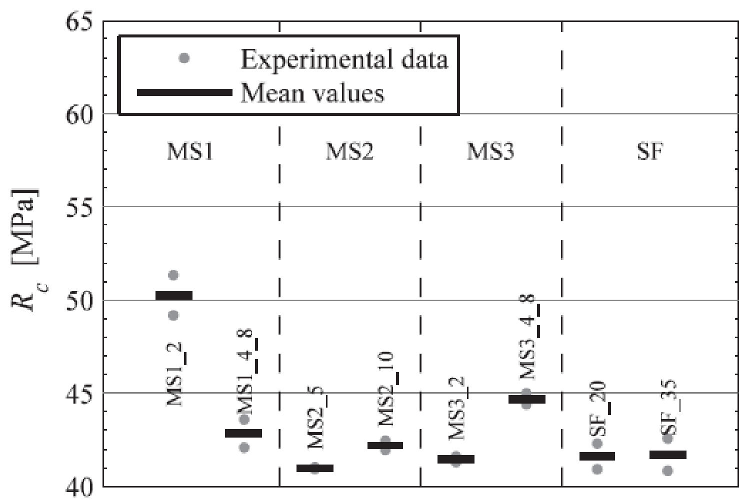

Figure 2-4: Relative performance of macro synthetic fibres and steel fibres in concrete compression.

2.3 Plastic Shrinkage and Settlement Cracking

Fibres restrain shrinkage due to the bond with concrete. Previous experimental results show that macro synthetic fibres are more effective than steel fibres in reducing plastic shrinkage and settlement cracking even at low dosages (Juhasz et al., 2015). This is due to the different bond performance of macro synthetic fibres as compared to steel fibres, which only work in hardened concrete. The critical time frame to form settlement or plastic shrinkage cracks is within the first 10 minutes to six hours after pouring when the concrete is setting, but has not yet developed sufficient strength to firmly hold the steel fibres. The anchorage element of steel fibres, typically end hooks, doesn't find sufficient resistance against pull-out and thus, little to no crack bridging effect can take place. In contrast, BarChip macro synthetic fibres are bonding over their entire length so that the intrinsic stresses can be taken up and even micro cracks can be bridged.

2.4 Durability

BarChip macro synthetic fibres are manufactured from polypropylene and have been shown to be durable in concrete (The Concrete Society, 2007). It is also stated that "macro synthetic fibres will not be significantly affected by moisture and will not be attacked by chlorides when used in marine structures or those subjected to de-icing salts". A number of studies have been performed recently to assess the durability performance of both steel and macro synthetic fibres. In recent papers the inherent corrosion problem of steel fibres was brought to light, showing that steel fibre reinforced concrete loses performance with age in cracked sections due to corrosion of the fibres.

The critical crack width can be as small as 0.1mm, depending on the environmental conditions (Bernard, 2015) and (Kaufmann, 2014). Steel fibre reinforced concrete can also lose performance in uncracked sections, due to matrix hardening over time. This embrittlement effect, related to late-age strength gain, can yield post crack performance losses of up to 50% as compared to 28- day standard test results. It was also shown that these detrimental phenomena do not occur in macro synthetic fibre reinforced concrete.

2.5 Concrete Mix

The important parameters that affect workability of macro synthetic fibre reinforced concrete are:

- The fibre length
- Fibre fineness
- Fibre content
- The aggregate content
- Aggregate size and grading and
- Water to cementitious ratio in the mix.

The higher the fibre length and the finer the fibres, the less workability of the fresh fibre concrete (Muller et al., 2012). An excessive amount of fibres in the mix reduces workability (Buratti et al., 2011).The addition of appropriate admixture, i.e. high range water reducers or superplasticizers to improve the workability of fibre concrete is thus recommended. It is also suggested that the "grain size should also not be in excess of one third of the fibre length to allow the fibres to overlap sufficiently". This concept is illustrated in figure 2-5. High proportions of large aggregates displace the fibres so that these cannot be effective in bridging the cracks that initiate at the interface of aggregate and binder matrix.

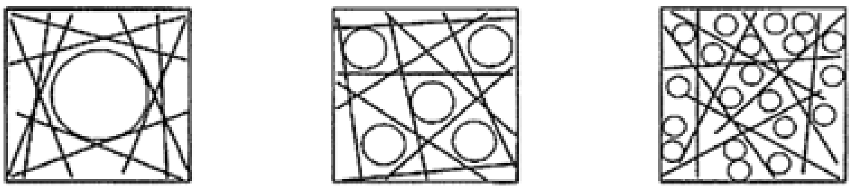

Figure 2-5: The impact of grain size on fibre distribution by Muller et al (2012).

Batching and mixing of fresh fibre concrete is a critical process, in order to obtain a regular dispersion of fibres in the mix. Thus, the batching procedure, cementitious paste content and aggregate size, content and grading should be closely monitored and designed to assure sufficient workability.

The methodology to optimize batching and mixing of BarChip fibres is discussed in detail in Section 5.2.

2.6 Design Considerations

When designing fibre reinforced concrete, the post crack strength specifications are the governing indicators for performance. The revised Concrete Society technical report TR34 4th edition references the three-point notched beam test as per EN 14651:2005 (Figure 2-6). "The post crack properties of fibre-reinforced concrete are now determined from the European Notched Beam Test…" (The Concrete Society, 2013). The new performance indicator in the fourth edition is the residual flexural tensile strength at a given Crack Mouth Opening Displacement (CMOD). Thus, a residual stress–crack width relationship is the ruling design parameter.

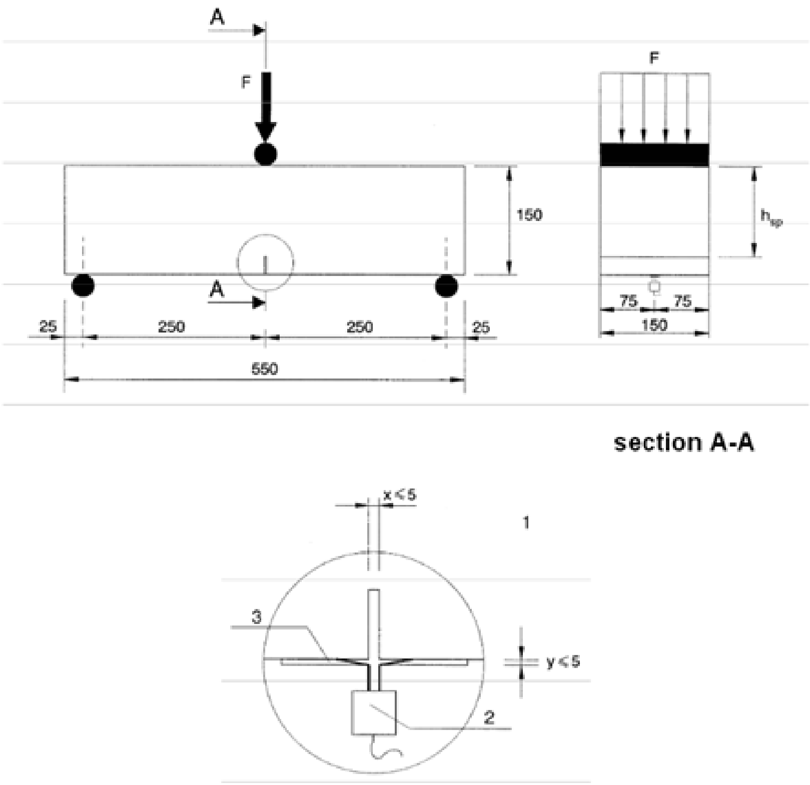

Figure 2-6: Three-point notched beam test setup from EN 14651 (2005)

CMOD is measured with a strain gauge over the sawn notch. The depth of the notch must be determined so that the remaining section depth h_{sp} is 125 ±1 mm.

Alternatively, or for additional measurement of the displacement, a linear variable differential transformer (LVDT) can be used to control the test. Figure 2-7 shows a test setup with CMOD control and additional measurement of displacement with a LVDT.

The relationship between CMOD and deflection can be approximated by the following equation

Equation 2-1

$$d = 0.85\ CMOD + 0.04$$

d = deflection

d and $CMOD$ in [mm]

For further detail of the tests, refer to EN 14651:2005.

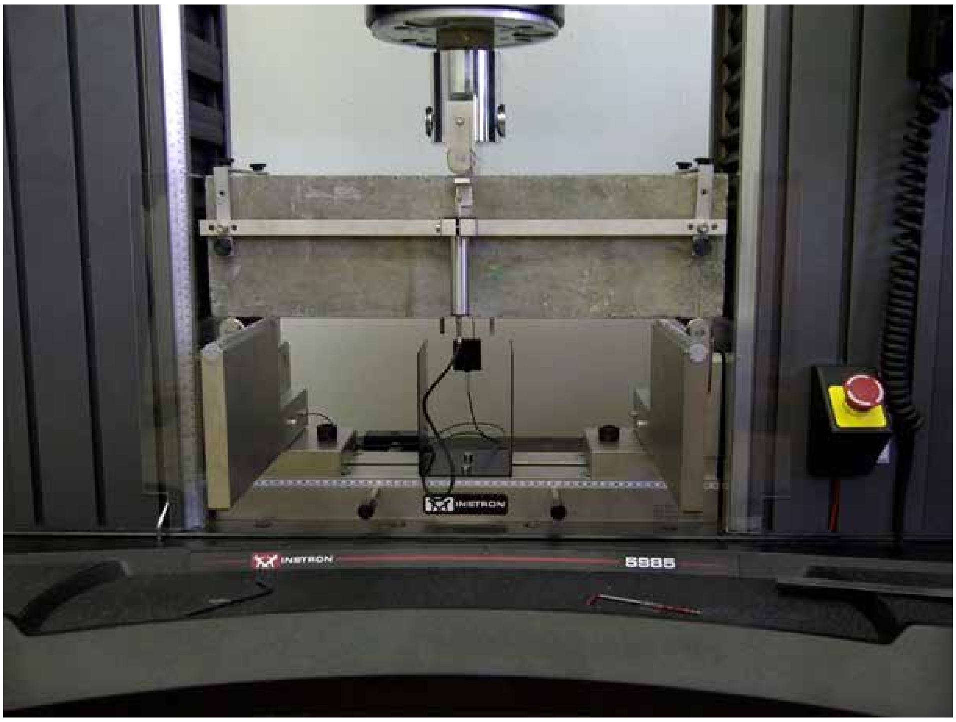

Figure 2-7: Beam test setup to EN 14651 with CMOD gauge and additional LVDT for displacement measurement.

