Dramix®

Convert your residential projects into sustainable designs

Design guideline for residential applications using steel fiber reinforced concrete

Bekaert

Contents

Stronger, safer, more sustainable residential applications

Converting a project into a success depends on **having the right materials** and understanding them.

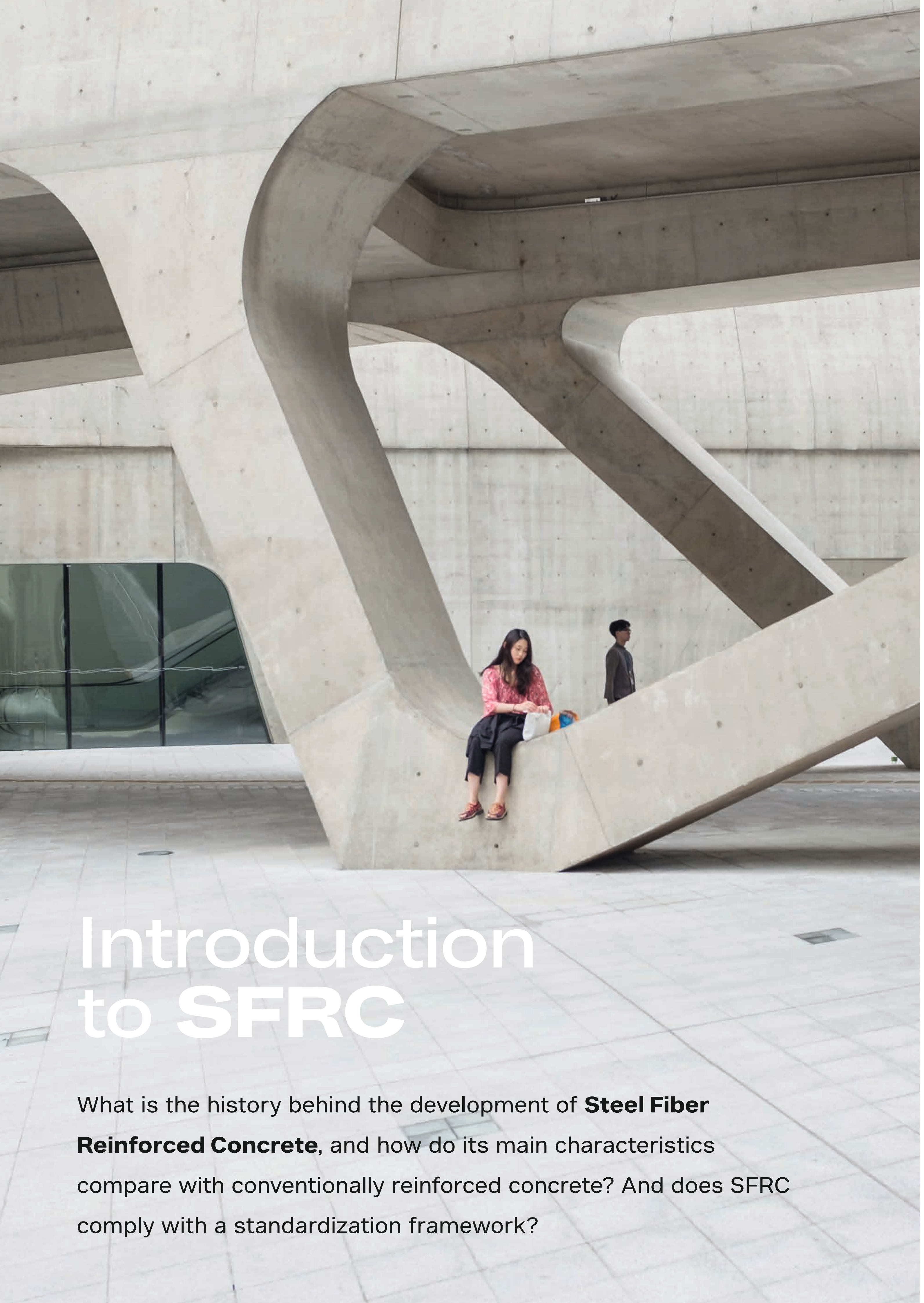
In recent decades, Steel Fiber Reinforced Concrete (SFRC) has evolved from an “exotic” building material to a well-accepted alternative or even an improvement to both reinforced and unreinforced concrete. It allows architects and structural engineers worldwide to bring their creative ideas to fruition in all kinds of applications. These include floors, prefabricated elements, residential and public buildings, tunnels and mining.

Despite the high number of residential applications using SFRC, and the extensive theoretical knowledge and practical experience gained, you may still have questions about how best to design a residential structure using steel fibers. You may be unsure as to the best reinforcing method to use, or have questions concerning the strength, safety and reliability of SFRC.

This design guideline addresses all these and other issues. It summarizes the main principles of SFRC, describes the properties of Dramix® steel fibers, and focuses on the design fundamentals of SFRC for residential applications. The calculation methods described here are fully in line with current standards and are certified by SECO.

Thanks to this in-depth information, you will have all the data necessary to design residential applications that are strong, safe, and sustainable.

Are you ready to convert your residential projects into sustainable designs?



Introduction to **SFRC**

What is the history behind the development of **Steel Fiber Reinforced Concrete**, and how do its main characteristics compare with conventionally reinforced concrete? And does SFRC comply with a standardization framework?

A brief history of fiber reinforcement

Adding fibers or fibrous materials to a building material to improve its brittle and grainy structure is not new. In ancient China, rice fibers were used to increase the resistance of sun-dried clay blocks to weathering. From the early Middle Ages, straw and animal hair were used as reinforcement for clay, loam or plaster. For technological reasons (better workability, limitation of cracking by drying), but sometimes also as a structural reinforcement, fibrous materials were used in cement-bonded applications such as for roof elements, wall panels, ceiling panels, drainpipes, formworks, etc.

Nowadays, Fiber Reinforced Concrete (FRC) consists of an appropriate concrete composition, a suitable fiber type, and a corresponding number of fibers to meet the required performance for the intended application. Today, a variety of fiber types is available, with different constituting materials, geometry, mechanical properties, or anchoring with the concrete matrix. The most used fiber materials are:

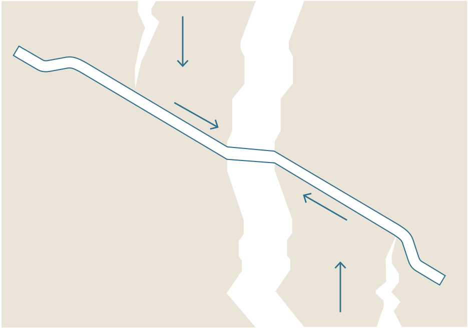
- Metallic fibers (steel, galvanized steel, stainless steel), referred to in this document as steel fibers to which belongs the Dramix® portfolio;
- Synthetic fibers (polypropylene, carbon, nylon, Kevlar, aramid, polyester, etc.), to which belongs the Synmix® and Duomix® portfolio.

Synthetic fibers are classified into micro-synthetic fibers and macro-synthetic fibers. While the former is mainly suitable for shrinkage control in the plastic phase of the concrete and for fire resistance, the latter is used in a wider range of applications. However, to really play a structural role in a rigid concrete matrix, similar to that of traditional reinforcing steel, fibers must combine a high modulus of elasticity with a high tensile strength. They also must not be significantly affected by long-term effects derived from thermo-hygrometrical phenomena. As synthetic fibers fail in these key areas, this guideline focuses only on steel fibers – the only suitable fiber type for structural residential applications – and on Steel Fiber Reinforced Concrete (SFRC). At Bekaert we developed our innovative Dramix® steel wire technology in the early 1970s and began to use it to reinforce concrete in the 1980s.

The main advantage of SFRC

The major characteristic of SFRC is its ability to transfer stresses over a cracked section. This is unlike unreinforced concrete, which loses its entire load-bearing capacity once it is cracked. Just like traditional reinforcing steel, steel fibers act as reinforcement.

Steel fibers bridge the cracks and transfer tensile stress across them. This changes the mode of fracture from brittle for unreinforced concrete, to ductile for SFRC, and contributes to crack control. The improved ductility has the potential to increase the load-carrying capacity, impact resistance, fatigue strength and consequently reduce or eliminate the use of traditional reinforcement.



How does SFRC compare with conventional reinforced concrete?

There is no doubt that conventional reinforced concrete offers advantages. It is a relatively cheap material that mainly uses natural raw materials. It provides a high compressive strength and can be processed in an infinite number of shapes. Overall, reinforced concrete is economical, durable, dimensionally stable, wear-resistant and fire-resistant.

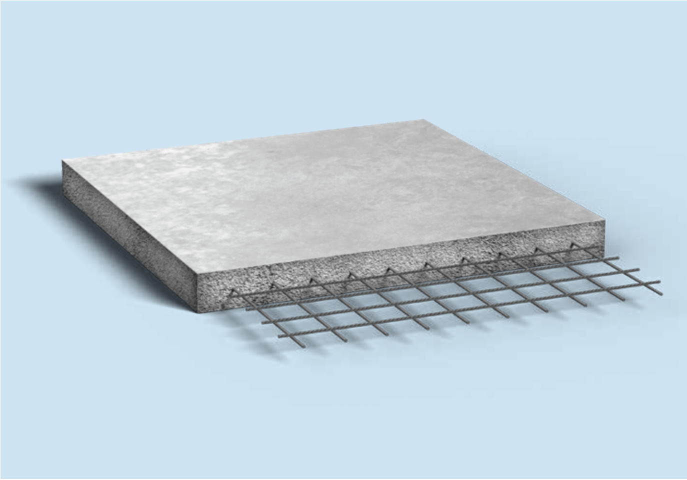
However, conventional reinforced concrete also has some disadvantages. These are mostly related to the installation of the steel rebar or mesh reinforcement, which is extremely labor-intensive. In areas of high stress concentrations, the highly congested reinforcing layout may lead to difficulties in making a proper concrete casting. Moreover, the reinforcement only works where present in the concrete; thus a strict distinction must be made between the longitudinal reinforcement and that for resisting shear or punching stresses. This requires meticulous detailing and execution. If inaccurately placed, the reinforcement may contribute insufficiently, causing the element to be under-dimensioned.

When steel fibers are added, they become part of the concrete matrix, turning it into a composite material. Instead of providing strength only in distinct locations, steel fibers form a three-dimensional reinforcing network throughout the entire concrete structure.

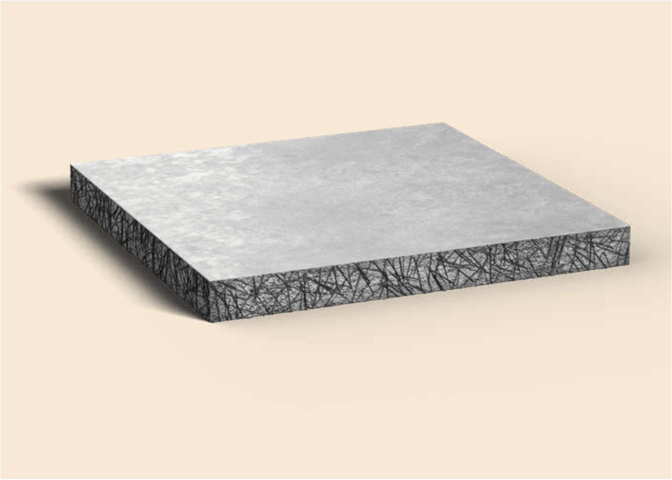
A steel fiber reinforcement system is also less labor-intensive. This can lead to substantial reductions in time and labor, as well as safer execution.

