



STRUCTURAL APPLICATION OF STEEL FIBRE REINFORCED CONCRETE WITH AND WITHOUT CONVENTIONAL REINFORCEMENT

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ABSTRACT: *Structural steel fibre reinforced concrete applications differ mainly from well-known fibre applications like floors and pavements. In structural applications, steel fibres are the main or the secondary reinforcement to take up bending moments and the shear stresses. The new Australian Standards AS3600 Concrete Structures and AS 5100.5 Bridge Design – Concrete, released in 2018 and 2017, respectively, have now included the provision of using steel fibres in concrete structures. This paper presents some basic principles governing the structural design of SFRC based on the available design codes. Starting from the classification of various types of steel fibres, which have profound effect on the performance of concrete structures, the simple constitutive models are presented, allowing engineer and designer to design with SFRC. Numerous projects have been carried out. A few of them are presented, giving insight information on where steel fibre only reinforcement and combined steel fibre and conventional reinforcement were used.*

KEYWORDS: steel fibre, bending moment, shear, crack control, quality control, concrete

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1 INTRODUCTION

Adding fibres in concrete can no longer be considered as new or novel; fibres have been used to reinforce brittle materials, such as straw in mud for masonry construction dating back to the Babylonian and Egyptian eras. From a modern perspective, research into steel fibre reinforced concrete (SFRC) was pioneered by Romualdi and Batson [1] in the early 1960s where it was demonstrated that tensile strength and crack resistance of concrete can be improved by providing suitably arranged, closed spaced, wire reinforcement. After more than 50 years of research in the development and placement of fibres in reinforced concrete, the concept has matured and its adoption in practice is rapidly developing.

Today, steel fibres are used in an increasing number of applications as main and secondary concrete reinforcement in heavy pavements, slab tracks, shotcrete linings and precast applications. More recent SFRC applications can be seen in the domain of structural raft foundations, liquid tight slabs, heavy structure pile caps and piled supported slabs, and even bridges and suspended structures.

These developments are steered and boosted by a steady build-up of knowledge as well as the research carried out at various universities and research institutions in order to understand and quantify the SFRC properties. Owing to better knowledge of SFRC, numerous design guidelines, standards and codes have since published globally.

The Australian Standard for the design of Concrete bridges [2] was released on 31st March 2017; this is the first standard in Australia to include procedures for the design of SFRC structural elements. The latest AS 3600 Concrete Structures code released on 29th June 2018 [3] also includes procedures for the design of SFRC structural elements.

This paper presents some basic principles governing the structural design of SFRC. Starting from the classification of various types of steel fibres, which have profound effect on the performance of concrete structures, the simple constitutive models are presented, allowing engineer and designer to design with SFRC. Numerous projects have been carried out. A few of them are presented, giving insight information on where steel fibre only reinforcement and combined steel fibre and conventional reinforcement were used.

2 SFRC MATERIAL BEHAVIOUR

2.1 GENERAL

The most important property when designing of a SFRC structural element is its post-cracking or residual tensile strength. Steel fibres are active as

soon as micro-cracks are formed in the concrete. The fibres are able to bridge the crack, transmit stress across the crack and, in the process, provide some resistance to the widening and fracture process of the crack. Thus, unlike plain concrete, an appropriately reinforced SFRC structural element will not completely fail after crack initiation but some residual strength after cracking will be available.

The tensile behaviour of SFRC can either be classified as strain-softening or strain hardening (Figure 1). For strain softening materials, failure occurs over a localised single dominant crack. The behaviour is characterised by the residual tensile strength of the structural element never reaching the tensile strength of the cementitious matrix after it cracks, but tends to zero as the crack widens. For strain hardening materials, on the other hand, the residual stress increases after first cracking, and this may result in multiple cracking within the sample, which is then followed by failure at a localised crack.

Design procedures in AS 5100.5 and AS 3600 standards [2-4] are, however, limited to SFRC with a softening classification only.