3. Synthetic Fibres Properties

3.1 General

Fibres are regulated by the European harmonized set of Standards. Polymer fibres are classified in EN 14889-2:2006. Polymer fibres are divided into two main classes according to their physical form:

Class 1: Micro fibres:

- Class 1a: Micro fibres < 0.3 mm in diameter, mono-filamented
- Class 1b: Micro fibres < 0.3 mm in diameter, fibrillated

Application: plastic shrinkage control, impact protection, anti-spalling and fire resistance.

Class 2: Macro fibres > 0.3 mm in diameter

Application: structural reinforcement in concrete where an increase in residual flexural strength is required.

3.2 Macro Synthetic Fibres - BarChip

BarChip macro synthetic fibres are engineered polymer fibres used for structural reinforcement as well as for crack control. BarChip fibres are certified to CE for "structural use in concrete, mortar or grout" under the requirements of EN 14889-2:2006 (European Committee for Standardisation (CEN), 2006). Further, BarChip fibres comply with ASTM C1116-03, Standard Specifications for Fibre Reinforced Concrete and Shotcrete, Type 3 (American Society for Testing and Materials, 2010).

BarChip fibres for flooring and paving have the following specifications listed in Table 3-1.

	BarChip 48	**BarChip MQ58**	**Standard**
Fibre Class II	For structural use in concrete, mortar and grout		EN 14889-2
Tensile Strength	640 MPa	640 MPa	JIS L 1013/ISO 2062
Young's Modulus	12 GPa	10 GPa	JIS L 1013/ISO 2062
Anchorage	Continuously Embossed	Continuously Embossed	
Base Material	Virgin Polypropylene	Polymer bi-component	
Alkali Resistance	Excellent	Excellent	
Length	48 mm	58 mm	
Fibres / kg	59,520	53,880	
Reinforcing Length	2,857 m/kg	3,125 m/kg	
CE Certification	0120 - GB10/79678		
ISO 9001:2008 Certification	JKT0402914		

Table 3-1: Selected BarChip Properties

The characteristics of BarChip fibre are:

- Can be used to replace steel mesh and welded wire reinforcement
- Do not leave 'hairy' finish on the concrete
- Do not negatively affect finishing techniques
- Do not damage pumping or placing equipment
- Do not greatly reduce concrete slump

There is a wide range of different BarChip fibres of different structural performance for different applications. Each fibre type has its size, bond and anchorage configuration that affect the composite strength and toughness performance differently from others. BarChip MQ58 was specifically developed for industrial floors and pavements. This fibre does not provide the same level of structural performance as compared to BC48, but excels with an outstanding finishing ability, which is one of the paramount criteria in flooring.

Please consult our technical service for the most appropriate fibre for your application.

4. Design of Ground Supported Slabs using BarChip Fibre Reinforcement

4.1 General

This section illustrates the design steps for ground supported concrete slabs using BarChip macro synthetic fibres. The design assumes the slab is fully supported on undisturbed ground and/or subbase and that there is no access below the slab for its intended structural life.

The two possible failure modes for ground supported slabs are flexural and punching shear. In order to avoid potential punching and potential slab curling TR34 4th edition recommends that the minimum design thickness for ground supported slab is 150 mm. This minimum thickness is chosen in order to minimise the curling and warping of slabs, which can occur due to moisture and temperature differentials between the top and bottom surfaces of the slabs. By ensuring an adequate dead load through this minimum thickness requirement the risk of curling and warping is significantly reduced.

The general design principal of ground supported slabs in flexure is based on the Yield Line Theory, using the ductility provided by fibre reinforcement to achieve plastic behaviour after cracking. Partial safety factors are required at the ultimate limit state (ULS) design to control the surface cracks at the hogging (negative moment) region and residual post crack value at the sagging (positive moment) region. The design of punching shear is based on the approach in Eurocode 2 for suspended slabs with allowance for loads to be transferred directly through the slab to the ground.

4.2 Partial Safety Factors

The partial safety factors used in ground supported floors are listed in tables 4-1 and 4-2.

Material	γ_m
Concrete	1.5
Concrete with fibre	1.5
Reinforcement (bar or fabric)	1.15

Table 4-1: Material partial safety factors

Load Type	γ
Defined Racking	1.2
Other	1.5
Dynamic Loads	1.6

Table 4-2: Load partial safety factors

4.3 Design Procedure Input Data (Step 1)

Follow steps 1, 2 and 3 to obtain the basic concrete properties for design.

4.3.1 Strength Properties for Concrete (Step 1-1)

The mean compressive strength, mean axial tensile strength and secant modulus of elasticity can be derived from the known characteristic compressive cylinder strength f_{ck} based on Eurocode 2.

Description	**Symbol**	**Explanation**
Mean Compressive Strength (cylindrical)	f_{cm}	$= f_{ck} + 8$
Mean Axial Tensile Strength	f_{ctm}	$= 0.3\ f_{ck}^{2/3}$ $(f_{ck} \leq 50\ MPa)$ $= 2.12\ ln[1+(f_{cm}/10)]$ $(f_{ck} > 50\ MPa)$
Secant Modulus of Elasticity	E_{cm}	$= 22\ (f_{cm}/10)^{0.3}$

Table 4-3: Concrete Properties and Relationships

MPa			
Characteristic Compressive Strength (Cylindrical)	Mean Compressive Strength	Mean Axial Tensile Strength	Short Term Modulus of Elasticity (rounded to 500)
f_{ck}	f_{cm}	f_{ctm}	E_{cm}
20	28	2.2	30000
25	33	2.6	31500
28	36	2.8	32500
30	38	2.9	33000
32	40	3.0	33500
40	48	3.5	35000

Table 4-4: Concrete Properties

4.3.2 Flexural Tensile Strength (Step 1-2)

The characteristic flexural tensile strength of plain concrete of specified thickness can be found using the following equation:

Equation 4-1

$$f_{ctd,fl} = f_{ctm} \times (1.6 - h / 1000) / \gamma_m$$

Alternatively, the flexural tensile strength of a slab with known thickness and concrete strength can be obtained from table 4-5.

Thickness	**Flexural Tensile Strength [MPa]**					
h	$f_{ctd,fl}$					
	20	25	28	30	32	40
150	2.1	2.5	2.7	2.8	2.9	3.4
175	2.1	2.4	2.6	2.8	2.9	3.3
200	2.1	2.4	2.6	2.7	2.8	3.3
225	2.0	2.4	2.5	2.7	2.8	3.2
250	2.0	2.3	2.5	2.6	2.7	3.2
275	2.0	2.3	2.4	2.6	2.7	3.1
300	1.9	2.2	2.4	2.5	2.6	3.0

Table 4-5: Flexural tensile strength for different concrete strength classes

4.3.3 Radius of Relative Stiffness (Step 1-3)

There are different load categories and each is defined with the concept of radius of relative stiffness l. Radius of relative stiffness (or elastic length) is determined as:

Equation 4-2

$$l = [\,(E_{cm}\, h^3 \times 10^6) / (12\,(1 - v^2)\, k)\,]^{0.25}$$

Where:

E_{cm} = short-term elastic concrete modulus [MPa]
h = slab thickness [mm]
k = modulus of subgrade reaction [MPa/mm or N/mm^3]
v = Poisson's ratio, taken as 0.20 [-]

Description of Material	***k* [MPa/mm]**	
	Lower Value	Upper Value
Fine or slightly compacted sand	0.015	0.03
Well compacted sand	0.05	0.10
Very well compacted sand	0.10	0.15
Loam or clay (moist)	0.03	0.06
Loam or clay (dry)	0.08	0.10
Clay with sand	0.08	0.10
Crushed stone with sand	0.10	0.15
Coarse crushed stone	0.20	0.25
Well compacted crushed stone	0.20	0.30

Table 4-6: Typical k values from TR34 3rd edition (The Concrete Society, 2013)

4.4 Structural Properties (Step 2)

4.4.1 Negative Moment Capacity (Step 2-1)

The first tier calculation of moment capacity for a given slab thickness shall be treated as plain concrete for hogging moments in accordance with TR34 using the following equation:

Equation 4-3

$$M\mathrm{un} = f_{\mathrm{ctd,fl}} \, (h^2 / 6)$$

Alternatively, the moment capacity of a slab with known thickness can be taken from Table 4-7.

Thickness [mm]	**Plain Concrete Moment Capacities [kNm/m]**					
h	M_{un}					
	20	25	28	30	32	40
150	8.0	9.3	10.0	10.5	11.0	12.7
175	10.7	12.4	13.4	14.0	14.7	17.0
200	13.8	16.0	17.2	18.0	18.8	21.8
225	17.1	19.8	21.4	22.4	23.4	27.1
250	20.7	24.0	25.9	27.2	28.3	32.9
275	24.6	28.6	30.8	32.2	33.7	39.1
300	28.7	33.3	36.0	37.7	39.3	45.6

Table 4-7: Negative (hogging) moment capacities for different concrete strength classes.

4.4.2 Positive Moment Capacity with Macro Synthetic Fibre Reinforced Concrete (Step 2- 2)

4.4.2.1 Determining Fibre Reinforced Concrete Properties

In accordance with TR34, the residual flexural strength provided by the fibres is determined using a three-point notched beam test with a notch at mid span as per the European harmonised standard EN 14651:2005 (refer to Image 1).

The beams are tested in a servo controlled machine, which applies load to the beam in order to achieve a constant rate of crack mouth opening displacement (CMOD). The load applied and displacement measured are recorded and used to provide a *Load vs. CMOD* plot, an example of which can be seen below:

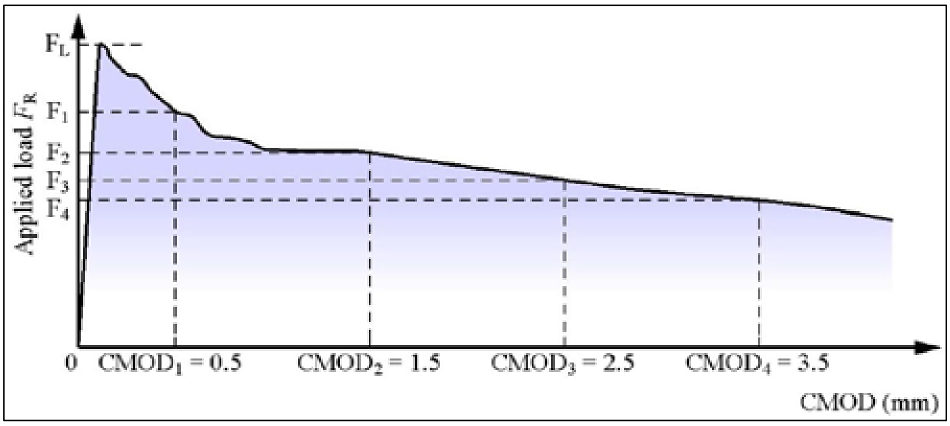

Figure 4-1: Example of Load vs. CMOD plot derived from EN14651 beam test (European Committee for Standardisation (CEN), 2005).