Moreover, SFRC has the potential to reduce crack widths and the number of cracks. Spalling of exposed surfaces can also be expected to improve with the use of fibers, which can enhance the quality of the structure and limit its deterioration. As a result, the use of SFRC can lead to an extended lifetime and a reduction of long-term maintenance costs.

Conventional reinforcement



Steel fiber reinforcement



> “
>
> Often, the use of SFRC allows a **reduction in the thickness of concrete and/or the total amount of steel** compared to conventional reinforced concrete, leading to structures that are **more sustainable and have a low carbon footprint**. Sustainability plays a crucial role in the development of the construction market worldwide.

Standardization framework of SFRC

The first calculation methods with SFRC were intended for the design of classic floors on an elastic sub-base. These were already, at that time, based on a yield line theory at Ultimate Limit State (ULS). According to these methods, the improved ductility of SFRC is taken into account by an upgrading factor affecting the flexural tensile strength of the unreinforced concrete. This approach has been applied to industrial flooring, tunneling, and mining for several decades.

In the early 2000s, Bekaert introduced the use of SFRC in residential applications. The structural use of this material and the lack of prior experience within this application required a high level of safety. Almost simultaneously, the scientific world, through RILEM, established the technical committee TC-TDF 162 "Test and Design Methods for Steel Fiber Reinforced Concrete". The aim was to reach a better understanding of the material behavior of SFRC. RILEM is an international association of testing and research laboratories for construction materials and structures founded in 1947.

This committee established the stress-strain design philosophy, which still forms the basis of the current international guidelines and standards. Among these, the fib Model Code 2010 [1] and the DAfStb guideline [2] are two of the most used documents nowadays. The upcoming second generation of Eurocode 2 [3], which for the first time will cover the design of SFRC structures (in Annex L), will also be based on this concept.

Designing with Dramix® steel fibers: certified with the SECO assurance of safety

SECO was the first independent technical expert to be established for the construction industry. It was set up in 1934 to improve global quality and safety standards, and minimize risks for the construction industry. SECO has worked closely with Bekaert to technically analyze the use of Dramix® steel fibers for multiple applications, taking into account:

- The viability of applications with SFRC;
- The preconditions for use;
- The calculation methods used;
- The material properties to be specified in designs;
- The overall level of safety;
- The measures for quality control.

To date, Bekaert and Seco have developed several application certificates as a result of this work. These certificates give you full confidence in the design and specification of Dramix® steel fiber reinforcement, and provide you with an exceptional assurance of safety.

The basics of Dramix® technology

How do **steel fibers** look like and how can they **reinforce concrete?** What is unique about the **Dramix® 5D family**?

Our Dramix® products

3D

- Single hook
- Tensile strength up to 1100 MPa
- 0.8% wire ductility

4D

- One and a half hook
- Tensile strength above 1450 MPa
- 0.8% wire ductility

5D

- Double hook
- Tensile strength up to 2300 MPa
- 6% wire ductility

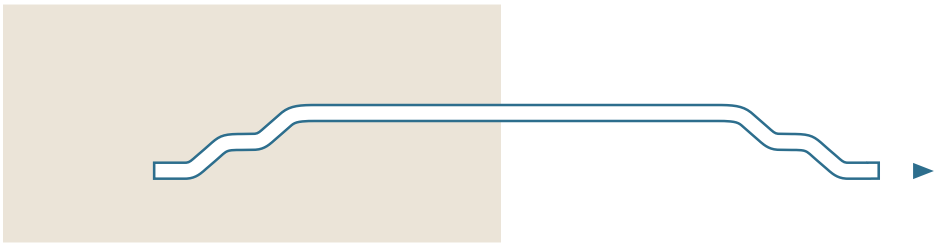
The 5D family is particularly well suited to residential applications such as foundation slabs, strip foundations and cellar walls, which are covered in depth in this guideline.

> **Dramix® 5D series is the best choice.**
>
> Given its higher level of performance, the Dramix® 5D series is the best possible solution to reinforce structural elements by eliminating most of the conventional reinforcement or even completely.
>
> Higher performing fibers allow lower dosages for an even **better structural response.** The conversion from double-layer reinforcement to fibers is mostly possible **without a thickness increase**.
>
> In practice, these two aspects allow for either a reduction of the element thickness or the amount of steel, leading to structures that are more sustainable and have a low carbon footprint.

Anchorage

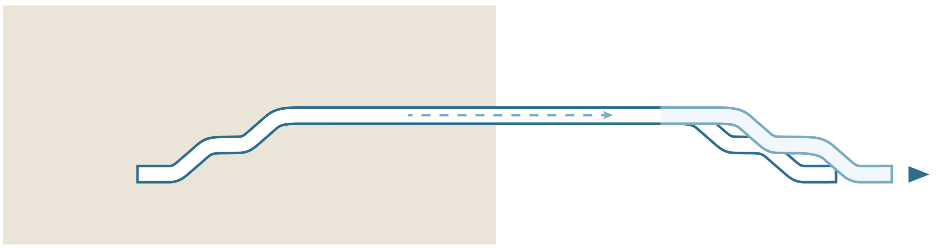
The type of anchorage can significantly affect the performance of a fiber. End hooks have proven to provide excellent performance both in the initial and final stages of fiber pull-out:

- The hooked ends of Dramix® 3D ensure the desired fiber pull-out. This is the mechanism that generates the renowned concrete ductility and post-cracking strength;
- The improved anchorage of Dramix® 4D utilizes the same principle but the better anchorage and higher steel strength lead to higher performance;
- Dramix® 5D, in contrast, is shaped to form the “perfect anchor”; the pull-out mechanism is replaced by fiber elongation.



Non-deformable hook

The improved hook of the 5D fibers is non-deformable, providing perfect anchorage, and keeping the fibers firmly in place inside the concrete.



Ductile wire

The ductile wire of the 5D series elongates while the hook remains firmly in place, enhancing both the strength and the ductility of the concrete like the reinforcing mechanism of traditional rebar and mesh.

Wire tensile strength

Dramix® is manufactured from cold drawn steel wire and guarantees high tensile strength of the steel wire with a minimum of 1100 N/mm².

The tensile strength of a steel fiber must increase in parallel with the strength of its anchorage. Only in this way the fiber can resist the forces acting upon it. Otherwise, it could snap, causing the concrete to become brittle. On the other hand, a stronger wire cannot be fully utilized with an ordinary anchor design. Therefore, the tensile strength of a fiber must be perfectly aligned with its anchorage design.

Dramix® 3D, 4D and 5D are each designed to benefit from the wire strength to the maximum degree (Figure 1).

Wire ductility

Wire ductility and concrete ductility are two different aspects. Dramix® 3D and 4D provide concrete ductility and toughness by the slow deformation of the hook, providing sustained resistance during the pull-out process.

This is different with Dramix® 5D. By the **"perfect anchor" design, the fiber cannot be pulled out. Instead, the wire elongates, leading to concrete ductility on the same principle as traditional reinforcing steel when yielding**. This is only possible with the combination of large wire tensile strength, elongation capacity, and improved anchorage.

Tensile curves 3D-4D-5D wire qualities

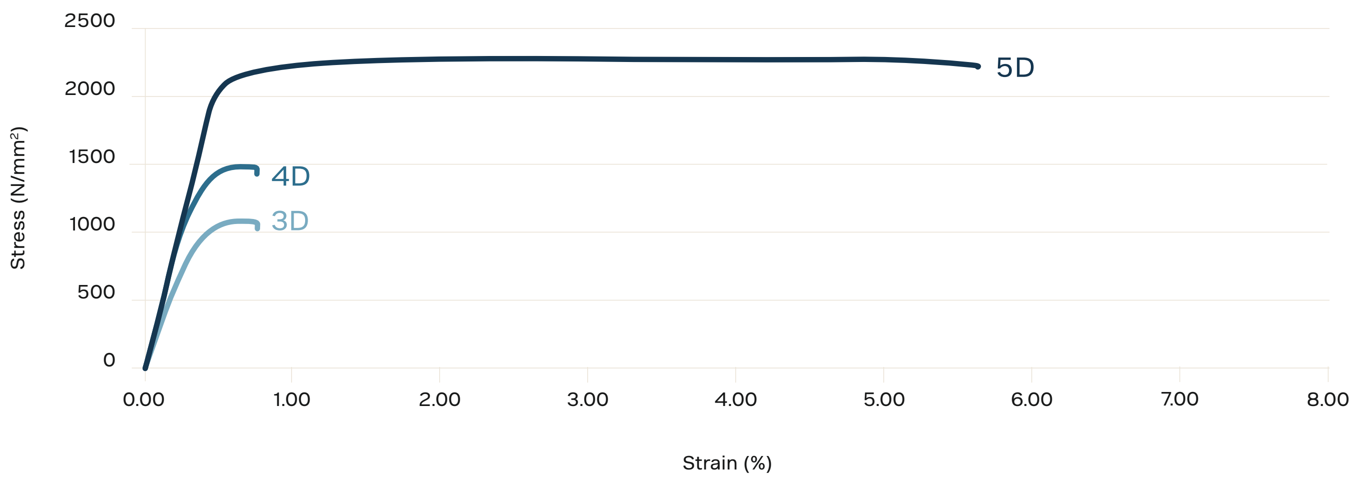


Figure 1. The Dramix® 3D, 4D and 5D series offer different tensile strength levels for different applications (only the minimum strength of each fiber family is visualized).

Geometrical properties

Length

The length of the steel fibers commonly used varies between 35 and 60 mm. Typically, the longer the fiber length, the better the performance is at bigger deformations (Figure 2). There are two additional aspects to consider which are related to the fiber length:

- Fibers must be able to bridge the crack between aggregates. This means that the maximum aggregate size is decisive for the fiber length;
- When applicable, the steel fiber concrete must be pumpable.

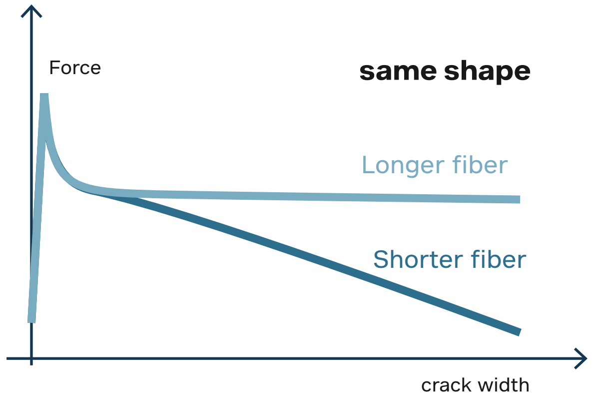


Figure 2. Effect of fiber length on the flexural performance.

Diameter

The diameter of the steel fibers commonly used varies between 0.40 and 1.05 mm. The diameter affects the following factors:

- The smaller the diameter, the more fibers per unit weight;
- The smaller the spacing between the different fibers, the greater the network effect;
- The smaller the diameter, the larger total contact area between fibers and concrete matrix per unit weight.

Aspect ratio l/d

The ratio of fiber length to diameter gives a good estimate of fiber performance (Figure 3). The higher this value, the more fibers per kg of steel, the denser the fiber network, and the better the redistribution of stresses in all possible directions, resulting in material ductility.