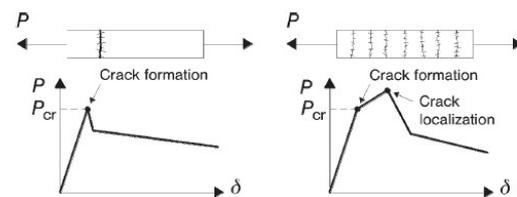


Figure 1: Typical load-deflection curve for SFRC: (a) Strain softening; and (b) strain hardening behaviours [5]

2.2 ESTABLISHING PROPERTIES OF SFRC

The SFRC residual tensile strength may be determined by a direct tension test or indirect tensile tests such as three-point notched prisms bending test recommended in EN 14561 [6]. In the latter case, the relationship between the direct and indirect tensile strength is established based on Amin [7].

3 SFRC FOR LIMIT STATE DESIGN

3.1 GENERAL

A major principle in construction is to create robust structures. Robustness is directly linked to the ductility of a structure. To prevent brittleness in structural elements, AS 3600 [3-4] suggests that steel fibres can be used to substitute conventional reinforcement at limit state, if the following relationships:

$$f_{R1m} / f_{Lm} \geq 0.4 \quad (1)$$

$$f_{R3m} / f_{R1m} \geq 0.5 \quad (2)$$

where f_{Lm} is mean value of Limit of Proportionality determined from EN 14651 [6] and f_{R1m} and f_{R3m} are the characteristic residual flexural strength of SFRC corresponding to a crack mouth opening displacement (CMOD) of 0.5 mm and 2.5 mm, respectively.

Alternatively, the minimum fibre dosage to ensure sufficient continuity and network of steel fibres in the concrete matrix can be determined based on fibre spacing theory (Figure 2).

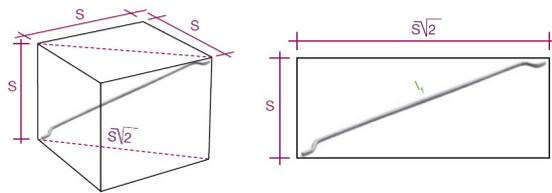


Figure 2: Minimum dosage based on minimum overlap concept

McKee [8] suggested that the average distance between fibres, s , can be estimated as:

$$s = \sqrt[3]{\frac{\pi \times d_f^2 \times l_f}{4 \rho_f}} \quad (3)$$

where l_f is the length of the fibre, d_f is the diameter of the fibre and ρ_f is the percentage of fibre by volume.

Both the AS 5100.5 and AS 3600 standards [2-4] suggest that the average distance between steel fibres, s , should be lower than $0.45l_f$ in order to ensure a minimum overlap between fibres.

3.2 BENDING MOMENT CAPACITY

The bending moment capacity of SFRC can be calculated based upon the fundamental SFRC constitutive laws. The ultimate limit state design of a cross-section for bending with or without axial force is based on following assumptions:

- (i) Plain sections remain plain.
- (ii) The strain distribution is aligned with the strain distribution of reinforced concrete where the maximum strain the in extreme compression fibre, ϵ_{cu} , is taken as 0.003 (as per Australian Standards recommendation) to 0.0035 (as per Eurocode 2 [8] and fib Model Code [5])

In order to calculate the cross-section bending moment capacity, the static equilibrium needs to be determined. Figure 3 schematically represents the relation between stresses (and resultant forces) and strains. Instead of neglecting the resistance of

concrete in the tension zone (i.e. concrete carries zero tension), the steel fibres take a share in the tensile resistance. The bending failure stage is supposed to be reached when one of the following conditions applies:

- attainment of the ultimate compressive strain in the SFRC, ϵ_{cu} ;
- attainment of the ultimate tensile strain in the steel (if present, in particular for Class L reinforcement), ϵ_{su} ;
- attainment of the ultimate tensile strain in the SFRC, ϵ_{Fu} .