Each load is used to derive a residual flexural tensile strength f_R

$$f_R = 3\ F_R\ l\ /\ (2\ b\ h_{sp}^{\ 2})$$

Where:

F_R = applied load at stage R
l = the loading span (500 mm)
b = the beam width (150 mm nominal)
h_{sp} = depth of the section to the tip of the notch (125 ±1mm)

Four values f_{Ri} are reported at $CMOD_1$ to $CMOD_4$.

4.4.2.2 Calculation of Residual Moment Capacity from Notched Beam Tests

With reference to RILEM TC 162-TDF (RILEM TC 162-TDF, 2003), the moment capacity can be calculated by first calculating the direct axial tensile strength from the residual flexural strength at each of the two CMOD's. These are σ_{r1} and σ_{r4} which correspond to a CMOD of 0.5 mm and 3.5 mm respectively in the notched beam test. The crack depths herein are assumed to be 0.66 and 0.9 of the beam depth.

The following formulae are then derived:

$\sigma_{r1} = 0.45\, f_{R1}$

$\sigma_{r4} = 0.37\, f_{R4}$

Where: f_{R1} = the residual flexural strength at CMOD 0.5 mm

f_{R4} = the residual flexural strength at CMOD 3.5 mm

In the floor cross section, at Ultimate Limit State (ULS), it is assumed that the axial tensile stress at the tip of the crack is equivalent to σ_{r1}, and at the extreme tensile face it is assumed to be σ_{r4}, with a triangular distribution in between as shown in figure 4-2.

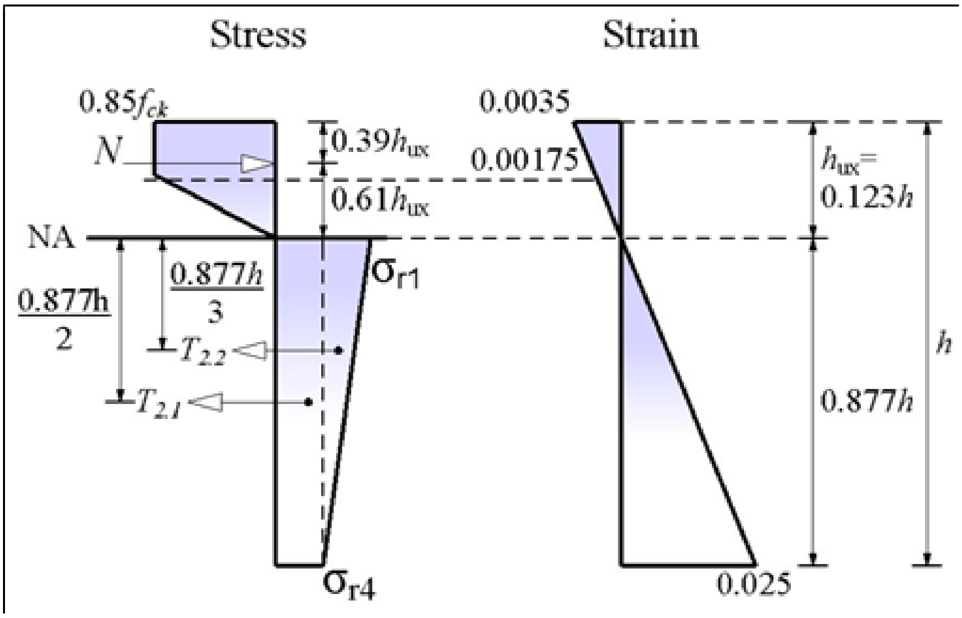

Figure 4-2: Stress block for fibre reinforced concrete

Using the partial material safety factor γ_m the ultimate sagging (positive) moment capacity of a fibre reinforced concrete section can then be calculated using the simplified formula below:

Equation 4-4

$$M_{up} = h^2 / \gamma_m \times (0.29\, \sigma_{r4} + 0.16\, \sigma_{r1})$$

4.5 Select Design Loads (Step 3)

The design loads can act at various locations of the floor and designers should be aware of the load locations defined by TR34. Three scenarios are defined (see Figure 4-3):

- Internal condition
- Edge condition and
- Corner condition

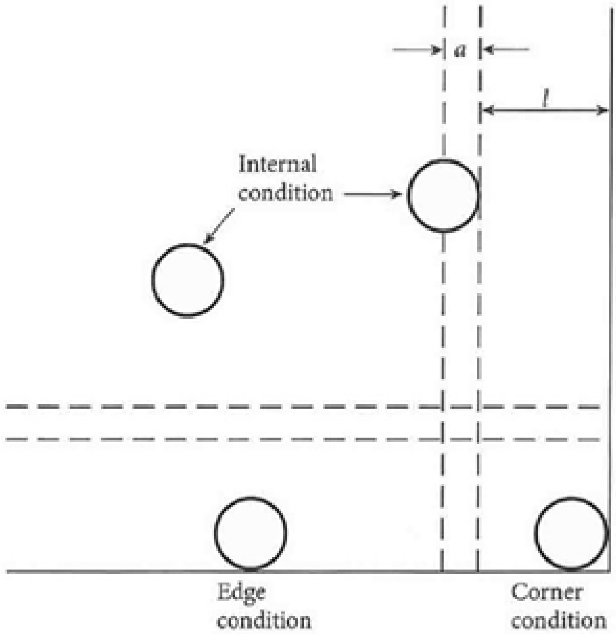

Figure 4-3: Definitions of loading conditions

Internal load condition is given when the load has a minimum distance of *l* (radius of relative stiffness) from any edge. The full two-way load-bearing mechanism of the slab can be activated leading to the positive moment underneath the slab and a negative moment circumferential around the load point.

An *edge condition* is given, when the load is located within a distance of *l* to an edge. This can be a joint (saw cut or construction joint) or simply the boundary edge of the slab (free edge). In this condition the slab can only activate a one-way load-bearing, i.e. a bending moment lateral to the edge. Thus, the load-bearing capacity in edge condition can be markedly reduced as compared to internal condition. At joints, the load-bearing capacity is dependent from the type of the joint and its load transfer capacity, but is significantly higher as compared to a free edge.

An entirely different load-bearing behaviour is given when the load is located in *corner condition*, especially when the corner marks the boundary corner of the slab. In this case, the corner will be bent down, creating a hogging (negative) bending moment diagonally across the edges. The load bearing capacity will be significantly reduced compared to internal condition. At joints, the load- bearing capacity is dependent from the type of the joint and its load transfer capacity, but is significantly higher as compared to a free corner.

4.5.1 Single Point Load (Step 3-1)

The positive bending moment induced by a single point load is radial and has its maximum directly under the load. The point of counter-flexure (zero bending moment) is located approximately at radial distance of 1.0 l (where l = radius of relative stiffness) from the load. The maximum negative circumferential moment is at an approximate radial distance of 2.0 l from the load. The moment approaches zero at an approximate radial distance of 3.0 l from the load.

To determine the characteristic of a single point load as defined by the ratio of a/l where:

a = equivalent radius of the contact area of the load (in mm^2) based on the effective contact area. Refer to manufacturer's information for specific contact area (e.g. wheels or base plates from rack feet or mezzanine columns). The effective dimension of the base plate shall be taken as d + 4t, then rearrange for the equivalent radius r where:

$$\pi r^2 = (d + 4t)^2$$

$$r = \sqrt{[(d + 4t)^2 / \pi]}$$

t = thickness of the base plate [mm]

d = width of the racking leg/column [mm]

It is sometimes difficult to find exacting dimensions of the baseplates. In the absence of project- specific details, an effective dimension of 100 mm x 100 mm should be used.

A single point load such as:

- Racking leg or mezzanine column

Shall satisfy the following condition:

$P^* \leq P_u$

The point load can act at various locations on the slab and the locations are divided into three main categories; **internal load**, **edge load** and **corner load**.

For **internal load** with:

Equation 4-5

$a/l = 0$: $P_{u,0} = 2\pi (M_p + M_n)$

Equation 4-6

$a/l \geq 0.2$: $P_{u,0.2} = 4\pi (M_p + M_n) / [1 - (a / 3l)]$

For free **edge load** with:

Equation 4-7

$a/l = 0$: $P_{u,0} = [\pi (M_p + M_n) / 2] + 2M_n$

Equation 4-8

$a/l \geq 0.2$: $P_{u,0.2} = [\pi (M_p + M_n) + 4M_n] / [1 - (2a / 3l)]$

For free **corner load** with:

Equation 4-9

$a/l = 0$: $P_{u,0} = 2M_n$

Equation 4-10

$a/l \geq 0.2$: $P_{u,0.2} = 4M_n / [1 - (a / l)]$

Interpolate for values of a/l between 0 and 0.2.

4.5.2 Dual Point Load (Step 3-2)

This section applies to two point loads with centre line spacing 'x' more than twice the slab thickness (2h). If $x \leq 2h$, they shall be treated as an aggregate single point load, acting on the combined area. The dual loads are to be treated as two single point loads when they are centre spaced more than $x > 2h$.

Multiple point loads such as:

- Truck wheel loads
- Multiple racking loads (back to back)

Shall satisfy the following condition:

$P^* \leq P_u$

For **internal load** with:

Equation 4-11

$a/l = 0$: $P_{u,0} = [2\pi + (1.8x / l)] \times [M_p + M_n]$

Equation 4-12

$a/l \geq 0.2$: $P_{u,0.2} = [4\pi / (1 - (a / 3l) + 1.8x / (1 - (a / 2))] \times [M_p + M_n]$

4.5.3 Quadruple Point Load (Step 3-3)

The quadruple point load capacity is the smallest of 1) sum of 4 individual point load capacities, 2) sum of 2 dual point load capacities or 3) by the approximate quadruple point load capacity.