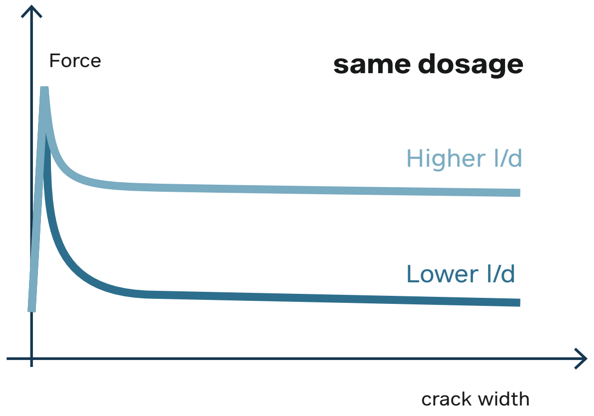


Figure 3. Effect of l/d-ratio on the flexural performance.

CE marking

Steel fibers for use in structural applications must comply with the conditions of CE marking based on the Attestation of Conformity under system 1. According to EN 14889-1 [4], a minimum level of performance must be guaranteed. In that respect, the manufacturer declares the unit volume of fibers in kg/m³ that achieves a residual flexural strength* of 1.5 MPa at 0.5 mm CMOD (Crack Mouth Opening Displacement) and a residual flexural strength of 1 MPa at 3.5 mm CMOD. In Belgium, an additional requirement applies regarding the use of steel fibers in concrete with the BENOR quality certificate.
To maintain the BENOR label of the concrete, steel fibers must have an ATG certificate.

---

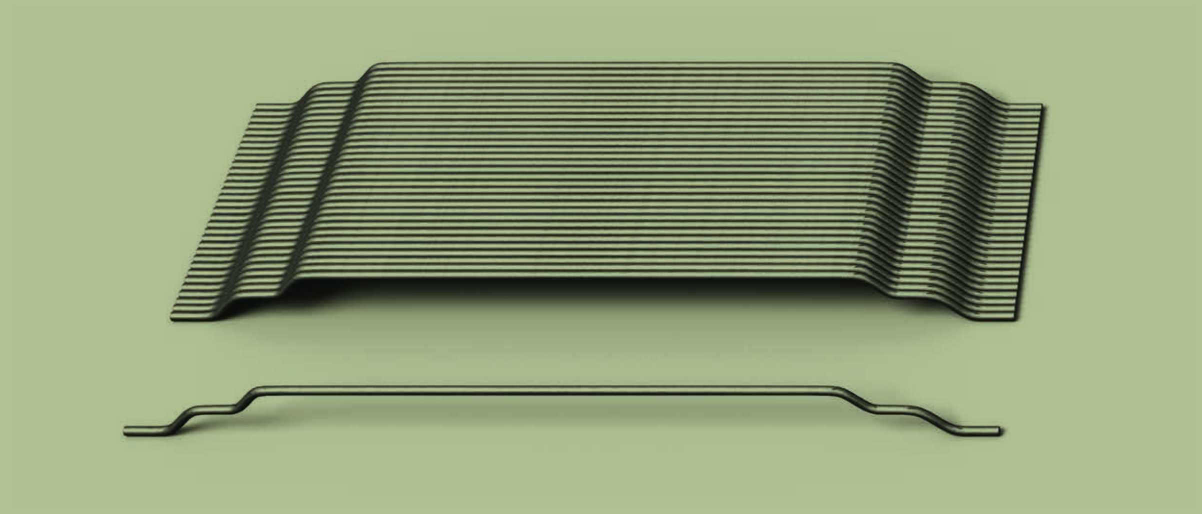
*See definition in next chapter.

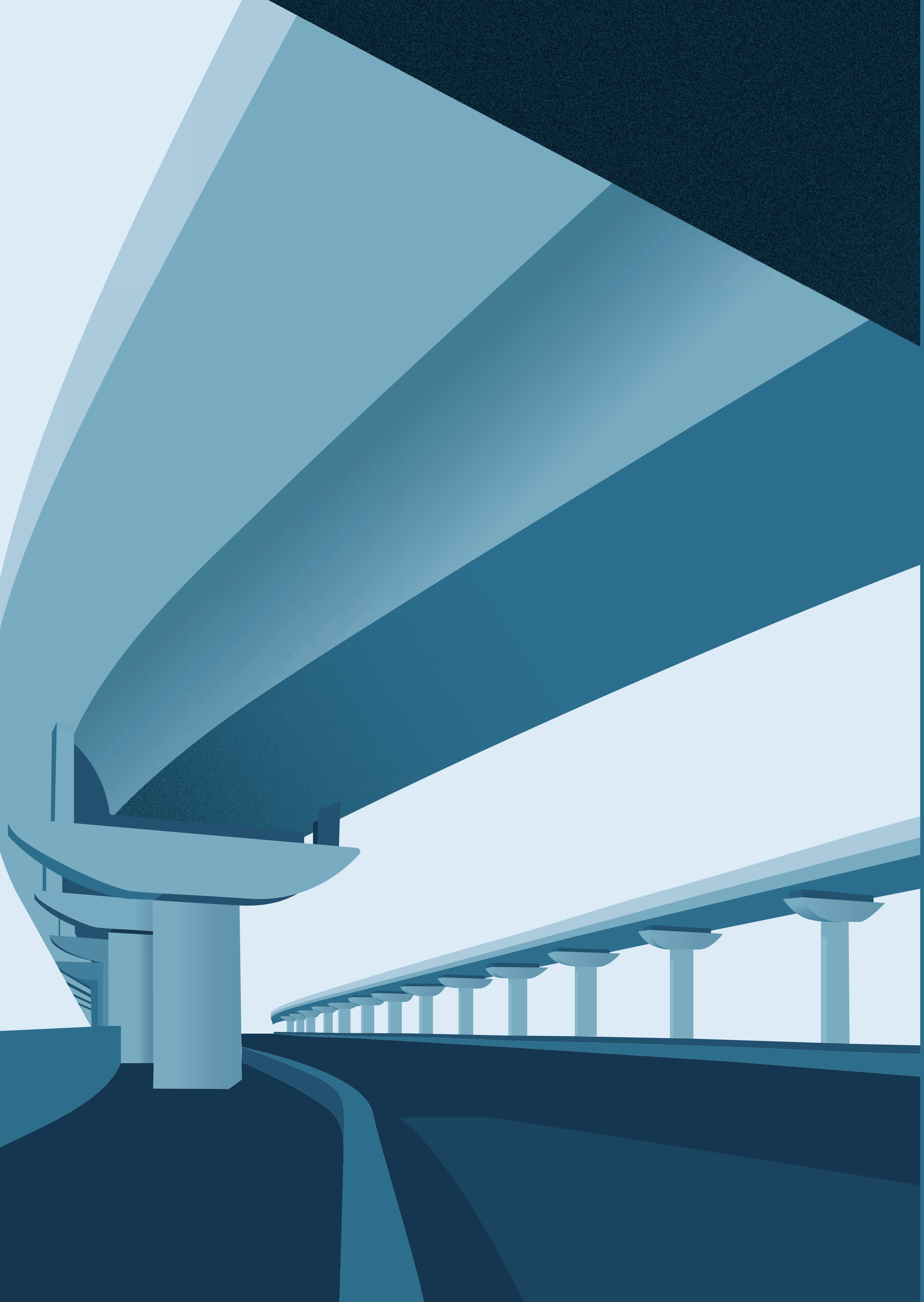
Why glued fibers?

“Loose” is a common form of delivery for fibers with a relatively low aspect ratio, e.g. l/d ≤ 50. Balling or other difficulties related to workability are mostly avoided. However, due to the low aspect ratio, the performance level of these fibers may be considered basic.

To avoid the potential for balling related to adding loose fibers with a high (and thus better performing) aspect ratio, Bekaert developed the glued fiber technology. After adding glued Dramix® steel fibers to concrete, the bundles spread evenly at the “macro”-level. Continued mixing let the individual fibers separate quickly so that they can be homogeneously distributed also at the “micro”-level.

> Glued steel fibers **facilitate the dosing and mixing process and ensures a homogeneous distribution**.
>
> Glued steel fibers can be **added right out of the bag, directly into a mixing truck or central mixer**, **or indirectly via a conveyer belt**. Automatic dosing equipment is also available for this purpose.





The design fundamentals of SFRC

How **strong** is **Steel Fiber Reinforced Concrete**? Which test methods exist? How do we use these test results in a design?

Material characterization

Characterization of the mechanical properties of SFRC is of major importance for the effective and economical structural design of elements using this material. Strength and toughness are the parameters best suited for establishing design criteria. Most recent guidelines use measurements of post-cracking residual strength to characterize material performance.

From a design-oriented perspective, the most widely used test methods for assessing post-cracking tensile behavior of SFRC are bending tests on beam specimens. Among them, the most used test method is the three-point bending test according to EN 14651 [5].

Test specimens consist of notched prisms with dimensions 150 mm × 150 mm × 550-700 mm, where the notch allows to record the development of the crack (Figure 4). The testing machine continuously records the load applied at mid-span and the corresponding CMOD (Crack Mouth Opening Displacement) at fixed rates. The test can also be operated based on the deflection at mid-span as an alternative to the CMOD.

The residual flexural tensile strengths $f_{R,1}$, $f_{R,2}$, $f_{R,3}$ and $f_{R,4}$ represent the flexural tensile stresses at $CMOD_1$=0.5 mm, $CMOD_2$=1.5 mm, $CMOD_3$=2.5 mm and $CMOD_4$=3.5 mm, respectively (Figure 5). For j = 1, 2, 3 and 4, we can calculate:

$$f_{R,j} = \frac{3F_j l}{2bh_{sp}^2}$$

where

F_j	is the load corresponding to CMOD = $CMOD_j$ (j=1, 2, 3, 4), or to the equivalent deflection level
l	is the span length
b	is the width of the specimen
h_{sp}	is the distance between the tip of the notch and the top of the specimen.

Note that $f_{R,1}$ and $f_{R,3}$ are the basic values to be used in cross-sectional calculations.

For a set of six standard beams, the coefficient of variation typically ranges between 20% and 30%. This parameter describes the ratio between the standard deviation and the mean value of a set of tests, and it is highly influenced by the size of the area in tension of the specimens.

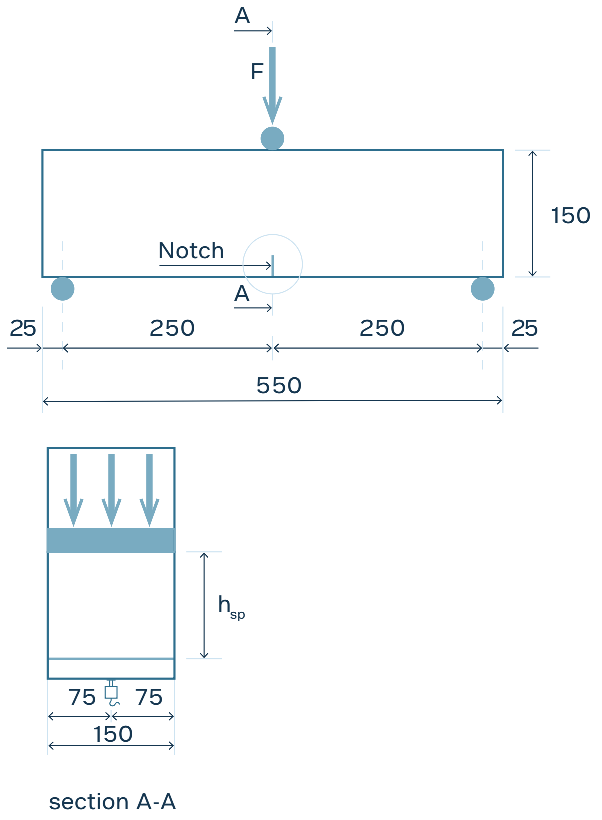


Figure 4: Setup of the three-point bending test according to EN 14651 [5], dimensions in mm.