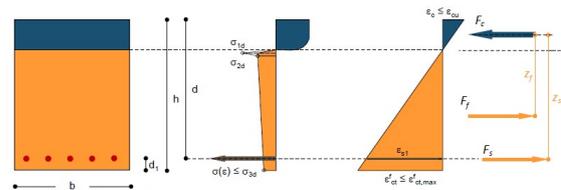


Figure 3: Static equilibrium of the cross section under bending

From Figure 3, the ultimate bending moment capacity, M_u , of the cross section can be written as follows:

$$M_u = F_f \times z_f + F_s \times z_s \quad (4)$$

AS 5100.5 and AS 3600 standards [2-4] use a simplified SFRC residual tensile strength stress blocks as shown in Figure 4. In this case, the contribution of the fibres is taken to be plastic with a constant stress at 1.5 mm crack opening distance of $f'_{1.5}$ applied to the section on the tensile side of the neutral axis. Forces and moments are resolved using equilibrium and compatibility in the usual way as per Equation 4.

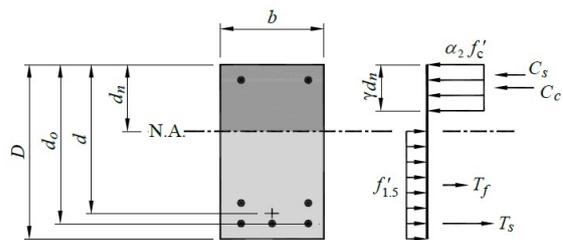


Figure 4: Design for bending in accordance with Australian Codes [2-4].

In the case of structural elements, subjected to bending, where steel fibres completely replace the conventional reinforcement, a minimum redundancy level is required. This residual post crack strength of the SFRC becomes significant as a remarkable stress redistribution must occur in order to achieve the required ductility. It is obvious that a flexural strain softening SFRC cannot be used in this case; the fact is that the flexural tensile

strength of the uncracked SFRC is higher than the flexural tensile strength of the cracked SFRC. This means that as soon as the first crack strength is exceeded due to the loading, the cracked section is no longer capable of resisting the acting bending moment. Consequently, the structure will collapse, i.e. the first crack is the last crack. Of course, this applies to plain concrete as well.

For this reason, in addition to the limitations provided by Equations (1) and (2), SFRC used in structural elements without conventional reinforcement, subjected to bending, must at least have a flexural hardening behaviour, if not strain hardening behaviour. Once the SFRC is cracked, the flexural hardening SFRC can take a higher flexural strength.

While the design procedures in Australian Codes are limited to combined steel fibres and conventional reinforcements, the design procedures of SFRC without conventional reinforcement are available in fib Model Code [5] and the German Committee for Structural Concrete (DafStb) Guidelines for SFRC [10] and, hence, are allowable under National Construction Code (NCC) provided that the ‘performance solution’ pathway is satisfied. [11,12].

3.3 SHEAR AND PUNCHING SHEAR CAPACITIES

Steel fibres can act as shear ligatures or stirrup reinforcements and are distributed all over the entire cross section of the structural element. The shear capacity of the element is increased as a function of the performance of the SFRC used. This can lead to a significant reduction (or even a complete elimination) of conventional shear reinforcement. Installation of stirrups or shear links can be omitted in such a case.

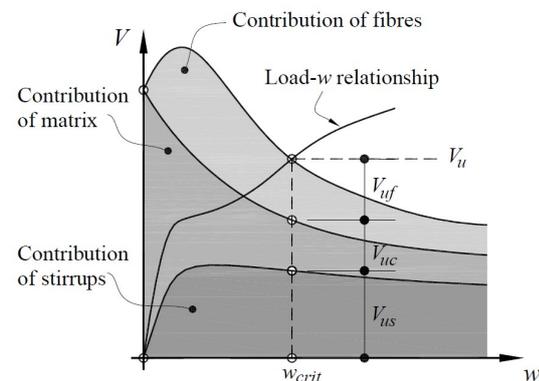


Figure 5: Shear strength contribution [15]

The total shear capacity of a SFRC element, V_u , can be calculated using the Equation (5). The flexural shear model adopted for AS 5100.5 and AS 3600 standards is based on the simplified modified compression field approach [13]. The shear

contributions of the concrete matrix, V_{uc} , stirrup reinforcement, V_{us} , and fibres, V_{uf} , are coupled as each is a function of the width of the critical shear crack and, thus, must be solved simultaneously. This is illustrated in Figure 5.

$$V_u = V_{uc} + V_{us} + V_{uf} \quad (5)$$

For Australian Codes initial implementation, some additional rules are adopted.