Quadruple point loads such as:

- Truck wheel loads
- Multiple racking loads

Shall satisfy the following condition:

$P^* \leq P_u$

For **internal load** with:

Equation 4-13

$$a/l = 0: \quad P_{u,0} = [2\pi + (1.8\,(x + y) / l)] \times [M_p + M_n]$$

Equation 4-14

$$a/l \geq 0.2: \quad P_{u,0.2} = [4\pi / (1 - (a / 3l) + 1.8\,(x + y) / (l - (a / 2))] \times [M_p + M_n]$$

For **edge load**:

TR 34 4th edition does not have suggestions for quadruple point loads on edge of slab, as it is unlikely for this loading arrangement to ever occur in practice.

Interpolate for values of a/l between 0 and 0.2.

4.6 Punching Shear Capacity and Ground Support

4.6.1 General

Punching shear capacity of ground slab is determined by minimum of:

- Shear at the face of the contact area u_0 and
- Shear at the critical perimeter distance 2.0d

4.6.2 Shear at Face of Loaded Area

To determine the maximum load capacity in punching:

Max punching load capacity

Equation 4-15

$$P_{p,max} = v_{max}\, u_0\, d^*$$

Compressive Strength f_{ck} [MPa]	**20**	**25**	**28**	**30**	**32**	**40**
Max Shear Strength v_{max} [MPa]	3.7	4.5	5.0	5.3	5.6	6.7

Table 4-8: Max shear strength v_{max} depending on compressive strength

4.6.3 Shear on the Critical Perimeter

Punching load capacity;

Equation 4-16

$$P_P = v_{Rd,c,min}\, u_1\, d^*$$

Unreinforced concrete minimum shear stress;

Equation 4-17

$$v_{Rd,c,min} = 0.035 k_s^{1.5} f_{ck}^{\ 0.5}$$

Where:

u_0	=	length of the perimeter of the loaded area
	=	$4 \times (d + 4t)$ for square plate (refer 4.5.1)
u_1	=	length of the perimeter at a distance 2d from the loaded area = $4d \times \pi + 4 \times (d+4t)$ for a square plate
	=	u_0, for base plates
d^*	=	effective depth of cross section
	=	0.75 h for fibre reinforced concrete, where h is the slab thickness
k_s	=	$1 + (200 / d^*)^{0.5} \leq 2.0$

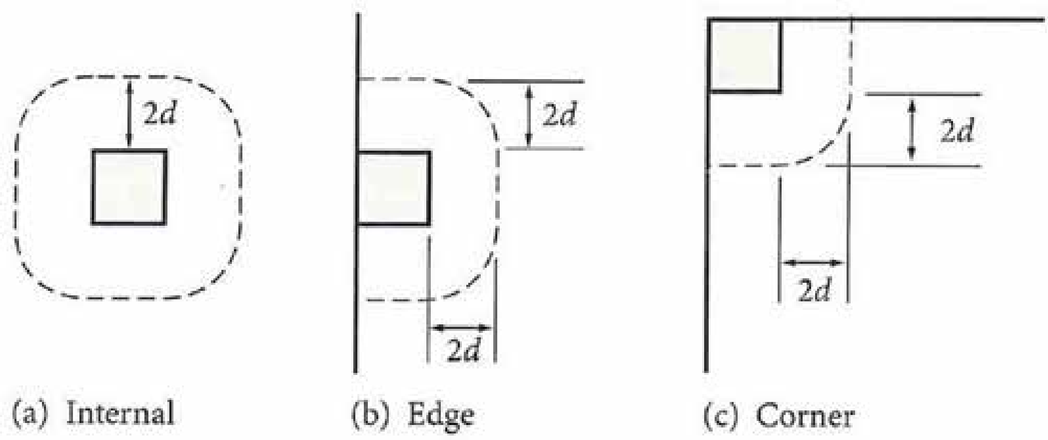

Figure 4-4: Critical perimeters for punching shear for internal, edge and corner loading

	$v_{Rd,c,min}$ [MPa]					
	Concrete Compressive Strength $f$ck [MPa]					
Slab Depth h [mm]	20	25	28	30	32	40
150 - 250	0.44	0.50	0.52	0.54	0.56	0.63
275	0.44	0.49	0.52	0.54	0.55	0.62
300	0.42	0.47	0.50	0.52	0.54	0.60

Table 4-9: Unreinforced concrete minimum shear strength

TR34 4th edition states that 'there are no data available to demonstrate that shear capacity enhancement is provided by macro-synthetic fibres and therefore no enhancement should be assumed, and the calculation is made using plain concrete parameters for punching shear capacity in macro synthetic fibre reinforced sections.

4.6.4 Loads applied through a stiff bearing

This section is only applicable for point loads that are applied through a stiff bearing $a/l < 0.2$, which allows a proportion of the load at punching shear perimeter to be applied directly to the subgrade and hence, reduces the design force. In the absence of a stiff bearing ($a/l \geq 0.2$) a reduced reaction may be applied.

For **internal load** with a stiff bearing:

Equation 4-18

$a/l < 0.2$: Ground Pressure $R_{cp} = 1.4(d^* / l)^2 P + 0.47(x + y)(d^* \times P / l^2)$

In absence of a stiff bearing:

Equation 4-19

$a/l \geq 0.2$: Ground Pressure $R_{cp} = 1.4 (d^* / l)^2 P$

For **edge load** with:

Equation 4-20

$a/l < 0.2$: Ground Pressure $R_{cp} = 2.4 (d^* / l)^2 P + 0.8 (x + 2y)(d^* \times P / l^2)$

In absence of a stiff bearing:

Equation 4-21

$a/l \geq 0.2$: Ground Pressure $R_{cp} = 2.4 (d^* / l)^2 P$

Where:

P	=	point load
d^*	=	effective depth
x, y	=	effective dimensions of the bearing plate, where x is dimension parallel to edge
l	=	radius of relative stiffness

4.7 Design of Joints

4.7.1 General

Slabs on ground often have joints to control temperature and autogenous cracking as well as separating concrete pour stages. Joints have to be adequately designed to ensure loads can be transferred across to any adjacent slabs to eliminate vertical differential movements in ground slabs. Where there is discontinuity in a ground supported slab separated by joints, the slab discontinuity shall be treated as an edge with increased capacity due to two mechanisms lists below. TR34 4th edition suggests load transfer by aggregate interlock of 15% and that it is impossible to transfer more than 50% of the design load across joints (TR34 section 7.9)(The Concrete Society, 2013).

The zone of influence for dowels working at full capacity is the radial distance of 0.9l from the load.

There are two types of mechanisms for transferring loads at joints:

- Aggregate interlock
- Dowels

TR34 4th edition design approach is:

1. Determine edge capacity X (ultimate free edge load from Equation 4-8)
2. Assume 15% load transfer, so effective edge capacity is $X / (1 - 0.15) = 1.176\,X$
3. Determine dowel capacity Y
4. Total effective edge capacity = $1.176\,X + Y$, which must not be greater than the ultimate load in internal condition from Equation 4-6.

4.7.2 Shear Capacity Per Dowel

Equation 4-22

$$P_{sh} = 0.6\, f_{yd}\, A_v$$

Where:

f_{yd} = f_{yk} / γ_s

γ_s = partial safety factor for steel, taken as 1.15

f_{yk} = yield strength of reinforcement, taken as 500 MPa shear area (mm^2)

A_v = $0.9 \times (\pi\, d^2/4)$ for round dowels

	Dowel Diameter [mm]		
Round Dowels	12	16	20
Shear Capacity (kN)	26.6	47.2	73.8

Table 4-10: Shear capacity per dowel

4.7.3 Bearing/Bending Capacity per round Dowel

Equation 4-23

$$P_{bear} = d_d^2 (f_{cd} f_{yd})^{0.5} [(1 + \alpha^2)^{0.5} - \alpha]$$

Where:

d_d = dowel diameter (mm)

f_{cd} = concrete design compressive cylinder strength [MPa]

= f_{ck} / γ_c

f_{yd} = f_{yk} / γ_s

f_{yk} = yield strength of reinforcement, taken as 500 MPa

α = $[3e (f_{cd} / f_{yd})^{0.5}] / d_d$

e = eccentricity or distance of application of load from face of concrete (mm)

= half of the joint opening by symmetry

Dowel Diameter [mm]	Bearing / Bending Capacity per Dowel [kN]					
	Concrete Compressive Strength f_{ck} [MPa]					
	20	**25**	**28**	**30**	**32**	**40**
			e = 1			
12	10.5	11.7	12.3	12.7	13.1	14.6
16	18.9	21.0	22.2	22.9	23.7	26.3
20	29.7	33.1	34.9	36.1	37.3	41.5
			e = 5			
12	8.8	9.6	10.0	10.3	10.6	11.4
16	16.6	18.2	19.0	19.5	20.1	21.9
20	26.7	29.4	30.9	31.8	32.7	35.8
			e = 10			
12	7.2	7.6	7.9	8.0	8.2	8.6
16	14.1	15.2	15.8	16.1	16.5	17.6
20	23.5	25.5	26.5	27.2	27.8	29.9
			e = 20			
12	5.0	5.2	5.2	5.3	5.3	5.5
16	10.5	11.0	11.3	11.4	11.6	12.0
20	18.4	19.5	20.0	20.4	20.7	21.7
			e = 30			
12	3.7	3.8	3.8	3.8	3.9	3.9
16	8.2	8.4	8.5	8.6	8.7	8.9
20	14.8	15.4	15.7	15.8	16.0	16.5

Table 4-11: Bearing / bending capacity per round dowel

4.7.4 Bursting Force Capacity of the Dowel

Equation 4-24

$$P_{burst} = 0.035\ k_s^{1.5}\ f_{ck}^{0.5}\ u_1\ d_1$$

Where

k_s = $1 + (200 / d)^{0.5} \leq 2.0$

u_1 = length of the perimeter = $8\ d_d + 0.5\ h\ \pi$

d_d = diameter of the dowel

h = slab thickness

d_1 = effective depth of the dowel, usually 0.5 h

The maximum capacity of one dowel is the minimum value of shear capacity, bearing/bending capacity or the bursting force capacity.