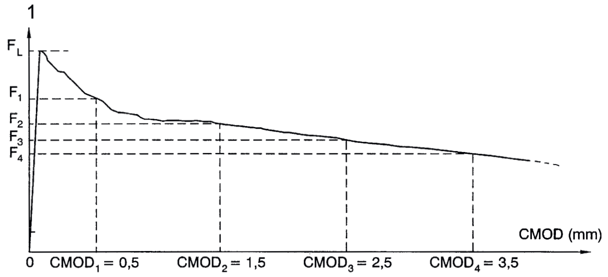


Figure 5. Typical Load-CMOD result of an EN14651 beam test.

Determination of characteristic values

The characteristic flexural strengths ($f_{R1,k}$ and $f_{R3,k}$) are typically determined from the average values ($f_{R1,m}$ and $f_{R3,m}$), based on a normal or log-normal distribution. In any case, the characteristic values are limited to 0,6 times their average values.

Testing beams according to EN14651 is the most commonly used method to quantify and compare the performance of SFRC. The effect of the fiber family on the performance is demonstrated in the graph aside. Three type of fibers (Dramix® 3D, 4D and 5D), all with the same l/d-ratio (65) and length (60 mm), were tested using the same dosage (35 kg/m³) in the same concrete class (C35/45). In this concrete, the 4D-fiber performs clearly better than the 3D-fiber, while the 5D-fiber outperforms both others. The load-deflection response of the 5D-fiber is also special, because the curve shows a bending hardening behavior, which is not possible to obtain with 3D or 4D fibers in normal circumstances. This behavior allows engineers to use this 5D-fiber concrete even in specific isostatic stress situations under pure bending.

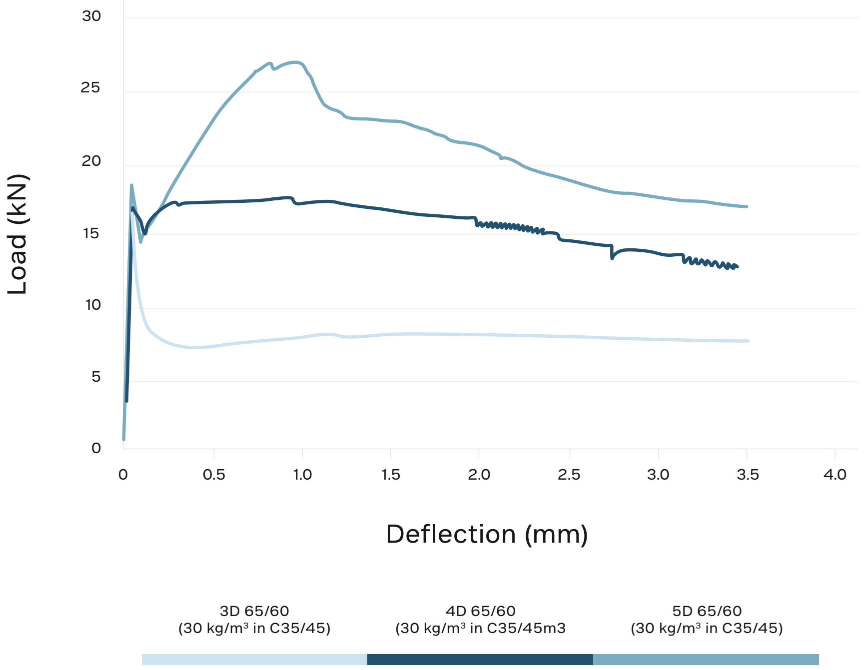


Figure 6. Effect of the Damix® series on the load-deflection response of an EN14651 beam test.

Constitutive law for structural analysis

The most common approach for design of SFRC is the use of a constitutive model based on a stress-strain relationship (Figure 7). The behavior under compression is typically assumed based on the models described in Eurocode 2 for reinforced concrete [6]. In tension, a multi-linear model is often assumed, where the main parameters are derived from the beam test as described in the previous section. For that, residual flexural strengths are converted to residual tensile strengths by means of conversion factors (see next section).

The multi-linear model described by the equations below is based on an initial linear branch with a slope equal to the modulus of elasticity of uncracked concrete. Following that, the post-cracking behavior is described using two linear branches, up to an ultimate strain of 25 ‰.

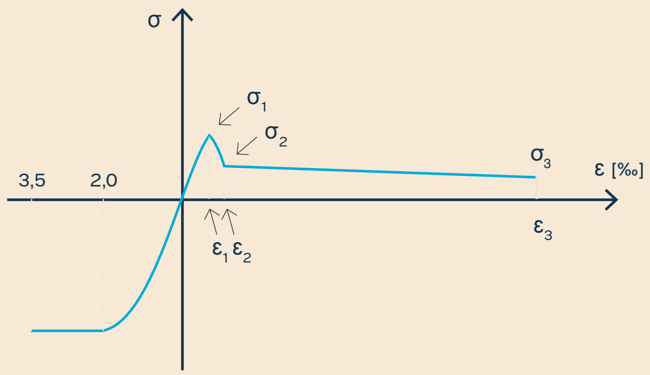


Figure 7. Stress-strain (σ-ε) relationship used for design of SFRC.

The parameters used to define the tensile part of the stress-strain relationship for the analysis of structures in the ultimate limite state (ULS) are the following:

$\sigma_{1d} = f_{ctm} \cdot max\{1.6 - d; 1.0\}$ when f_{ctm} is used, or

$= 0.5 \cdot \sigma_{2d}$ when f_{ctm} is not used

$$\sigma_{2d} = \kappa_G \cdot \eta_{hyp} \cdot \alpha_{R1} \cdot f_{R1,k}/\gamma_{SF}$$

$$\sigma_{3d} = \kappa_G \cdot \eta_{hyp} \cdot \alpha_{R3} \cdot f_{R3,k}/\gamma_{SF}$$

where

f_{ctm}	is the mean axial tensile strength of the concrete
d	is the effective depth of a cross-section, in m
κ_G	is the size factor (see p. 30-31)
η_{hyp}	is the hyperstaticity factor, depending on the application (see 30 & 32)
α_{R1}, α_{R3}	are the conversion factors applied to $f_{R1,k}$ and $f_{R3,k}$ respectively (see this page)
$f_{R1,k}, f_{R3,k}$	are the characteristic values of the residual strengths, as defined according to EN14651 for the corresponding $CMOD_1$ and $CMOD_3$ (see this page)
γ_{SF}	is the partial factor for SFRC in tension (see this page)

Note that for other applications than those covered by this quideline might require the use of an orientation factor.

Conversion factors

Conversion factors transform residual flexural strengths to residual tensile strengths. They are calculated by equating two bending moments. One is the bending moment from a linear elastic stress distribution, the other is the bending moment from the assumed stress-strain relationship.

In the literature, conversion factors vary to a certain extent. The following values are applied in this guideline:

Table 1. Conversion factors, in function of the ratio $f_{R3,m}/f_{R1,m}$.

Ratio	**Conversion factor**	
$f_{R3,m}/f_{R1,m}$	α_{R1} ($f_{R1,m} \rightarrow \sigma_2$)	α_{R3} ($f_{R3,m} \rightarrow \sigma_3$)
< 0.5*	*	*
0.5	0.40	0.05
0.7	0.40	0.25
1.0	0.40	0.35
1.5	0.40	0.44
> 1.5	0.40	0.44

* Ratios $f_{R3,m}$ / $f_{R1,m}$ < 0.5 are not expected in the scope of this guideline

Material safety factors

To work according to the semi-probabilistic approach of the Eurocodes, all SFRC design values are additionally reduced by the partial safety factors for materials. For residential applications covered by this guideline, the following values are used for Ultimate Limit State (ULS) design:

- SFRC in compression: γ_c for plain concrete applies;
- SFRC in tension: $\gamma_{SF} = 1.50$.

> We have always **participated** in shaping the national, European and intercontinental **standards and guidelines**.

Structural residential applications using Dramix®

How to define the design parameters for a **foundation slab**, **cellar wall** and **strip foundation**? Can I eliminate all conventional reinforcement when using **Dramix® 5D steel fibers**?

Design method

EN 14889-1 [4] clearly states: "Structural use of fibers occurs when the addition of fibers is intended to contribute to the load-bearing capacity of a concrete element". For residential applications, the use of steel fibers has proven to offer a practical and economical advantage compared to conventionally reinforced solutions.

The design method for SFRC according to this guideline is based on the safety concept according to the semi-probabilistic approach of EN 1990 "Basis for structural design" [7]. Material properties of SFRC are, in turn, approached in the same way as for ordinary concrete in Eurocode 2 [6].

It is therefore important to verify that no limit state is exceeded for the relevant design situation and load cases, when design values for actions and resistances are used in design models.

Design values of resistances should be obtained by using the characteristic values as derived from average values, in combination with partial safety factors. In a similar way, design values of actions are derived from their characteristic values and subjected to the necessary partial factors.

As a basic principle of design, the design value of the effect of actions should not exceed the design value of the corresponding resistance.

In this section, the parameters for the constitutive law which depend on the application are further elaborated.

Hyperstaticity factor

A main property of SFRC is the ability to redistribute stresses in the structure. This means that instead of having a few large cracks, the structure shows a larger number of cracks with smaller crack widths. This behavior can be used in multiple hyperstatic members. General foundation slabs on ground, regarded as spring-supported, are the application par excellence in this regard.

The hyperstaticity factor (η_{hyp}) larger than 1.0 can be applied if a crack distribution effect can be expected. When applicable, SECO and Bekaert conservatively defined that η_{hyp} is equal to 1.24. This effect depends on the design of the foundation slab, and also on the location of the cross-section under consideration. Due to this, we must distinguish between the edge zone and the center of the slab.

The width of the peripheral zone (Figure 8) is in the range of 1 to 2 times the elastic stiffness radius used for designing floors on ground. This radius is a function of the concrete quality, the thickness of the slab, the k-value of the subgrade, among others. In most cases, its value is in the range of 0.75 to 1.5 m. However, its exact value is to be determined by the design office.

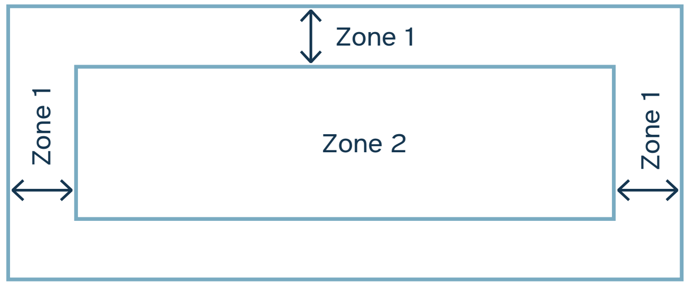


Figure 8. Plan view of a foundation slab, where the width of the peripheral zone (zone 1) has to be calculated.

Table 2. Hyperstaticity factor to be adopted at the peripheral and central zone, depending on the solution for the frost protection edge.