The Australian Codes presently do not have provisions for punching shear design of SFRC element. Readers can refer to fib Model Code [5], DafStb guidelines [10] and Maya et al. [14] for punching shear design of SFRC element.

3.4 SERVICEABILITY DEFLECTION CONTROL

For service design, steel fibres assist in the control of cracking and deflections. After cracking, the SFRC in the tension zone carry some tensile stresses and, hence, improving the stiffness, reducing the curvature and deflection of the SFRC member.

For design based on Australian Codes, it is assumed that a uniform tension is taken by the fibres equivalent to a stress in the concrete of $1.1f'_{1.5}$ and the curvature and effective second moment of area of the SFRC member can then be calculated from the slope of the strain diagram in Figure 6(b) and obtained by satisfying the requirements for rotational and horizontal equilibrium of the stress distribution in Figure 6(c).

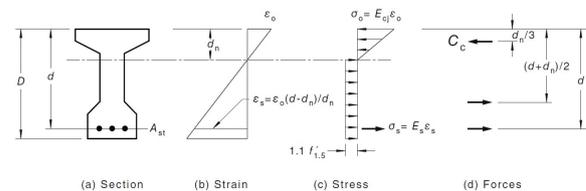


Figure 6: Stress and Strain Distribution on a Cracked SFRC Member

3.5 SERVICEABILITY CRACK CONTROL

The strain softening behaviour of SFRC is problematic in terms of calculating crack widths. Although it is theoretically possible to calculate a crack width in a section that has a permanent compression zone, the fact is that the tensile strength of the uncracked fibre reinforced concrete is higher than the tensile strength of the cracked fibre reinforced concrete. This means that for a concrete element where the full section is in tension, for example, due to restraint of shrinkage and temperature stresses in a ground slab, the cracked section is the weakest section and it is not possible to determine accurately if and where the concrete section will crack again, i.e. it is

impossible to determine a theoretical spacing between cracks and without a crack spacing it is also impossible to determine a crack width using current crack width calculation theory.

When conventional and steel fibre reinforcement are combined the strain softening behaviour of SFRC does not change. However, the post-cracking tensile capacity of the SFRC can be taken into account when calculating crack widths for the conventional reinforcement. The basic principle is that due to increasing post crack strength the released force at crack formation decreases: The fibres carry a part of the released force. As a consequence, the reinforcing steel needs to transfer only a reduced force back into the concrete. Therefore the strain in the reinforcing steel, as well as the required transfer length, is directly reduced. For a given crack width, the use of steel fibres can thus significantly decrease the required amount of conventional reinforcement. Additional effects from enabling the use of smaller diameters can be utilised.

The Australian Bridge Code for Concrete Design AS5100.5 adopts a deemed-to-comply crack control provision derived from RILEM guidelines [16], NZS3101:Part 2 [17] and the fib Model Code [5]. The minimum amount of longitudinal reinforcement required to obtain controlled crack formation is:

$$A_{st,min} = \left(k_1 k_c k_p f_{ct,ef} - 1.1 f'_{1.5} \right) \frac{A_{ct}}{f_{s,max}} \quad (6)$$

where $A_{st,min}$ is the area of reinforcement required within the tensile zone, if $A_{st,min}$ is zero only steel fibres are necessary to control cracking; A_{ct} is the area of concrete on the tensile side of the elastic centroidal axis; $f_{s,max}$ is the maximum stress permitted in the reinforcement immediately after formation of the crack; $f_{ct,ef}$ is the greater of $0.6 f_{cm}$, where f_{cm} is the mean strength of the concrete, and 3.0 MPa. The coefficients k_1 , k_c and k_p are adjustments for shrinkage and temperature, the nature of the stress distribution immediately prior to cracking and for the level of prestress on the section, respectively.