Equation 4-25

$$P_{max.dowel} = \min (P_{sh};\ P_{bear};\ P_{burst})$$

4.8 Line Loads

Line loads shall satisfy the following condition:

$P_{lin}^{*} \leq P_{lin}$

For **internal load**:

The line load capacity is determined as follows:

Equation 4-26

$$P_{lin} = 4\ \lambda\ M_{un}$$

For **edge load**:

The line load capacity at a free edge is determined as follows:

Equation 4-27

$$P_{lin} = 3\ \lambda\ M_{un}$$

Where:

M_{un} = hogging moment capacity of plain concrete (refer Table 4-7)

λ = characteristic length

= $[3\ k / (E_{cm} \times h^3)]^{0.25}$

k = modulus of subgrade reaction (refer Table 4-6)

E_{cm} = short-term modulus of concrete elasticity (refer Table 4-4)

h = slab thickness

The line load capacity near a slab joint within a distance of (0 – 1/λ) is 3 λ M_{un} and is to be increased linearly to 4 λ Mun over a distance of (3/λ – 1/λ).

The line load capacity can be taken to 4 λ M_{un} from a distance of 1/λ from a joint if the joint has a minimum 15% load transfer capacity (refer Figure 4-5).

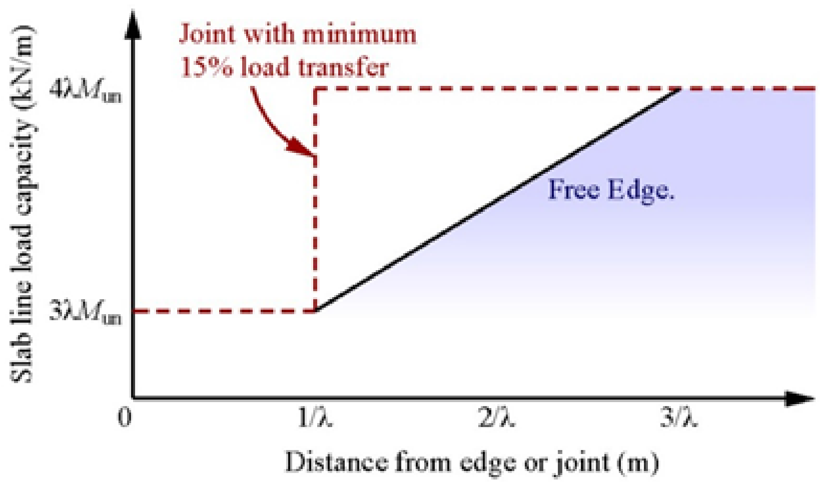

Figure 4-5: Line load capacity near free edges or joints from TR34 4th edition

4.9 Uniformly Distributed Loads

Uniformly distributed or pressure loads defined as per unit area such as:

- Block stacking
- Pallet loading

Shall satisfy the following condition:

$P_{UDL}^{*} \leq q$

The load capacity per unit area (kN/m²) q, is given by:

$q = 5.95\ \lambda^2\ M_{un}$

Where:

λ	=	characteristic length
	=	$[3\ k / (E_{cm} \times h^3)]^{0.25}$
M_{un}	=	moment capacity of plain concrete (refer Table 4-7)

See Appendix A for a worked example using 4kg/m³ of BarChip 48 fibres.

5. Construction of Ground Supported Slabs using BarChip Fibre Reinforcement

5.1 General

In general, macro synthetic fibre reinforced concrete ground slabs are constructed in a similar manner to conventionally reinforced concrete floors, without the need to spend time and money in setting up reinforcement before the concrete is poured. Generally, fibres are ordered through the readymix concrete supplier, who will add the fibres to the concrete at the batch plant and arrive at site with the fibre reinforcement already in the fresh concrete, ready to be placed. This section will outline some of the alternate practices that are required, specific to BarChip fibre reinforcement, during batching, mixing and construction of fibre reinforced ground supported slabs.

5.2 Batching and Mixing

When batching and mixing BarChip macro synthetic fibres a few simple steps should be followed to ensure homogenous mixing of the fibres throughout the concrete matrix.

5.2.1 Mixing at the Batch Plant with BarChip Soluble Bags

- Determine the correct number of BarChip bags per batch
- Add BarChip bags, “Bag and all”, to the empty agitator
- Add some initial batch water, approximately 12L/kg of fibre quantity per cubic meter of concrete (e.g. add 60 litres for a dose rate of 5.0kg/m^3).
- Mix for 1-2 minutes before adding the remaining concrete constituents
- Add the remaining constituents and mix for five minutes at mixing speed before leaving the concrete plant
- When the truck arrives at site, mix at mixing speed for a further 3-5 minutes before discharging concrete from agitator

5.2.2 Mixing at the Batch Plant with an automatic dosing machine using BarChip pucks

- Add fibre pucks, sand and aggregate to the agitator using a conveyor belt.
- Add cement and water
- Mix the truck at mixing speed for 5 minutes before leaving the concrete plant
- When the truck arrives at site, mix at mixing speed for a further 3-5 minutes before discharging concrete from agitator

5.2.3 Mixing fibres on-site using BarChip soluble bags

This method is not recommended, however if it must be used, please follow these steps:

- Determine the correct number of bags per batch
- Ensure the concrete has a minimum slump of 120 mm before adding fibres
- Ensure the agitator is at mixing speed before adding bags to the truck
- Add the BarChip bags to the mixer at a maximum rate of 10kg/minute
- After all of the fibres have been loaded, the agitator must mix at mixing speed for 1 minute per cubic metre of concrete in the truck

Following these steps when batching BarChip fibres leads to a concrete in which the fibres are homogenously distributed, and fibre balls can be avoided. If mixed correctly, BarChip fibres will not ball. Regular dose rates of BarChip fibres (i.e. 3 – 6 kg/m^3) can lead to a reduction in slump of 20-40mm. This should be accommodated for by admixture in the mix design, and not through addition of water on site.

5.3 Finishing

5.3.1 Finishing Techniques

No significant modification to standard procedures or techniques is required when finishing BarChip reinforced concrete. However, to achieve a completely 'fibre free' surface finish, finishing tools need to be kept flatter for longer, compared to non-fibre reinforced concrete. When using power trowels, the blades should be kept flat for the first two passes, and should be at right angles to each other. The finisher will find this 'flat' technique provides them with adequate surface paste when at the final finishing stage (when the blades start 'ringing' against the crisp concrete) and will be able to achieve any desired finish from non-slip to high burnish using normal techniques and timing.

It is also good practice when using tools such as a broom or float to only use them in a single direction on the concrete surface. If tools are used in both directions, i.e. pushed across the surface away from the concreter, then immediately dragged back towards the concreter, the tendency for the surface to 'tear' and the fibres to be pulled from the surface increases significantly.

5.3.2 Joints and Joint Layout

The UK Concrete Society's TR34 (2013) provides excellent guidance for the construction of joints in industrial flooring. It is recommended that joint spacing should not be larger than 6m x 6m for sawn joints, to minimize the risk of cracking as a result of shrinkage and restraint. Proper base preparation and mix design, as well as adequate curing are all advised to further minimize this risk.

Saw cuts should be applied as soon as practically possible once the concrete has set. This again minimizes the occurrence of uncontrolled cracking, by reducing the restraint in the concrete slab.

5.3.3 Curing

It is important to employ proper curing practices when finishing concrete floors to prevent excess moisture loss from the surface of the concrete. This can lead to plastic shrinkage cracking, as well as dusting of the concrete surface. Curing compounds can be sprayed on the concrete surface, or alternatively wet hessian can be placed onto the concrete surface and kept damp for at least 24 hours.

A good guide for curing practices is the Concrete Institute of Australia's (CIA) Recommended Practice for Curing of Concrete (Concrete Institute of Australia, 2011).

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Appendix A - Worked Design Example

A.1 Design Example 1 – Point Loads on 150 mm thick slab solely reinforced with BarChip 48 @ 4kg/m^3

A1.1.1 Step 1 – Slab Properties Part 1

Input:

Slab thickness	h	=	150 mm
Concrete comp. strength	f_{ck}	=	32 MPa
Modulus of subgrade reaction	k	=	0.05 N/mm^3

(Note: geotechnical investigation is required to obtain parameter k)

Output:

Flexural tensile strength	$f_{ctd,fl}$	=	2.9 MPa	(refer Table 4-5)
Short term elastic concrete modulus	E_{cm}	=	33500 MPa	(refer Table 4-4)

Radius of relative stiffness l

$$l = [(E_{cm}\, h^3) / (12\,(1 - \nu^2)\, k)]^{0.25}$$
$$= [(33500 \times 150^3) / (12\,(1 - 0.2^2) \times 0.05)]^{0.25}$$
$$= [1.126 \times 10^{11} / 0.576]^{0.25}$$
$$= 665.7 \text{ mm}$$

A1.1.2 Step 2 – Slab Properties Part 2

Input:

Radius of relative stiffness l = 665.7 mm

In absence of project-specific detail for adjustable pallet racking, an effective dimension of 100 mm x 100 mm should be used.

Racking leg width d = 100 mm

Output:

Equivalent radius of contact area (radius of equivalent circle)

$$a = \sqrt{[(d)^2 / \pi]}$$
$$= \sqrt{[(100)^2 / \pi]}$$
$$= 56.4$$

Contact area to stiffness ratio

$$a/l = 56.4 / 665.7$$
$$= 0.085$$

A1.1.3 Step 3 – Moment Capacities

General Design Steps

Step A) Nominate BarChip fibre with its residual tensile stresses σ_{r1} and σ_{r4}

Step B) Nominate concrete strength

Step C) Compute Moment Capacities using above inputs

Step A) Input fibre data: **Barchip 48 @ 4 kg/m³ dosage**

Residual stress $CMOD_1$ $\quad \sigma_{r1} = 0.45 \times f_{R1}$

$= 0.45 \times 2.0$

$= 0.90$ MPa

Residual stress $CMOD_4$ $\quad \sigma_{r4} = 0.37 \times f_{R4}$

$= 0.37 \times 2.2$

$= 0.81$ MPa

Step B) Nominate concrete strength

Concrete compressive strength $\quad f_{ck} = 32$ MPa

Step C) Moment capacities

Positive moment capacity $\quad M_{up} = h^2 / \gamma_m \times (0.29\ \sigma_{r4} + 0.16\ \sigma_{r1})$

$= 150^2 / 1.5 \times (0.29 \times 0.85 + 0.16 \times 0.95) \times 10^{-3}$

$= 5.7$ kNm/m

Negative moment capacity $\quad M_{un} = f_{ctd,fl}\ (h^2 / 6)$

$= 2.9\ (150^2 / 6) \times 10^{-3}$

$= 10.9$ kNm/m

The positive moment capacity (M_{up}) and negative moment capacity (M_{un}) of a slab, derived from slab thickness (h), concrete strength (f_{ck}) and σ_{r1} and σ_{r4} from BarChip fibre notched beams, are to be used to determine the loading capacity described in section 4.5.