	Zone 1: Peripheral zone	Zone 2: Central zone
A slab with a frost protection edge separated from the slab or no frost protection edge	$\eta_{hyp} = 1.0$	$\eta_{hyp} = 1.24$
A slab with a frost protection edge cast along with the slab	$\eta_{hyp} = 1.24$	$\eta_{hyp} = 1.24$
A slab with a frost protection edge connected to the slab by means of reinforcement	$\eta_{hyp} = 1.24$	$\eta_{hyp} = 1.24$

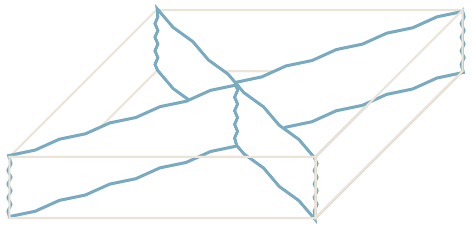
Size factor

The size factor κ_G is used to consider the effect of the member size on the coefficient of variation. This coefficient, which is essential for the calculation of the characteristic values, decreases as the area of tension zone increases with respect to that of the specimens from the characterization test EN14651. The concept of the size factor and its formulation is based on the DafStb guideline [2] and has been applied for years.

The following formula is used within the framework of this guideline:

$\kappa_G = 1.0 + A_{ct} \cdot 0.5 \leq 1.5$, with A_{ct} the area in tension in m².

Note that the combination of the size factor and the characteristic factor, which is the ratio of $f_{Ri,k}/f_{Ri,m}$, will never be higher than 0.9.

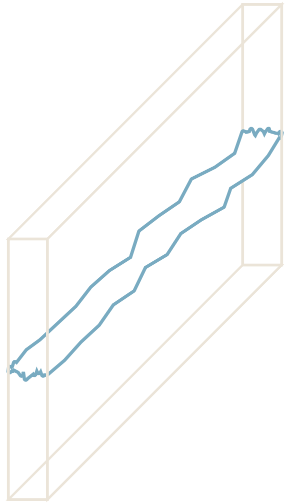


Foundation slabs

The cracked section of a general foundation slab is significantly large and the size factor can therefore be assumed in all cases to reach its maximum (1.5).

Example

Any foundation slab:
$\kappa_G = \min\{1.0 + A_{ct} \cdot 0.5; 1.5\} = 1.5$

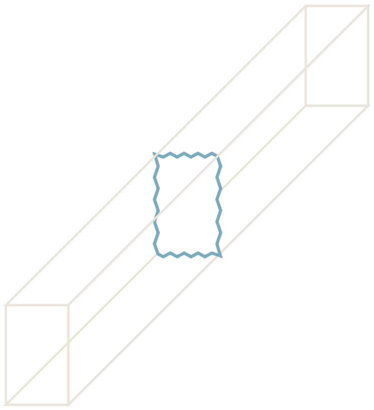


Cellar walls

Cellar walls are plate-like structural elements with a cracked section as illustrated.

Example

Cellar wall with a thickness (T) of 25 cm and a length (L) of 6 m:
$A_{ct} = 0.9 \cdot T \cdot L = 1.35\ \text{m}^2$
$\kappa_G = \min\{1.0 + A_{ct} \cdot 0.5; 1.5\} = 1.5$



Strip foundations

Strip foundations are beam-like structural elements with a cracked cross-section as illustrated. These cross-sections are still limited in size, as a consequence the size factor is also rather small. Frost beams can be treated similarly as strip foundations with regard to the size factor.

Example

Strip foundation with a width (W) of 500 mm and a height (H) of 600 mm:
$A_{ct} = 0.9 \cdot H \cdot W = 0.27\ \text{m}^2$
$\kappa_G = \min\{1.0 + A_{ct} \cdot 0.5; 1.5\} = 1.135$

Cross-sectional calculation

The design of structural elements reinforced with steel fibers is done in the Ultimate Limit State. For that, we evaluate the resistance of an element when reaching the state of structural failure, according to the assumed σ-ε relationship.

The resisting moment, M_{Rd}, is obtained from a cross-sectional analysis. Its value depends on the thickness of the element, the concrete strength class, the performance of the fibers and the structural application. For the residential applications described in this guideline, we apply the size factors and hyperstaticity factors as previously described.

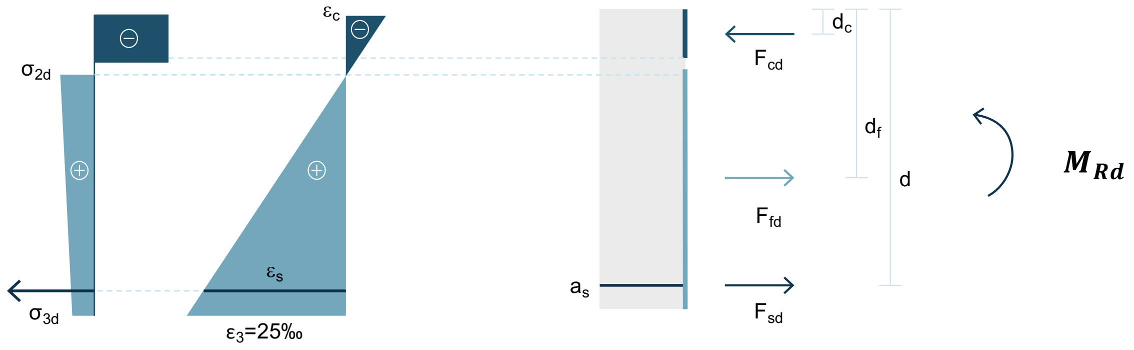
The occurring moment, M_{Ed}, is determined by the design office on the basis of the linear elastic theory.

In each cross-section, the condition must be met:
occurring moment $M_{Ed} \leq M_{Rd}$ resisting moment

As for the design of conventional reinforced concrete, all checks including shear capacity, punching capacity, deflection, settlement, etc. must be evaluated for the design with SFRC.

Under general circumstances regarding the applications treated in this guideline, - when using only steel fibers as concrete reinforcement - the moment check is governing in ULS. Steel fibers also contribute significantly to the shear and punching capacity. Feel free to contact Bekaert for further support.

If the occurring moment M_{Ed} cannot be achieved with an SFRC solution, a combination of reinforcing steel and steel fibers can be applied. Through this approach, it is also possible to evaluate the maximum crack width.



$$F_{cd} = F_{sd} + F_{fd}$$

$$M_{Rd} = -M_{cd} + M_{sd} + M_{fd} = -F_{cd} \cdot d_c + F_{sd} \cdot d + F_{fd} \cdot d_f$$

Figure 9. The sectional equilibrium of a SFRC section, with or without additional conventional reinforcement.

Summary of applied factors

The design of structural elements reinforced with steel fibers is done in the Ultimate Limit State. For that, we evaluate the resistance of an element when reaching the state of structural failure, according to the assumed σ-ε relationship.

Table 3. Summary of the factors to be applied depending on the application under consideration.

Application	Size factor (κ_G)	Hyperstaticity factor (η_{hyp})
Residential foundation slab	1.5	1.00 or 1.24
Cellar wall	1.5*	1.00
Strip foundation	1.0 → 1.5 (depends on the size of the element)	1.00

---

* Note that for very short cellar walls, the size factor could be smaller than 1.5.

Summary: from material to moment capacity

Material characterisation

- Beam tests
- Characteristic values

Material behavior (σ-ε)

- Conversion factors
- Material safety factor

Design value for the application

- Hyperstaticity factor
- Size factor

Moment capacity

- Cross-sectional equilibrium

General foundation slabs

The following aspects apply specifically to the design of residential foundation slabs:

- The slab thickness may vary between 200 and 400 mm;
- The maximum dimension without expansion joint is 25 m x 15 m. Pay attention to the length over width ratio. It is advisable to not exceed 1.5;
- Conventional auxiliary reinforcement may be required to accommodate occurring moments higher than the SFRC moment resistance and situations with peak stresses, e.g. due to indented corners;
- This solution can only be used for foundation slabs resting on an elastic soil and not being subjected to water pressure. The occasional use of thermal insulation under the slab requires a minimum compression modulus of 120 kPa at 10% deformation.

Table 4 shows a few examples of resisting moments M_{Rd} in Ultimate Limit State. Refer to the tables in chapter 7 for the complete list of moment capacities.

Table 4. Concrete strength class C30/37: resisting moments, general foundation slabs.

Slab thickness [mm]	Resisting moment at ULS (kNm/m)		Dramix® 5D 65/60 dosage [kg/m³]
	With hyperstaticity effect	Without hyperstaticity effect	
200	20.1	16.4	20
	28.4	23.2	35
300	45.2	36.8	20
	63.9	52.3	35
400	80.4	65.5	20
	113.6	93.0	35

Cellar walls

The following aspects apply specifically to the design of cellar walls:

- The wall thickness may vary between 250 and 350 mm, with a maximum height of 3.5 m. Ratio height/thickness ≥ 11.5;
- The maximum length without expansion joint is 8 m;
- Conventionally auxiliary reinforcement may be required to cope with peak moments higher than the SFRC moment resistance;
- The usual waterproofing measures should be taken;
- This solution is not suitable for walls that are calculated as "inverted beam";
- The connection reinforcement between the wall and the slab must be calculated without taking into account the contribution of steel fibers;
- It is advised to place additional bars in the longitudinal direction in the bottom 0.75 m of the wall, attached to the connection reinforcement.

Table 5 shows a few examples of resisting moments M_{Rd} in Ultimate Limit State. Refer to the tables in chapter 7 for the complete list of moment capacities.

Table 5. Concrete strength class C30/37: resisting moments, cellar walls.

Wall thickness [mm]	Resisting moment at ULS (kNm/m)	Dramix® 5D 65/60 dosage [kg/m³]
250	25,6	20
	36.3	35
350	50.1	20
	71.2	35

Strip foundations

The following aspects apply specifically to the design of strip foundations:

- The height of the strip foundation may vary between 300 mm and 950 mm. The width ranges between 300 mm and 900 mm. Additional notes with regard to the dimensions of the strip foundation: see figure 10;
- This solution may only be used for strip foundations resting on an elastic soil whether on insulation or not;
- Additional W x H combinations are presented in the tablesin chapter 7, to reflect frost beams.

Refer to the tables in chapter 7 for the complete list of moment capacities.

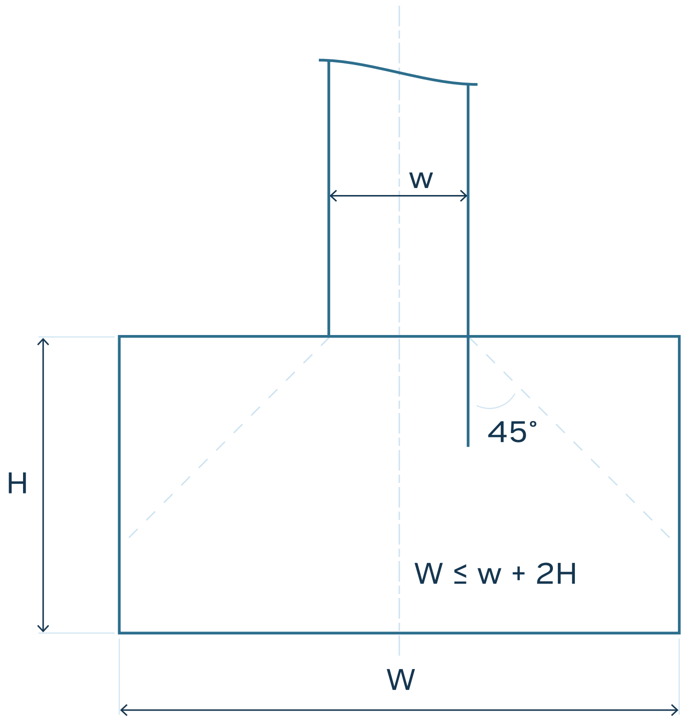


Figure 10. Section view of a strip foundation. In case W > w + 2H, the acting moment in the transversal direction also needs to be checked with regard to the provided moment capacity of the SFRC solution.