The AS3600 standard [3,4] now allows engineers to design crack control by calculation of crack widths. The fundamental crack width prediction equation is:

$$w = s_{r,max} (\epsilon_{sm} - \epsilon_{cm}) \quad (7)$$

where w is the predicted crack width, $s_{r,max}$ is the maximum crack spacing and $(\epsilon_{sm} - \epsilon_{cm})$ is the difference between the mean strain in the reinforcement and the mean strain in the concrete. Adding steel fibres into the concrete, it reduces both $s_{r,max}$ and $(\epsilon_{sm} - \epsilon_{cm})$ and, hence, reducing the crack width.

Taking an example, for a 40 MPa SFRC with $f'_{1.5}$ of 0.9 MPa, it can reduce the crack spacing by 44% and the difference between the mean strain in the reinforcement and the mean strain in the concrete is now $(\epsilon_{sm} - 1.4\epsilon_{cm})$.

4 QUALITY CONTROL OF SFRC

Quality assurance is fundamental in SFRC construction so as to provide safe and durable structures. The quality control process shall involve all parties working in the project; noting that it may be too risky to rely on the promises of a manufacturer alone. Table 1 lists the responsibility of each party.

Table 1: Responsible Parties

Party	Responsibility
Fibre manufacturer & supplier	Ensure the fibres are complied with ISO 13270 or EN 14889-1
Concrete supply company	Record & document the correct type of fibre with the correct fibre dosage is batched.
Engineer & contractor on site	Check & verify the QA documentation of concrete supply company and ensure the fibres are uniformly distributed in the concrete.

4.1 MANUFACTURING OF STEEL FIBRE

Australian Codes require all steel fibres to be complied with ISO 13270 [18] or EN 14889-1 [19] with CE Marking Class 1. Likewise, the UK Concrete Society Technical Report No. 34 [20] also requires the fibres used in slab and pavement construction to be manufactured in accordance with EN14889-1 [19].

ISO 13270 and EN 14889-1 are quality control performance based manufacturing standard for steel fibres. It is mandatory in European Union member states for steel fibres used in construction to be manufactured in accordance with the standards. There are two types of classification, Class 1 for structural use and Class 3 for non-structural use. The term “structural use” is where the addition of fibres is designed to contribute to the load bearing and carrying capacity of the concrete element including pavements and slabs on grade. For this reason, Class 1 steel fibres are submitted to more scrutiny during manufacture (more intensive sampling and testing) and production is monitored by an external third party. Other standards, such as ASTM A 820 [21], do not necessarily require third party verification and are not performance based. Hence, ISO 13270 and EN

14889-1 can provide engineers a higher level of confidence that the fibres have a minimum level of quality and performance.

By adhering to the standard, manufacturers are required to:

- Class their fibre in accordance with the base material; cold drawn wire, cut sheet, melt extract, shaved cold drawn wire or milled from blocks and then declare the shape; straight or deformed. This allows any steel fibre to be manufactured in accordance with this standard, provided it can be produced within the control and tolerances set to guarantee quality and consistency;
- Declare values for each individual fibre characteristics that influence performance; such as length, diameter, aspect ratio, fibre tensile strength, etc and these values must not deviate by more than the tolerances specified in the standard;
- Declare a minimum fibre dosage to meet:
 - (i) A level of consistency or workability; and
 - (ii) A prescribed residual flexural strength values in a reference concrete.

This enables complete transparency allowing the engineer, concrete company, and contractor to legitimately compare the expected performance of different fibre types on offer.

(It is important to note that nowhere in the standard a minimum fibre dosage has been defined. The minimum fibre dosage shall be determined using Equations (1), (2) and (3) in Section 3.1 above.)