A1.1.4 Step 4-1 – Single Point Load

Input:

Ultimate design point load $P^* = 65$ kN

Output:

For **Internal load**:

$a/l = 0$: $P_{u,0} = 2\pi (M_p + M_n)$

$= 2\pi (5.7 + 10.9)$

$= 104.3$ kN

$a/l \geq 0.2$: $P_{u,0.2} = 4\pi (M_p + M_n) / [1 - (a/3l)]$

$= 4\pi (5.7 + 10.9) / [1 - (56.4 / (3 \times 665.7))]$

$= 4\pi (16.9) / 0.97$

$= 214.7$ kN

Interpolation for $a/l = 0.085$:

$P_{u,0.085} = 104.3 + [(214.7 - 104.3) \times 0.085 / 0.2]$

$P_{u,0.085} = 151.2$ kN $> P^*$ (pass)

For free **edge load**:

$a/l = 0$: $P_{u,0} = [\pi (M_p + M_n) / 2] + 2M_n$

$= [\pi (5.7 + 10.9) / 2] + 2 \times 10.9$

$= 47.9$ kN

$a/l \geq 0.2$: $P_{u,0.2} = [\pi (M_p + M_n) + 4M_n] / [1 - (2a / 3l)]$

$= [\pi (5.7 + 10.9) + 4 \times 10.9] / [1 - (2 \times 56.4 / 3 \times 665.7)]$

$= 101.5$ kN $> P^*$ (pass)

Interpolation for $a/l = 0.085$:

$P_{u,0.085} = 47.9 + [(101.5 - 47.9) \times 0.085 / 0.2]$

$P_{u,0.085} = 70.7$ kN $> P^*$ (pass)

(Note: refer to joint design to determine effective edge load capacity where edge of slab is supported via connecting dowels)

Input:

Ultimate design point load	P_1^*	=	45 kN
Ultimate design point load	P_2^*	=	30 kN
Center spacing of two point loads	x	=	400 mm > (2 × h = 300)

(Note: For point loads spacing less than 2 × h, they are considered to act jointly as single point load on contact area = individual load area expressed as circles with radius 'a' + area between them)

Output:

For **Internal load**:

a/l = 0: $P_{u,0} = [2\pi + (1.8x / l)] \times [M_p + M_n]$

$= [2\pi + (1.8 (400) / 665.7)] \times [5.7 + 10.9]$

$= 122.3$ kN

a/l ≥ 0.2: $P_{u,0.2} = [4\pi / (1 - (a / 3l) + 1.8x / (l - (a / 2))] \times [M_p + M_n]$

$= [4\pi / (1 - (56.4 / (3 \times 665.7))$

$+ 1.8(400) / (665.7 - (56.4 / 2))] \times [5.7 + 10.9]$

$= 233.4$ kN

Interpolation for a/l = 0.085:

$P_{u,0.085} = 122.3 + (233.4 - 122.3) \times 0.085 / 0.2$

$P_{u,0.085} = 169.5$ kN $> (P_1^* + P_2^*)$ (pass)

For **edge load**:

According to TR34: where dual point loads are found near an edge, the internal load can be factored down by the ratio of the edge to internal load for a single point load.

Single point load capacity for **internal load** was:

Interpolation for a/l = 0.085:

$P_{u,0.085} = 104.3 + [(214.7 - 104.3) \times 0.085 / 0.2]$

$P_{u,0.085} = 151.2$ kN

Single point load capacity for free **edge load** was:

Interpolation for a/l = 0.085:

$P_{u,0.085} = 47.9 + [(101.5 - 47.9) \times 0.085 / 0.2]$

$P_{u,0.085} = 70.7$ kN

Multiplier factor:

mf = 70.7 / 151.2

= 0.47

Dual point load capacity for **edge load**:

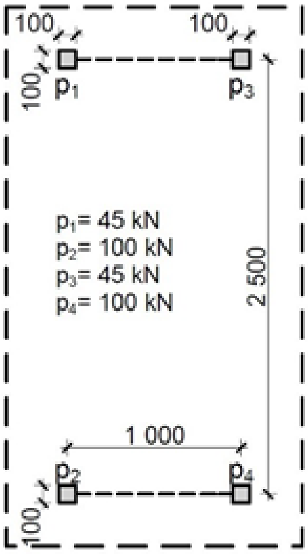
$P_u = 169.5 \times 0.47$

$= 79.7$ kN $> (P_1^* + P_2^*)$ (pass)

The moment capacity at free edge must be smaller than the moment capacity at internal position, so the multiplier factor is maximum 1.0.

A1.1.6 Step 4-3 – Quadruple Point Loads

Input:



Ultimate design point load 1 $P_1^* = 45$ kN

Ultimate design point load 2 $P_2^* = 100$ kN

Ultimate design point load 3 $P_3^* = 45$ kN

Ultimate design point load 4 $P_4^* = 100$ kN

Center spacing of two point loads $x = 1000$ mm

Center spacing of two point loads $y = 2500$ mm

Output:

For **Internal load**:

$a/l = 0$: $P_{u,0} = [2\pi + (1.8(x + y) / l)] \times [M_p + M_n]$

$= [2\pi + (1.8(1000 + 2500) / 665.7)] \times [5.7 + 10.9]$

$= 261.4$ kN

$a/l \geq 0.2$: $P_{u,0.2} = [4\pi / (1 - (a / 3l) + 1.8(x + y) / (l - (a / 2))] \times [M_p + M_n]$

$= [4\pi / (1 - (56.4 / (3 \times 665.7)) + 1.8(1000$

$+ 2500) / (665.7 - (56.4 / 2))] \times [5.7 + 10.9]$

$= 378.7$ kN

Interpolation for $a/l = 0.085$:

$P_{u,0.085} = 261.4 + [(378.7 - 261.4) \times 0.085 / 0.2]$

(a) $P_{u,0.085} = 311.3$ kN

4 × single point load capacity (b) $4_{Pu,o.085} = 4 \times 151.2$ (see A1.1.4 Step 4-1)

$= 604.8$ kN

2 × dual point load capacity (c) $2_{Pu,o.085} = 2 \times 169.5$ kN (see A1.1.5 Step 4-2)

$= 339$ kN

Min [a, b, c] $= 311.3 \text{ kN} > (P_1^* + P_2^* + P_3^* + P_4^*)$ (pass)

The 4 × single point load capacity and 2 × dual point load capacity are only valid in this case, if we use the same racking leg dimensions (d=100 mm) for each.

A1.2 Design Example 2 – Punching Shear 150mm thick slab solely reinforced with BarChip 48 @ 4kg/m³

A1.2.1 Step 1 – Obtain Design Parameters

Input:

Design point load	P^*	=	30 kN
Concrete compressive strength	f_{ck}	=	32 MPa
Base plate thickness	t	=	12 mm
Racking leg width	d	=	100 mm
Contact area to stiffness ratio	a/l	=	0.085 (refer A1.1.2)

(note: $a/l < 0.2$, allows design force to be reduced from effect of ground support, refer Section 2.6.4)

Output:

Max shear stress	v_{max}	=	5.6 MPa (refer 8)
Effective slab depth	d^*	=	0.75×150
		=	112.5 mm

A1.2.2 Step 2 – Internal Slab

Length of the loaded perimeter $u_0 = 4 \times d$ (square plate)

In absence of project-specific detail for adjustable pallet racking, an effective dimension of 100 mm x 100 mm should be used.

$= 4 \times 100$

$= 400$ mm

Max punching load capacity $P_{p,max} = v_{max}\, u_0\, d^*$

$= 5.6 \times 400 \times 112.5 \times 10^{-3}$

$= 252$ kN

Concrete min. shear stress (unreinforced)

$V_{Rd,c,min} = 0.56$ MPa (refer Table 4-9)

Length of the critical perimeter $u_1 = 4\pi \times d^* + 4 \times d$ (square plate)

at a distance 2d from loaded area $= 4\pi \times 112.5 + 4 \times 100$

$= 1814$ mm

Punching load capacity (unreinforced) $P_P = V_{Rd,c,min}\, u_1\, d^*$

$= 0.56 \times 1814 \times 112.5 \times 10^{-3}$

$= 114.3$ kN

$\text{Min}\,[P_{p,max}, P_P] = 114.3$ kN $> P^*$ (pass)

A1.2.3 Step 3 – Edge

Length of the loaded perimeter	u_0	=	$3 \times d$ (square plate)
		=	3×100
		=	300 mm
Max punching load capacity	$P_{p,max}$	=	$v_{max}\ u_0\ d^*$
		=	$5.6 \times 300 \times 112.5 \times 10^{-3}$
		=	189 kN
Concrete min. shear stress (unreinforced)	$v_{Rd,c,min}$	=	0.56 MPa
Length of the loaded perimeter	u_1	=	$2\pi \times d^* + 3 \times d$ (square plate)
at a distance 2d from loaded area		=	$2\pi \times 112.5 + 3 \times 100$
		=	1007 mm
Punching load capacity (unreinforced)	P_P	=	$v_{Rd,c,min}\ u_1\ d^*$
		=	$0.56 \times 1007 \times 112.5 \times 10^{-3}$
		=	63.4 kN
	Min $[P_{p,max}, P_P]$	=	63.4 kN $> P^*$ (pass)

A1.2.4 Step 4 – Corner

Length of the loaded perimeter	u_0	=	$2 \times d$ (square plate)
		=	2×100
		=	200 mm
Max punching load capacity	$P_{p,max}$	=	$v_{max}\ u_0\ d^*$
		=	$5.6 \times 100 \times 112.5 \times 10^{-3}$
		=	63 kN
Concrete min. shear stress (unreinforced)	$v_{Rd,c,min}$	=	0.56 MPa
Length of the loaded perimeter	u_1	=	$\pi \times d^* + 2 \times d$ (square plate)
at a distance 2d from loaded area		=	$\pi \times 112.5 + 2 \times 100$
		=	553 mm

Punching load capacity (unreinforced)	P_p	=	$v_{Rd,c,min}\ u_1\ d^*$	
		=	$0.56 \times 553 \times 112.5 \times 10^{-3}$	
		=	34.8 kN	
	Min [$P_{p,max}$, P_p]	=	34.8 kN	$> P^*$ (pass)