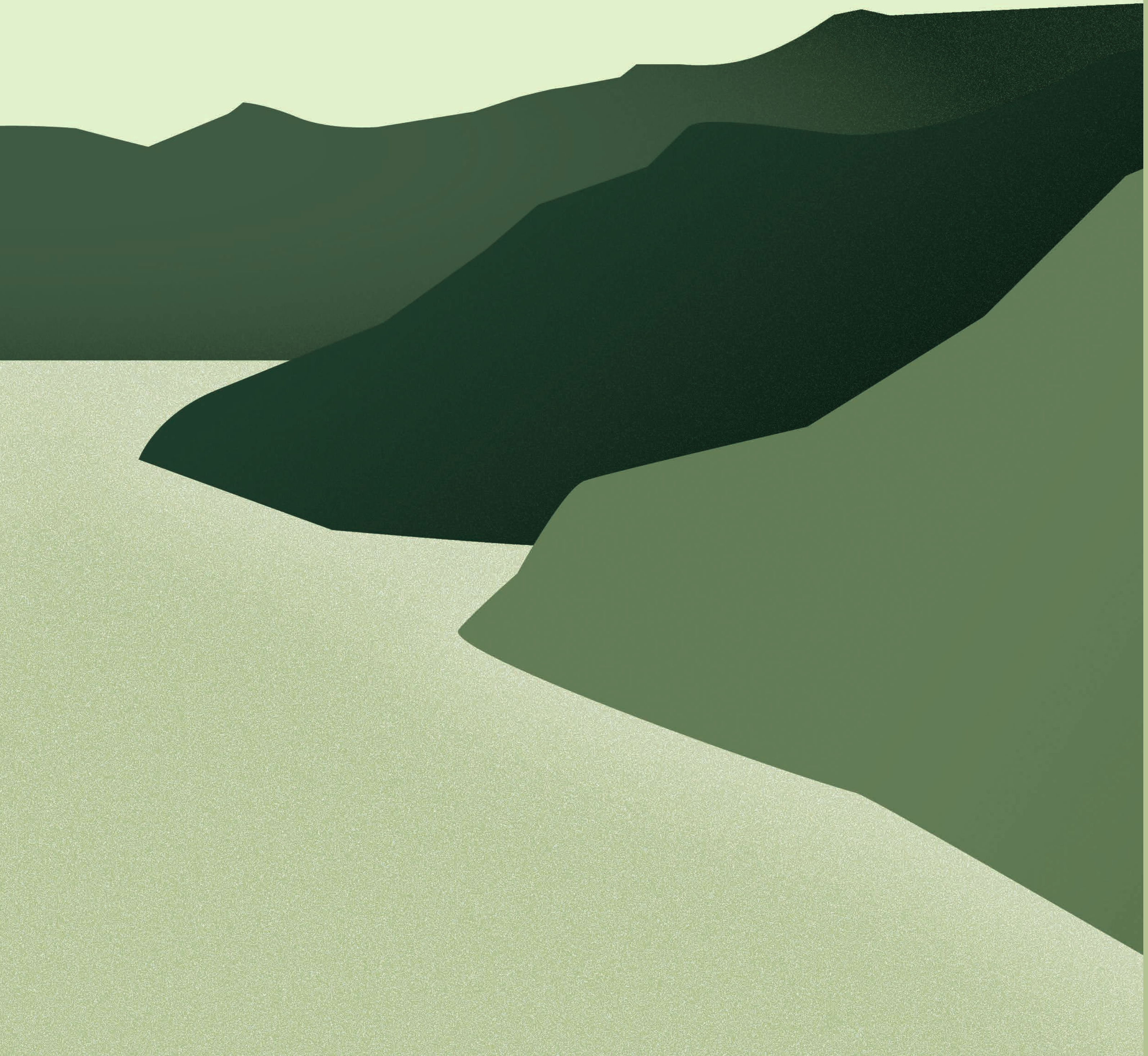
Structural applications for residential use

These applications are attested by SECO according to the following certifications:

MOAC/251/024/05/01:
Residential foundation slabs
with Dramix®

MOAC/251/024/04/01:
Cellar walls poured on site
with Dramix®

MOAC/251/024/06/01:
Calculated strip foundations
with Dramix®



Some examples of residential designs using Dramix®

Example 1: General foundation slab and strip foundation

Description of the example

This design example concerns a small 2-storey apartment building with a floor area of ± 260 m², resting on an elastic soil and constructed using traditional materials (brickwork, in-situ cast floors, flat roof). Around the foundation slab a strip foundation is provided which is cast along with the slab.

To simplify the modeling of the building, it is assumed that all load-bearing walls are positioned along the perimeter of the foundation slab, directly above the strip foundation. However, there are two load-bearing walls, marked in red on the plan (Figure 11) that rest directly on the foundation slab.

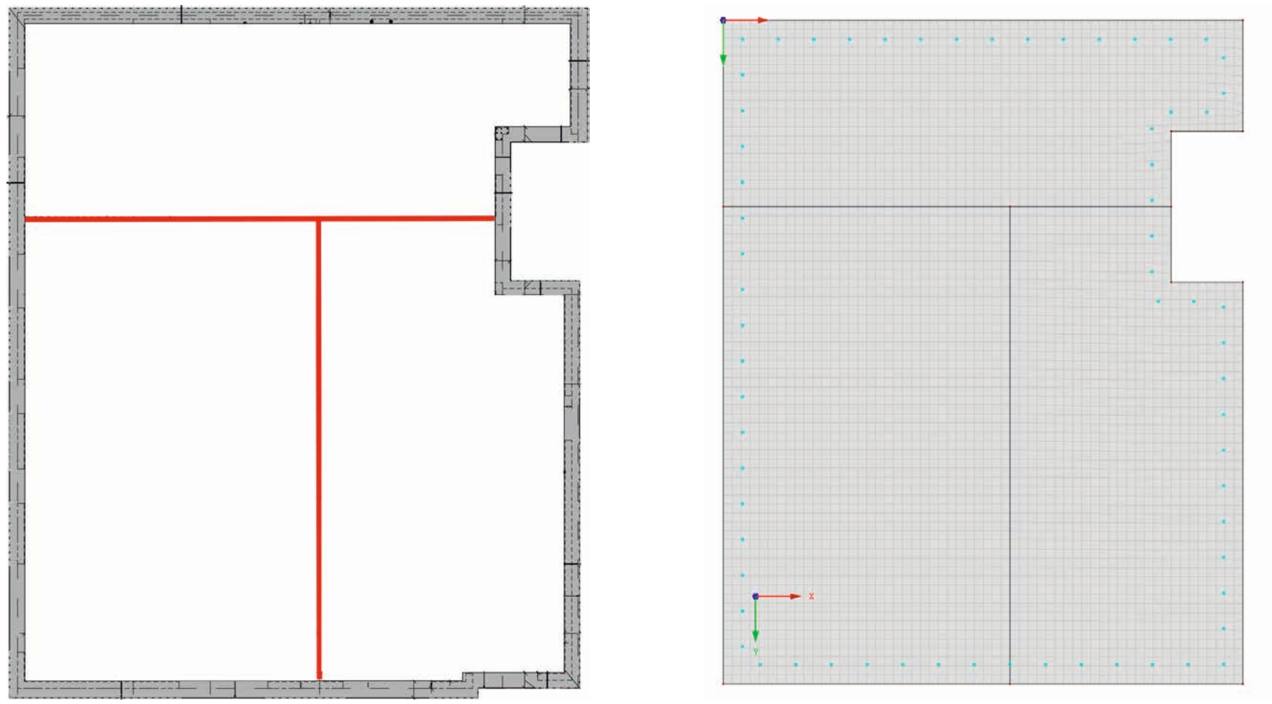


Figure 11. Plan view (left) and Finite element model of the foundation slab (right). The two red lines represent two load-bearing walls resting on the foundation slab.

Table 6. Project parameters.

Type of building	2-story appartement building
Description	Ground floor + 1 level under the roof
Size	260 m²
Foundation slab	Slab with protected frost edge cast along with te slab
Strip foundation	Frost edge to be designed as strip foundation
Soil stiffness	k_s = 0,0125 N/mm²
Loads	Typical for a masonry building with concrete slabs

Results of the internal moments calculation

For this example, a finite element model was built to obtain the internal moments in the slab, as well as in the strip foundation. You are of course free to choose any other applicable calculation method. However, in the framework of this guideline, it is important to perform these calculations in a linear elastic way. Later on, by applying the hyperstaticity factor, the redistribution of moments is accounted for.

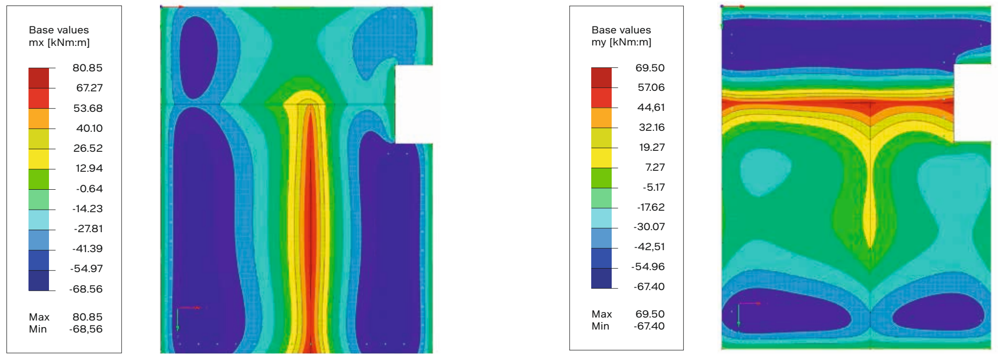


Figure 12. Contour plots of the moments $M_{Ed,x}$ (left) and $M_{Ed,y}$ (right) acting on the slab foundation expressed in kNm/m.

For the foundation slab, the results presented in Figure 12 show that no significant peak values in positive and negative bending moments are generated in the foundation slab. The range of bending moments are:

Table 7. Maximum and minimum moments in the foundation slab.

	$M_{Ed,x}$	$M_{Ed,y}$
Max.	80.85 kNm/m	69.50 kNm/m
Min.	- 68.56 kNm/m	- 67.40 kNm/m

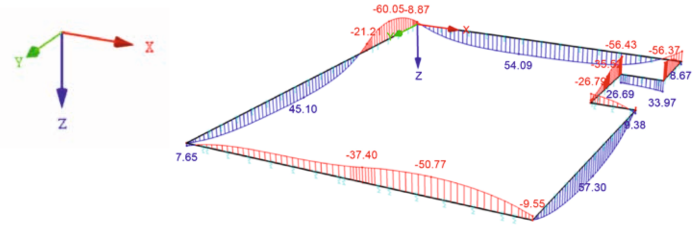


Figure 13. Diagram of the moments M_{Ed} acting on the strip foundations expressed in kNm.

For the strip foundation, the results presented in Figure 13 show that the maximum bending moments are:

Table 8. Max. and min. moments in the strip foundation.