Every packaging of steel fibres that complied with EN 14889-1 has a CE label attached. A typical example is shown in Figure 7. The concrete supply company must use this information to record that the correct fibre type and fibre properties have been used in the supply of their SFRC.

4.2 QA & QC - SFRC PRODUCTION

Steel fibres can be introduced to the concrete manually or through an automatic dosing equipment. The automatic dosing equipment can be linked to the central batching system which allows accurate dosing and provides a record for quality control documentation.

In Australia, it is still a common practice that steel fibres are batched manually at the concrete batching plants. For quality control in the SFRC production, the following steps shall be followed by the fibre batcher:

- Before batching and loading the fibres into the concrete truck, the fibre batcher shall check the CE label on the fibre package against the

delivery docket and circles the fibre type on the CE label if they match.

- After batching and loading the fibres into each concrete truck, the fibre batcher manually counts the number of the empty bags and writes the quantity of bags and the bag size on the delivery docket.

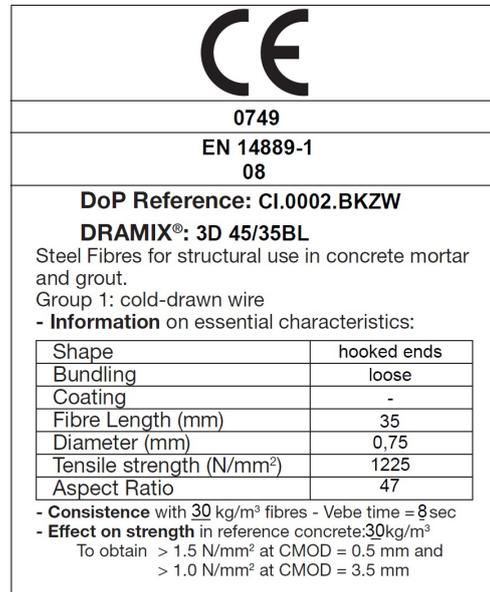


Figure 7: Example of CE Label

4.3 IN-SITU FRESH SFRC QUALITY INSPECTION

A visual inspection is a common practice to determine whether the random distribution and the separation of collated fibres have been achieved. Balling of steel fibres shall be avoided. At the same time, the concrete shall also be inspected to check the correct type of fibre is being used.

To quantify the fibre dosage and homogeneity in the fresh concrete, test shall be carried in accordance with EN 14721 [22] Method B. Each test is made up of three samples of at least 7 litres in volume, one in each third of the same load as follows:

- (i) at the beginning of the load (from the first third of the mix), after 0.5 m³ is unloaded;
- (ii) in the middle of the load (from the second third of the mix); and
- (iii) at the end of the load (from the last third of the mix), with 0.5 m³ minimum left in the truck.

All samples shall be taken directly out of the “concrete stream” at the end of the chute and not out of a wheelbarrow as it may give segregation.

This method has been adopted by AS 5100.5 and AS 3600 [2-4] and South Australian Water Corporation (SA Water) Technical Standard TS 710 – Concrete [23].

4.4 CONFIRMATION TESTING OF SFRC PERFORMANCE

Confirmation testing of the post-cracking flexural or tensile strength using the direct tensile test as per Australian Codes [2-4] or EN 14651 [5] three-point notched bending test are to obtain the first-hand information of the material properties of the concrete actually used. However, testing cannot be carried out on site and results can only be expected after 28 days, as the concrete has to be cured and gained strength. A 28 days waiting period represents a significant cost and delay to the construction program. Further, in Australia, only a limited NATA accredited laboratories that can perform the tests and it is sometimes not feasible to carry out the test. For this reason, project quality control plan can be developed as follows:

- (i) An initial or pre-construction post crack strength test is first be carried out; and
- (ii) Throughout the project, the confirmation testing of post crack strength may be replaced by testing of both first crack flexural strength and the fibre dosage. If first crack flexural strength is within 10 % of the initial type testing, and provided that the concrete mix design has not changed and fibre content is sufficient, the post-cracking strength can be assumed to be satisfactory as according to ÖVBB [24] and DafStb [10], the first crack strength and post-cracking strength are closely correlated if the same type of fibre is used in the same type of concrete.