A1.2.5 Step 5 – Effect of Ground Support (a/l < 0.2)

For slab properties with radius of relative stiffness $a/l < 0.2$

Input:

Design point load	P^*	=	30 kN	
Slab thickness	h	=	150 mm	
Effective dimensions of bearing plate	x	=	d	
(dimension parallel to edge)		=	100 mm	
Effective dimensions of bearing platey	y	=	d	
		=	100 mm	(square plate)
Radius of relative stiffness	l	=	665.7 mm	
Effective slab depth	d^*	=	0.75×150	
		=	112.5 mm	

Output:

Effective depth to stiffness ration	d^*/ l	=	112.5 / 665.7
		=	0.17
Effective depth, load to stiffness² ratio	$d^* \times P^*/l^2$	=	$(112.5 \times 30) / 665.7^2$
		=	7.6×10^{-3}

For **internal load** with:

Ground reaction	R_{cp}	=	$1.4\ (d^* / l)2\ P^* + 0.47\ (x + y)\ (d^* \times P^*/ l2)$
		=	$1.4 \times (0.17)^2 \times 30 + 0.47 \times (100 + 100) \times (7.6 \times 10^3)$
		=	1.9 kN

The equation $1.4(d^* / l)^2\ P^* + 0.47(x + y)\ (d^* \times P^*/ l2)$ is only valid if the point load pass over a stiff bearing plate ($a/l < 0.2$). In absence of stiff bearing plate ($a/l > 0.2$) only first part of the equation can be used: $1.4(d^* / l)2\ P^*$

$P^*- R_{cp}$	=	$30 – 1.9$	
	=	28.1 $< P_p = 114.3$ kN	(pass)

For **edge load** with:

Ground reaction R_{cp}	=	$2.4(d^* / l)^2\ P^* + 0.80\ (x + 2y)\ (d^* \times P^* / l^2)$
	=	$2.4 \times (0.17)^2 \times 30 + 0.8(100 + 2 \times 100) \times (7.6 \times 10^{-3})$
	=	3.91 kN

The equation $2.4(d^* / l)^2\ P^* + 0.80(x + 2y)\ (d^* \times P^* / l^2)$ is only valid if point load pass over a stiff bearing plate ($a/l < 0.2$). In absence of stiff bearing plate ($a/l > 0.2$) only first part of the equation can be used: $2.4(d^* / l)^2\ P^*$

$P^* - R_{cp}$	=	$30 – 3.91$
	=	26.09 $< P_p = 63.4$ kN(pass)

A1.3 Design Example 3 – Check Load Transfer at Joints

A1.3.1 Step 1 – Determine Ultimate Design Point Load

Input:

Ultimate design point load	P^*	=	90 kN	
Radius of relative stiffness	l	=	665.7 mm	(refer A1.1.1)

Output:

Zone of influence	$0.9l$	=	599.1

The determination for the number of dowels being influenced by the design edge load is governed by the location of the point load. The worst scenario is when only one dowel is in the zone of influence.

A1.3.2 Step 2 – Determine Edge Capacity X

Input:

Using previous slab moment capacities determined in section A1.1.3

$$M_{un} = 10.9 \text{ kNm/m}$$

$$M_{up} = 5.7 \text{ kNm/m}$$

Output:

For **edge load**:

$a/l = 0$:

$$P_{u,0} = [\pi (M_p + M_n) / 2] + 2M_n$$

$$= [\pi (5.7 + 10.9)/2] + 2 \times 10.9$$

$$= 47.9 \text{ kN}$$

$a/l \geq 0.2$:

$$P_{u,0.2} = [\pi (M_p + M_n) + 4M_n] / [1 - (2a / 3l)]$$

$$= [\pi (5.7 + 10.9) + 4 \times 10.9] / [1 - (2 \times 56.4 / 3 \times 665.7)]$$

$$= 101.5 \text{ kN}$$

Interpolation for $a/l = 0.085$:

$$P_{u,0.085} = 47.9 + (101.5 - 47.9) \times 0.085 / 0.2$$

$$P_{u,0.085} = X = 70.7 \text{ kN}$$

A1.3.3 Step 3 – Determine Dowel Capacity

The dowel capacity shall be taken as the minimum of shear and bearing/ bending obtained from Table 4-10 and Table 4-11. Input:

Concrete compressive strength	f_{ck}	=	32 MPa
Dowel diameter	d_d	=	16 mm

Output:

The shear capacity per dowel:	A_V	=	$0.9 \times (\pi r^2) = 181\ mm^2$ (for round dowels)
	P_{sh}	=	$0.6\ f_{yd}\ A_V$
		=	$0.6 \times 435 \times 181 \times 10^{-3}$
		=	47.2 kN

The bearing/ bending capacity per dowel:

e	=	5 mm
α	=	$[3e\ (f_{cd} / f_{yd})^{0.5}] / d_d$
	=	$[3 \times 5\ (21.3 / 435)^{0.5}] / 16$
	=	0.21
P_{bear}	=	$d_d^2\ (f_{cd} \times f_{yd})^{0.5}\ [(1 + \alpha^2)^{0.5} - \alpha]$
	=	$16^2\ (21.3 \times 435)^{0.5}\ [(1 + 0.21^2)^{0.5} - 0.21] \times 10^{-3}$
	=	20.1 kN

The bursting force capacity of the dowel:

k_s	=	$\min\ [1 + (200 / d)^{0.5}\ ;\ 2]$
	=	$\min\ [1 + (200 / 75)^{0.5}\ ;\ 2] \quad = 2$
u_1	=	length of the perimeter $= 8d_{dow} + 0.5\ h\ \pi$
	=	$8 \times 16 + 0.5\ h\ \pi \quad = 364$ mm
d_1	=	effective depth of the dowel, usually 0.5h
	=	$0.5 \times 150 \quad = 75$ mm
P_{burst}	=	$0.035\ k_s^{1.5}\ f_{ck}^{0.5}\ u_1\ d_1$
	=	$0.035 \times 2^{1.5} \times 32^{0.5} \times 364 \times 75 \times 10^{-3}$
	=	15.3 kN

The maximum capacity of one dowel is the minimum value of shear capacity, bearing/bending capacity or the bursting force capacity:

	$P_{max.dowel}$	=	$\min\ [P_{sh};\ P_{bear};\ P_{burst}]$
Dowel capacity	Y	=	$\min\ [P_{sh};\ P_{bear};\ P_{burst}]$
		=	15.3 kN
Number of the dowels which are working with their full capacity	n_d	=	$1.8 \times l / L_d \qquad L_d$ taken as 300 mm
		=	$1.8 \times 665.7 / 300$
		=	4.0

A1.3.4 Step 4 – Total Effective Edge Capacity

Total effective edge capacity	$P'_{u,0}$	=	1.176 X + Y	
		=	1.176 × 70.7 + 15.3	
		=	98.4 kN	$> P^*$ (pass)

The value 1.176 assumes a 15% load transfer by aggregate interlock, which can be taken into account only at saw-cut joints.

Total effective edge capacity	$P'_{u,0}$	=	$X + Y \times n_d$	
at expansion joints		=	70.7 + 15.3 × 4.0	
		=	132.9 kN	$> P^*$ (pass)

A1.4 Design Example 4 – Line Load Capacity

Input:

Ultimate design line load	P^*_{lin}	=	30 kN/m
Short term modulus of elasticity	E_{cm}	=	33500 MPa
	h	=	150 mm slab thickness
Moment capacity of plain concrete	M_{un}	=	10.9 kNm/m
Modulus of subgrade reaction	k	=	0.05 N/mm^3 (refer Table 4-6)

Output:

Characteristic length	λ	=	$[(3k) / (E_{cm} \times h^3)]^{0.25}$	
		=	$[(3 \times 0.05) / (33500 \times 150^3)]^{0.25} \times 10^3$	
		=	1.07 *1*/m	
For internal load:	P_{lin}	=	$4 \lambda M_{un}$	
		=	4 × 1.07 × 10.9	
		=	46.7 kN/m	$> P^*_{lin}$ (pass)
For edge load:	P_{lin}	=	$3 \lambda M_{un}$	
		=	3 × 1.07 × 10.9	
		=	35 kN/m	$> P^*_{lin}$ (pass)

A1.5 Design Example 5 – Uniformly Distributed Load / Area Load Capacity

Input:

Ultimate design line load	P^*_{UDL}	=	50 kN/m^2	
Short term modulus of elasticity	E_{cm}	=	33500 MPa	
Slab thickness	h	=	150 mm	
Moment capacity of plain concrete	M_{un}	=	10.9 kNm/m	
Modulus of subgrade reaction	k	=	0.05 N/mm^3	(refer Table 4-6)

Output:

Characteristic length	λ	=	$[(3k) / (E_{cm} \times h^3)]^{0.25}$
		=	$[(3 \times 0.05) / (33500 \times 150^3)]^{0.25} \times 10^3$
		=	1.07 l/m
Load capacity per unit area	q	=	$5.95\ \lambda^2\ M_{un}$
		=	$5.95 \times 1.072 \times 10.9$
		=	74.3 kN/m^2 $> P^*_{UDL}$ (pass)

Appendix B - Project Case Studies

Appendix B

International Project Sample

Over 4 million square metres of commercial and industrial flooring reinforced with BarChip macro synthetic fibre reinforcement.

Below is just a small sample of completed projects.

Hitachi distribution centre

Toyota manufacturing plant

Project Highlights	Total M2	Year
Carrefour Itapevi Distribution Centre	49,000	2009
Regina Festas	22,000	2010
Santher Braganca Paulista	15,000	2010
Hermes Rio de Janeiro	70,000	2010
Siemens	7,500	2010
Eucatex	35,000	2010
LG Electronics	12,000	2011
Aguas lindas Shopping Centre, Goiânia	8,000	2011
Sony Electronics	12,000	2012
Brooklyn Emprendimentos	12,000	2012
Libercon	25,000	2012
Hypermarcas Goiânia	28,000	2012
Pilot Pen	8,800	2012
John Deere	20,000	2013
Contagem Shopping Centre	120,000	2013
Iguatemi Rio Preto Shopping Centre	85,000	2013
Logixx Distribution Centre	25,000	2013
HABOM Aircraft Maintenance Facility	155,000	2013
IKEA	7,000	2014
Westfield Miranda Shopping Centre	12,000	2014
BMW Manufacturing Plant, Brazil	90,000	2014

BMW manufacturing plant

Carrefour itapevi distribution centre

Smooth fibre free surface finish

Bresco Distribution Centre
Itupeva, Brazil

BarChip Inc.
The Synthetic Fibre Experts

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Project Details

Bresco's Itupeva logistics condominium is a 75,000 m^2 multi-purpose warehouse and distribution centre approximately 75 km from Sao Paulo. Bresco has developed the facility to suit a wide range of business logistics needs.