	M_{Ed}
Max. (bottom)	57.30 kNm
Min. (top)	- 60.05 kNm

Remarks:

- The internal shear forces should be verified separately. In case of a fiber only solution, shear forces are typically not governing.
- It is assumed that the subsoil is sufficiently load-bearing, and significant settlements are not expected.

Design solution with SFRC

Based on the considerations above, it is possible to design the foundation slab using SFRC with only a limited amount of additional reinforcement.

The design proposal is the following:

- Slab thickness: 350 mm;
- Strip foundation: W 300 mm x H 800 mm;
- Concrete quality: C30/37;
- 25 kg/m³ Dramix® 5D 65/60BG.

Based on the tablesin chapter 7:

- C30/37 – Residential foundation slabs (η_{hyp} = 1.24)
  (Size factor = 1.5; Hyperstaticity factor = 1.24)
  M_{Rd} = 70.2 kNm/m
- Additional reinforcement is only required in the zones of the slab where $M_{Ed,x} > M_{Rd}$ = 70.2 kNm/m. The additional reinforcement could be determined in a simplified way, based on the difference between M_{Ed} and M_{Rd} provided by the SFRC;
- C30/37 – Strip foundations (Size factor = 1.11; Hyperstaticity factor = 1.0)
  M_{Rd} = 67.2 kNm > M_{Ed} = 60.05 kNm

Example 2: Cellar wall

Description of the example

The second design example is a cellar wall reinforced with Dramix® steel fibers. Here, we assume a fixed support at the bottom and hinge support at the top. A common model for a cellar wall is shown in Figure 14.

Table 9. Project parameters.

Type of building	Any type of building with a one story basement
Description	Cellar wall, connected to the basement slab
Height of cellar wall	2.5 m
Height of the water	2.5 m
Loads	Typical for a 2-story residential building

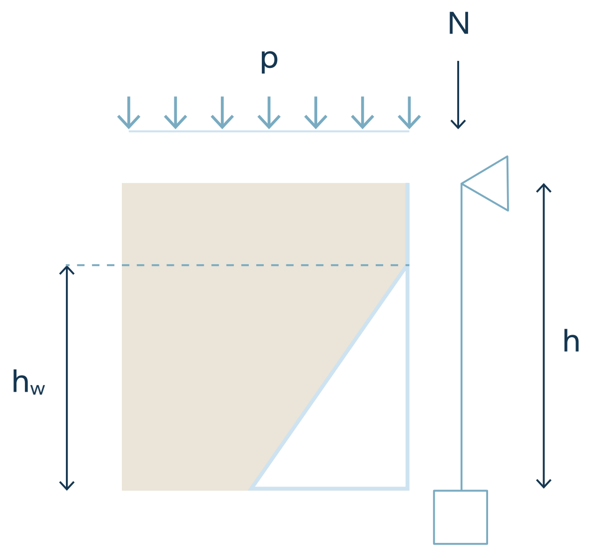


Figure 14. A sketch of the common loads acting on the cellar wall, including the loads on the ground, the height of the water table and the weight of the soil layers.

Results of the internal moments calculation

For this example, a simple model was used to obtain the internal moments in the cellar wall. You are of course free to choose any other applicable calculation method.

Table 10. Moments in the field and at the bottom of the cellar wall.

	M_{Ed}
In the field (middle)	11.03 kNm
At the fixed support (bottom)	24.02 kNm

Design solution with SFRC

Based on the above static calculation, the following proposal is made:

- Wall thickness: 250 mm
- Concrete quality: C25/30
- 20 kg/m3 Dramix® 5D 65/60BG

Based on the table C25/30:

- Residential foundation slabs and basement walls (η_{hyp} = 1.0)
  Size factor = 1.5; Hyperstaticity factor = 1.0)
  M_{Rd} = 24.0 kNm/m > M_{Ed} = 11.03 kNm

The reinforcement at the interface between the cellar wall and the foundation should to be calculated without taking the capacity of the SFRC into account (because no steel fibers are bridging the interface). The height of the conventional reinforcement is dependent on the provided SFRC moment capacity and the anchorage length. In any case, the conventional reinforcement needs to have a min. height of 75 cm.
It is recommended to provide horizontal reinforcement to cope with the potential restrained shrinkage, which is most severe at the bottom (close to the interface) of the cellar wall.

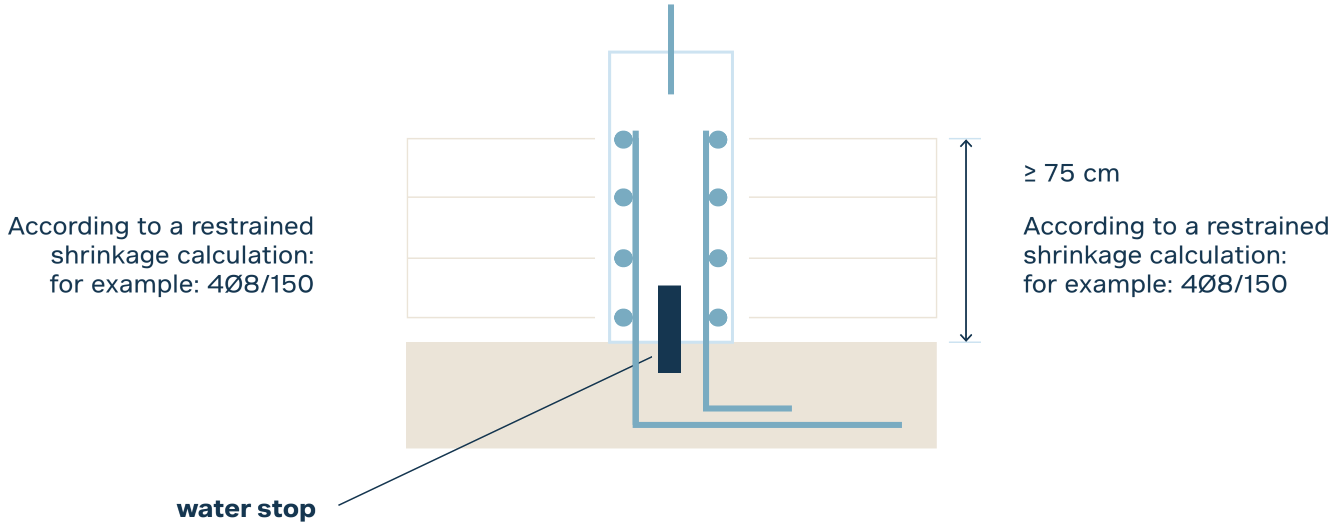


Figure 15. Detail of the interface between the cellar wall and the foundation.

Non-structural residential applications using Dramix®

Non-structural applications with Dramix® Duo100

Steel fibers can also be very useful, practical and economical in non-structural applications. As they are non-structural, there is no specific need for any ULS or SLS calculation. But even in these cases, we need to make sure that the structure can fulfill its final purpose.

During the hardening process, concrete tends to shrink. If the structure is restrained, cracks can be formed, which sometimes can lead to a loss of functionality. This risk can be managed and minimized:

- By eliminating stresses from restraint;
- By reducing plastic shrinkage;
- By controlling microcracking.

Typical applications facing these challenges are:

- Compression layers on hollow core slabs;
- Subfloor/underlay;
- Non-calculated strip foundations.

What is Dramix® DUO100?

Dramix® DUO100 is a specific fiber mix consisting of Dramix® steel fibers (type 3D 80/60BG) and Duomix® micro-synthetic fibers (type M12):

- The Duomix® micro-synthetic fibers will control the plastic shrinkage;
- The Dramix® steel fibers will reduce cracks during the hardening phase (compared to a light mesh).

One bag of Dramix® DUO is used per cubic meter of concrete; doing so the concrete will be reinforced with 10 kg/m³ 3D 80/60BG and 0.6 kg/m³ Duomix® M12.

How does Dramix® DUO100 work?

Plastic shrinkage control

During the first hours after pouring, the concrete slowly starts to harden and build up strength. In this phase the compressive strength is minimal (3 MPa), the resistance to tensile stresses negligible (0.3 MPa) and the modulus of elasticity very low (5 GPa). If cracks now appear in the concrete, the crack widths are very small and the stresses to be absorbed in a fiber are therefore very low. Each crack that develops is bridged by many microsynthetic fibers. In a composite material such as fiber concrete, a reinforcement effect can only occur if the reinforcement has a higher modulus of elasticity than the material it is intended to reinforce, such as concrete. Due to the dense network of fibers, microsynthetic fibers reinforce the fresh and still plastic concrete with ease: millions of synthetic fibers are scattered throughout the concrete.

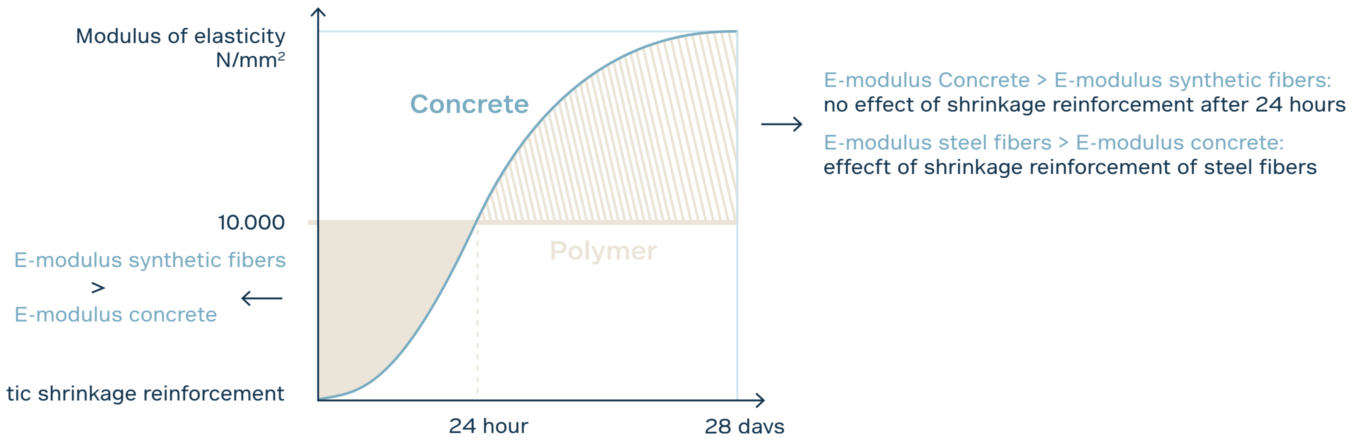


Figure 16. The evolution of the concrete modulus of elasticity during the first 28 days after pouring.

Drying shrinkage and crack width control

After 24 hours, the concrete properties change rapidly: the compressive strength increases above 10 MPa, the tensile strength reaches 1 MPa and the modulus of elasticity rises above 15 GPa. Now, when cracks occur, the stresses in the fibers will be significantly higher than in the fresh concrete. Synthetic fibers are now no longer of interest. Crack control when using conventional reinforcement is highly dependent on the reinforcement rate and correct placement of the mesh on site. The steel fibers therefore are distributed homogeneously over the whole section and will make sure that remaining stresses can be transferred over the cracks.

> **Dramix® DUO100 offers the perfect alternative for the often-proposed light mesh or rebar.**
>
> Steel fiber concrete with Dramix® DUO100 is **intrinsically a different material** compared to conventional reinforced concrete, but delivers **better results** with respect to shrinkage control.