5 SFRC FOR STRUCTURAL APPLICATIONS

A number of projects have been constructed in countries all over the world using SFRC for structural applications, some were used without conventional reinforcement while others used combined SFRC and conventional reinforcement.

5.1 RAIL BRIDGE LONGITUDINAL STITCH JOINT

SFRC is used in combination with conventional reinforcement for limiting the crack width in a rail line bridge U-trough beam system. Due to its size, all the U-trough beams were casted in 2 halves and transported and stitched together in-situ. Whilst the stitch joint section does not need to carry any load, the joint is located in the tension zone of the U-trough and subjects to 0.5% of longitudinal tensile strain in addition to thermal and shrinkage restraints. 40kg/m³ of Dramix® 4D together with 8 number of 15.2 mm nominal diameter unstressed prestressing strands top and bottom were used in the 800 mm x 400 mm longitudinal stitched joint to achieve a crack width of 0.2 mm.



Figure 8: Rail Bridge Longitudinal Stitch Joint with SFRC

5.2 DAM SPILLWAY CHANNEL

Located in South Australia, the Happy Valley Dam outfall channel is designed to have control joint-free and was constructed without any waterstop system (Figure 9). The channel is designed for 9 m/s of flow velocity and flow depths range from 0.35 m up to 2.1 m. The slab thickness was between 300 mm and 500 mm. It was optimised in keeping with desired pour lengths and drop structure locations to allow for the reduction in slab thickness to reduce cost and improve constructability. Due to the cut-offs, drop structures and the geometrical and shape (varying width) of the channel, the spillway channel chute was assumed to be fully restrained. Taking this restraint into account in the design through combining 35 kg/m³ of Dramix® 4D SFRC with one layer of N12 at 100 mm spacing custom-made steel mesh, enabled the construction of the floor without any joints for the entire 400 m length with a design nominal crack width of 0.20 mm. There were no limits on the time between adjacent slab pours or between the time that the floor had been poured and the walls being constructed. This solution was economically beneficial when compared to the conventional design which used 2 layers of N28-150 bars and the installation of expansion and control joints requiring dowels, waterstops and sealants.

5.3 HIGH BAY WAREHOUSE CLAD RACK FOUNDATION

A high bay warehouse clad rack building is a building consisting of a structural racking system.



Figure 9: SFRC Watertight Spillway Channel

The slab acts as the foundation for the walls, roof and the racks. Doing so, the slab foundation structure is not only carrying the stored goods but must also withstand external loads like wind load and earthquake load. The clad rack foundation for the IKEA High Bay Warehouse building in NSW, has a height of over 30m, requiring to carry 27 tonnes of post loads. Three important load cases are considered in the slab design:

- high wind load on the warehouse when the racks are empty;
- Seismic event when the racks are empty; and
- the racks are fully filled with goods.

The slab is 300 mm thick and the edges were thickened to 450 mm thick in order to resist the forces and moments transferred from the structural racking bracing towers at the edge. The entire slab area is in excess of 10000 m² and was designed as a monolithic slab, i.e. without any movement and control joints. To meet both serviceability crack control and ultimate limit state requirements the slab is reinforced with 35 kg/m³ of Dramix[®] 4D steel fibres, a top mesh consisting of 9 mm diameter bars at 125mm centres, both ways. At the

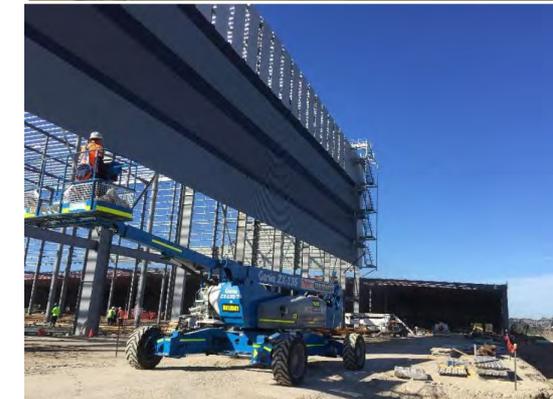


Figure 10: SFRC High-Bay Building Foundation

edge thickening section, a bottom mesh consisting of 9 mm diameter bars at 125mm centres, both ways was also placed.