Bresco's Itupeva includes;

- Land area: 75,000 m^2
- Built area: 38.808 m^2
- 80 docks
- 120 vehicle spaces
- 51 truck spaces
- Free standing right: 12 m
- Floor Resistance: 6 t / m^2

Design Details

The slab was designed in accordance with UK Concrete Society TR34 and residual strength performance. The concrete slab was 150 mm thick with 12.5 m by 13.5 m joint spacing and the following mix design;

- Modulus of Elasticity: E_c = 33,130 MPa
- Concrete Strength: f'_c = 35 MPa
- Modulus of Rupture: f_{tm} = 4.2 MPa
- Design Shrinkage Factor 0.04 %.

Concrete Reinforcement

Two reinforcement systems were considered for the Bresco facility, 4.68 kg/m^3 of BarChip MQ58 synthetic fibre and a 25 kg/m^3 jointless steel fibre system.

Along with the inherent durability benefits, the project owner chose to use BarChip synthetic fibre system as a result of the cost advantages.

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Ankara High Speed Train Station and Maintenance Complex

Owner: General Directorate of Turkish State Railways
General Contractor: CLK JV

Turkish Fast Track Rail

With 20 fast track rail projects planned or under construction it's safe to say Turkey is in the midst of a rail revolution! The busiest of these is these lines is the Ankara to Istanbul Fast Track Rail which will connect Turkey's two largest cities.

Technical Aspects

- 533 km long
- Max speed: 250 km/h.
- Double lines, electrified: (25 kV, 50 Hz AC)
- Current travel time: 4 hours. Target is 3 hours.
- Min radius: 3500 m
- Standard railway gauge: (1435 mm)
- Max gradient: 1,6%
- Max cant: 130 mm
- Project cost: 274.6 million

Ankara Fast Track Station

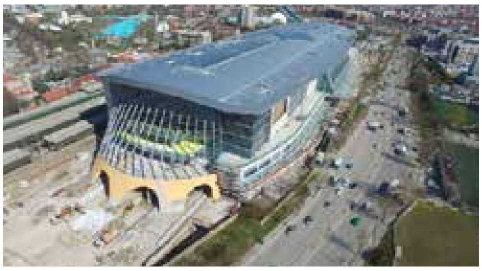
Included in the project is the construction of a new train station and maintenance complex at Ankara. The 29 ha facility consists of workshop buildings, an office building and the station itself.

Ankara's New Fast Track Train Station Project with its 200,000 m^2 closed area is a Build-Operate-Transfer model project and once the Project is completed, it will serve up to 50,000 passengers daily.

BarChip macro synthetic fibres are being used on the 10 cm thick topping concrete of the station's 50,000 m^2 indoor parking lot. With the usage of BarChip macro synthetic fibres, approximately 2,000 m^2 of concrete is being poured per day.

By using BarChip macro synthetic fibre as a replacement for steel mesh the project contract regularly achieved a 35% to 40% increase in construction speeds. On top of direct material cost savings, the site efficiency delivered substantial labour cost reductions and allowed for faster construction.

- Total Project Area: 200,000 m^2
- Total BarChip Used Area: 50,000 m^2
- Concrete Thickness: 10 cm
- Concrete Type: C25
- Loads: 750 kg/m^2
- Contractor: CLK JV.
- Concrete Reinforcement: BarChip 48



HABOM
Istanbul International Airport, Turkey

Based at Istanbul's Sabiha Gokcen International Airport (SAW) Airport, Turkish Technic is the leading aircraft maintenance, repair and overhaul (MRO) services company in the region. Turkish Technic has recently begun an ambitious construction of HABOM, a multi-story maintenance and repair facility. When completed it will be one of the largest in the region. BarChip48 synthetic fibre reinforcement was chosen as the primary crack control reinforcement for 155,000 m^2 of floor area. BarChip48 offered superior durability, simplified site processes and offered significant time and cost advantages, as outlined in the right hand column.

The estimated total investment requirement for the airframe and component maintenance centres is around US$ 500 million. By the year 2020, HABOM is estimated to generate a US$ 1 billion share from airframe and component maintenance segments. Turkish Technic will be the permanent shareholder of the HABOM Project. Besides that Turkish Technic is aiming to establish these new investments as an international joint venture with the participation of a leading global company or companies. With the making of this new investment, Istanbul will be the maintenance hub of the region within a short time period.

Prior to the switch to BarChip synthetic fibre, 12 man crews were completing approximately 800 m^2 per day using welded wire mesh reinforcement. After switching to BarChip synthetic fibres, 12 man crews were completing between 1200 m^2 and 1600 m^2 per day. As BarChip reinforcement is delivered mixed with the concrete the set up time for welded wire mesh was completely eliminated.

In all the contractor estimates that at the current speed they will realise a time saving of 35%, or two full months for the entire flooring project.

Quick Facts

- Total Concrete Area 372,000 m2
- Total Area BarChip Reinforced Concrete: 155,000 m^2
- Concrete Thickness: 10 cm
- Concrete Strength: C25 - 25/30 MPa
- Concrete Slump: 10 - 14 cm
- Load: 15 t/m^2 - 150 kN/m^2
- Client: YDA Construction
- BarChip Product: BarChip48

BarChip Inc.
The Synthetic Fibre Experts

www.barchip.com

Alekon Cargo Logistics Hub

Tallinn, Estonia

Alekon Cargo - is a state of the art provider of forwarding services, storage and warehousing services and handling of all types of cargo. Built in 2007 - 08 the Alekon Cargo Logistics Hub, located in Tallinn, Estonia, is a state of the art logistics centre incorporating road, rail and port services over a 12.5 hectare site.

The complex is equipped with warehouses, covered and open storage areas, three railway tracks and high-performance warehousing and cargo handling equipment. Warehousing and Storage Facilities on-site Include;

- 90,000 m^2 customs terminal area (75% monolithic concrete surfacing, 25% asphalt)
- 9,000 m^2 warehouse with 12 m high shelf stands and 15,000 standard pallet capacity
- 7,000 m^2 warehouse with 12,000 standard pallet capacity and 16t capacity overhead cranes
- 3,500 TEU container yard
- 22,000 m^2 parking yard for freight motor transport
- 3 railway branches with 1.3 km of total frontage.

The cargo handling machinery fleet on site included;

- 30 tonne capacity gantry crane
- 45 tonne capacity reach stacker for containers and equipment
- 9 lift trucks with up to 16 tonne capacity
- Fork lift trucks with lifting capacities of 1.5 to 4.5 tonnes
- Electric stacker
- Special electric lift truck with side grippers for handling tyres, paper drums, pulp etc.

BarChip structural synthetic fibre was used as the sole reinforcement in over 40,000 m^2 of the Logistic Hub's concrete flooring;

Concrete Class	C30	C37
Dose Rate	7 kg/m^3	5 kg/m^3
Slab Thickness	180 mm	150 mm
UDL acc.	6 T/m^2	4 T/m^2

By incorporating the use of BarChip synthetic fibre reinforcement, flooring contractors Savekate were able to realise a number of benefits;

- Eliminated the placement, storage and transport of steel mesh
- Increased durability and eliminated the risk of corrosion. BarChip synthetic fibre is inert and will never rust.
- Increased concrete toughness
- Increased on-site productivity
- Reduced overall costs
- Improved temperature and shrinkage crack control

Since construction in 2007 - 08 the concrete flooring has performed perfectly.

The selection of BarChip synthetic fibre as the primary concrete reinforcement eliminated significant man hours during construction and since construction in 2008 there have been no maintenance or serviceability issues with the BarChip reinforced concrete sections.

REINFORCED WITH BarChip

Appendix C - Cost Comparison

Cost Comparison of BarChip FRC vs. Conventionally Reinforced Concrete Industrial Floor

The comparison below has been obtained from an Australian pavement construction project. This particular project was originally designed to incorporate SL81 mesh in the top third of a 200mm thick concrete slab. This was replaced with a BarChip fibre reinforced concrete slab in order to complete construction within a shorter time frame and to save costs.

Slab Area	10,000	m^2			
Concrete Strength	32	MPa			
Traditional Mesh Reinforced Concrete			**BarChip Fibre Reinforced Concrete**		
Slab Thickness	200	mm	Slab Thickness	200	mm
Volume	2,000	m^3	Volume	2,000	m^3
\$ / m^3 Concrete	220		\$ / m^3 Concrete	270	
Concrete Cost	440,000	\$	Concrete Cost	540,000	\$
\$ / m^2 for Concrete	44	\$ / m^2	\$ / m^2 for Concrete	54	\$ / m^2
Mesh / Chairs / Labour / Waste	29.5	\$ / m^2	Mesh / Chairs / Labour / Waste	0	\$ / m^2
Concrete Placement Labour	35	\$ / m^2	Concrete Placement Labour	28	\$ / m^2
Pump	7	\$ / m^2	Pump	7	\$ / m^2
Concrete & Mesh Cost per m^2	**115.5**	**\$ / m^2**	**BarChip Fibre Reinforced Concrete Cost per m^2**	89	\$ / m^2

Saving per m^2	**\$ 26.5**
Total Saving on Project	**\$ 265,000**
Percentage Saving	**23 %**

BarChip Inc.
The Synthetic Fibre Experts

BarChip
Synthetic Reinforcing Fibre

BarChip Inc.

OUR VISION

BarChip has a simple vision - revolutionise the world of concrete reinforcement. For over 100 years the technology of concrete reinforcement has barely changed. We set out to create a new reinforcement for the 21st century. We created BarChip synthetic fibre reinforcement.

OUR PROCESS

We believe that long term business relationships can only be sustained by a commitment to provide the highest quality products and services. We make sure to understand your concrete, know the performance requirements and work with you to get the right design and the right performance outcomes.

YOUR PRODUCT

When you work with BarChip you know that your concrete asset has been reinforced to the latest engineering standards. It will never suffer from corrosion. It will be cheaper and quicker to build. It will be safer and it will keep performing throughout its entire design life.

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