Moment capacity tables

C25/30 – Residential foundation slabs (η_{hyp} = 1,24)

Thickness (mm)	Dramix® 5D 65/60BG (kg/m^3)			
	20	25	30	35
200	18.9	20.5	23.3	26.0
210	20.8	22.6	25.7	28.6
220	22.8	24.8	28.2	31.4
230	24.9	27.1	30.8	34.4
240	27.1	29.5	33.5	37.4
250	29.5	32.0	36.4	40.6
260	31.9	34.7	39.3	43.9
270	34.4	37.4	42.4	47.4
280	37.0	40.2	45.6	50.9
290	39.6	43.1	48.9	54.6
300	42.4	46.1	52.4	58.5
310	45.3	49.3	55.9	62.4
320	48.3	52.5	59.6	66.5
330	51.3	55.8	63.4	70.7
340	54.5	59.3	67.3	75.1
350	57.7	62.8	71.3	79.6
360	61.1	66.5	75.4	84.2
370	64.5	70.2	79.6	88.9
380	68.1	74.0	84.0	93.8
390	71.7	78.0	88.5	98.8
400	75.4	82.0	93.1	103.9

Resisting Moment at ULS in kNm/m
Material factor = 1.5; Size factor = 1.5; Hyperstaticity factor = 1.24

C25/30 – Cellar walls and Residential foundation slabs (η_{hyp} = 1.0)

Thickness (mm)	Dramix® 5D 65/60BG (kg/m^3)			
	20	25	30	35
200	15.4	16.7	19.0	21.3
210	17.0	18.5	21.0	23.5
220	18.6	20.3	23.0	25.8
230	20.4	22.1	25.2	28.2
240	22.2	24.1	27.4	30.7
250	24.0	26.2	29.8	33.3
260	26.0	28.3	32.2	36.0
270	28.0	30.5	34.7	38.9
280	30.2	32.8	37.3	41.8
290	32.4	35.2	40.0	44.8
300	34.6	37.7	42.9	48.0
310	37.0	40.2	45.8	51.2
320	39.4	42.9	48.8	54.6
330	41.9	45.6	51.9	58.0
340	44.5	48.4	55.0	61.6
350	47.1	51.3	58.3	65.3
360	49.9	54.3	61.7	69.1
370	52.7	57.3	65.2	73.0
380	55.6	60.5	68.8	77.0
390	58.5	63.7	72.4	81.1
400	61.6	67.0	76.2	85.3

Resisting Moment at ULS in kNm/m
Material factor = 1.5; Size factor = 1.5; Hyperstaticity factor = 1.0

C30/37 – Residential foundation slabs (η_{hyp} = 1,24)

Thickness (mm)	Dramix® 5D 65/60BG (kg/m³)			
	20	**25**	**30**	**35**
200	20.1	22.9	25.7	28.4
210	22.2	25.3	28.3	31.3
220	24.3	27.7	31.1	34.4
230	26.6	30.3	34.0	37.6
240	28.9	33.0	37.0	40.9
250	31.4	35.8	40.1	44.4
260	34.0	38.7	43.4	48.0
270	36.6	41.8	46.8	51.8
280	39.4	44.9	50.3	55.7
290	42.2	48.2	54.0	59.7
300	45.2	51.6	57.8	63.9
310	48.3	55.1	61.7	68.2
320	51.4	58.7	65.7	72.7
330	54.7	62.4	69.9	77.3
340	58.1	66.2	74.2	82.1
350	61.5	70.2	78.6	87.0
360	65.1	74.3	83.2	92.0
370	68.8	78.4	87.9	97.2
380	72.5	82.7	92.7	102.5
390	76.4	87.2	97.6	108.0
400	80.4	91.7	102.7	113.6

Resisting Moment at ULS in kNm/m
Material factor = 1.5; Size factor = 1.5; Hyperstaticity factor = 1.24

C30/37 – Cellar walls and Residential foundation slabs (η_{hyp} = 1.0)

Thickness (mm)	Dramix® 5D 65/60BG (kg/m³)			
	20	**25**	**30**	**35**
200	16.4	18.7	21.0	23.2
210	18.0	20.6	23.2	25.6
220	19.8	22.6	25.4	28.1
230	21.6	24.7	27.8	30.7
240	23.6	26.9	30.2	33.5
250	25.6	29.2	32.8	36.3
260	27.7	31.6	35.5	39.3
270	29.8	34.1	38.3	42.4
280	32.1	36.7	41.2	45.6
290	34.4	39.3	44.2	48.9
300	36.8	42.1	47.3	52.3
310	39.3	44.9	50.5	55.9
320	41.9	47.9	53.8	59.5
330	44.6	50.9	57.2	63.3
340	47.3	54.1	60.7	67.2
350	50.1	57.3	64.3	71.2
360	53.0	60.6	68.1	75.3
370	56.0	64.0	71.9	79.6
380	59.1	67.5	75.8	83.9
390	62.3	71.1	79.9	88.4
400	65.5	74.8	84.0	93.0

Resisting Moment at ULS in kNm/m
Material factor = 1.5; Size factor = 1.5; Hyperstaticity factor = 1.0

C25/30 – Strip foundations

Dimensions B×H (mm)	Dramix® 5D 65/60BG (kg/m³)			
	20	25	30	35
300 × 500	20.8	22.7	25.9	29.0
300 × 600	30.3	33.1	37.7	42.3
300 × 700	41.8	45.6	51.9	58.3
300 × 800	55.2	60.2	68.6	77.0
300 × 900	70.7	77.1	87.9	98.6
300 × 950	79.3	86.4	98.5	110.4
400 × 500	28.3	30.9	35.2	39.5
400 × 600	41.4	45.2	51.5	57.7
400 × 700	57.3	62.4	71.2	79.8
400 × 800	76.0	82.8	94.4	105.8
400 × 900	97.7	106.3	121.3	135.9
400 × 950	109.6	119.4	136.1	152.5
500 × 300	12.5	13.6	15.5	17.4
500 × 400	22.7	24.7	28.2	31.6
500 × 600	53.0	57.8	65.9	73.8
500 × 700	73.6	80.1	91.4	102.4
500 × 800	97.9	106.6	121.5	136.2
500 × 900	126.1	137.4	156.5	175.5
500 × 950	141.8	154.4	176.0	197.4
600 × 300	15.2	16.5	18.9	21.1
600 × 400	27.7	30.1	34.3	38.5
600 × 500	44.2	48.1	54.9	61.5
600 × 700	90.6	98.6	112.4	126.0
600 × 800	120.9	131.6	150.0	168.3
600 × 900	156.2	170.1	193.8	217.3
600 × 950	175.8	191.6	218.2	244.6
700 × 300	17.9	19.5	22.3	25.0
700 × 400	32.8	35.7	40.7	45.6
700 × 500	52.6	57.2	65.3	73.1
700 × 800	145.0	157.9	179.9	201.7
700 × 900	187.9	204.7	233.1	261.2
700 × 950	211.8	230.8	262.8	294.4
800 × 300	20.7	22.6	25.7	28.9
800 × 400	38.0	41.4	47.2	52.9
800 × 500	61.2	66.6	75.9	85.1
900 × 300	23.6	25.7	29.3	32.8
900 × 400	43.4	47.3	53.9	60.4
900 × 500	70.1	76.3	87.0	97.5

Resisting Moment at ULS in kNm
Material factor = 1.5; Size factor = 1 + A_{ct}·0.5 ≤ 1.5; Hyperstaticity factor = 1.0

C30/37 – Strip foundations

Dimensions B×H (mm)	Dramix® 5D 65/60BG (kg/m³)			
	20	25	30	35
300 × 500	22.1	25.3	28.5	31.6
300 × 600	32.2	36.9	41.5	46.0
300 × 700	44.4	50.8	57.1	63.4
300 × 800	58.7	67.2	75.5	83.8
300 × 900	75.2	86.1	96.7	107.4
300 × 950	84.2	96.5	108.3	120.3
400 × 500	30.1	34.4	38.7	43.0
400 × 600	44.0	50.4	56.6	62.9
400 × 700	60.9	69.7	78.3	86.9
400 × 800	80.7	92.4	103.8	115.3
400 × 900	103.7	118.8	133.4	148.0
400 × 950	116.4	133.3	149.7	166.1
500 × 300	13.3	15.2	17.1	19.0
500 × 400	24.1	27.6	31.0	34.4
500 × 600	56.3	64.5	72.4	80.4
500 × 700	78.1	89.5	100.5	111.5
500 × 800	104.0	119.0	133.7	148.3
500 × 900	134.0	153.4	172.3	191.1
500 × 950	150.7	172.4	193.6	214.8
600 × 300	16.1	18.5	20.7	23.0
600 × 400	29.3	33.6	37.7	41.9
600 × 500	46.9	53.8	60.4	67.0
600 × 700	96.2	110.1	123.7	137.3
600 × 800	128.4	147.0	165.1	183.1
600 × 900	166.0	189.9	213.4	236.7
600 × 950	186.9	213.8	240.4	266.4
700 × 300	19.0	21.8	24.5	27.2
700 × 400	34.8	39.8	44.7	49.7
700 × 500	55.8	63.9	71.8	79.7
700 × 800	154.1	176.3	198.2	219.6
700 × 900	199.8	228.5	256.8	284.6
700 × 950	225.5	257.6	289.4	320.8
800 × 300	22.0	25.2	28.3	31.5
800 × 400	40.4	46.2	51.9	57.6
800 × 500	65.0	74.4	83.5	92.7
900 × 300	25.1	28.7	32.2	35.8
900 × 400	46.1	52.8	59.3	65.8
900 × 500	74.4	85.2	95.7	106.2

Resisting Moment at ULS in kNm
Material factor = 1.5; Size factor = 1 + A_{ct}·0.5 ≤ 1.5; Hyperstaticity factor = 1.0

Specification text

The structure shall be reinforced using x kg/m³ Dramix® 5D 65/60BG. The steel fibers shall have a length of 60 mm, a diameter of 0.9 mm, a double hooked end anchorage and a nominal tensile strength of 2300 N/mm². The double hook shall have a minimum anchoring effectiveness of 90%. The wire shall have an extension capacity of at least 6%. The Dramix® steel fibers should be glued in bundles to allow homogeneous distribution in concrete. The fibers should comply with EN14889-1 (CE-label) and have an ATG-certificate.

References

[1] fib Model Code for Concrete Structures 2010, International Federation for Structural Concrete (fib)

[2] DafStb guideline Steel Fiber Reinforced Concrete. Berlin, Germany, DAfStb (German Committee for Structural Concrete), 2012

[3] prEN 1992-1-1:2021 Eurocode 2: Design of concrete structures - Part 1-1: General rules - Rules for buildings, bridges and civil engineering structures

[4] EN 14889-1:2006 Fibers for concrete – Part 1: Steel fibers – Definitions, specifications and conformity

[5] EN 14651:2005 Test method for metallic fiber concrete – Measuring the flexural tensile strength (limit of proportionality LOP, residual)

[6] EN 1992-1-1:2004 Eurocode 2: Design of concrete structures. General rules and rules for buildings

[7] NBN EN 1990 Basis for structural design

Note: This document replaces all previously communicated information about calculation methods and calculation values for Dramix® in residential construction.

> “
>
> We hope that this guideline provides some **clarity on the design principles** of SFRC for residential applications. Our experts are available **to discuss your specific requirements** and challenges in detail.

construction.bekaert.com

NV Bekaert SA
Bekaertstraat 2
BE-8550 Zwevegem
infobuilding@bekaert.com