5.4 SFRC SLAB FOR MODULAR CONSTRUCTION

ParkD, a company specialising in modular parking system, has developed an innovative lightweight concrete “modular” car parking system using Dramix[®] 5D SFRC suspended slab (Figure 11). The slab spans 1.2 m and is only 85 mm thick, designed to carry 0.5 kPa of superimposed dead load, 2.5 kPa of live load and a 13 kN live point load in every mid span.

5.5 STRUCTURAL TOPPING SLAB

In recent times, builders and contractors strive to improve construction efficiency and fasten the construction time frame. Precast form floors were used in a 6 storey apartment building construction Perth. To further reduce the construction time frame, 30 kg/m³ of Dramix[®] 4D SFRC were used



Figure 11: ParkD SFRC Modular Car Park Slab

to replace all conventional steel reinforcement for the in-situ topping slab (Figure 12). The design has been undertaken to ensure that the SFRC topping slab and the reinforcements in the precast form floor are sufficient to carry the sagging moments and for hogging moments, it relies fully on the SFRC. In localised areas where the hogging moment demand was higher than that of SFRC capacities, some conventional reinforcements were added locally. The SFRC also acts as crack control reinforcement, similar to that of SFRC used in the composite slab system [25].

5.6 WASTE TRANSFER STATION

35 kg/m³ of Dramix® SFRC and light conventional reinforcement, SL81, was used for the construction



Figure 12: SFRC Only Structural Topping Slab

of Veolia waste transfer station 12000 m² external apron slabs and hardstands and 2000 m² internal waste transfer processing slab (Figure 13). The entire external and internal slabs are joint free. The external hardstand is designed as 260 mm thick and is capable of withstanding loads from the 100t axle load Container forklift and containers. The internal waste transfer processing slab is designed to be watertight (crack width of 0.15 mm) and is constructed with high strength concrete, up to 90 MPa, in order to handle very aggressive domestic waste with low pH level. The conventional design would require control joints at regular interval with acid resistance liquid-stop. The combined SFRC and light reinforcement totally eliminate the needs for control joints and hence the expensive liquid-stop.

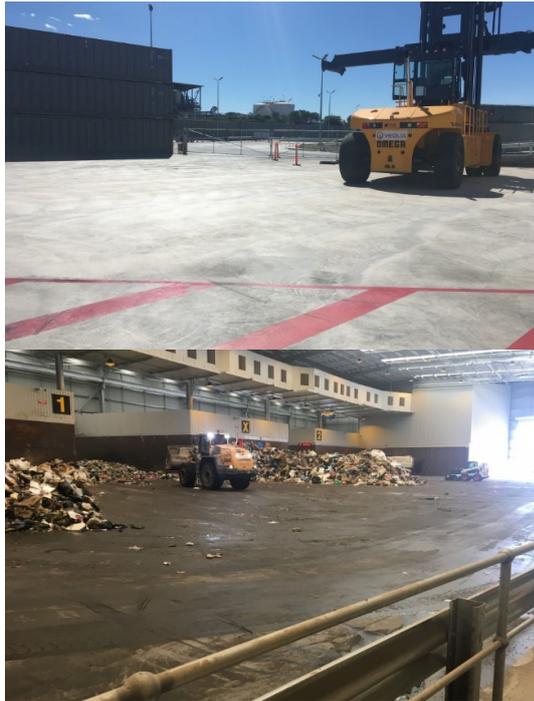


Figure 13: SFRC and conventional reinforcement for Veolia Major Waste Transfer Station, NSW

5.7 RAIL LOCOMOTIVE RAFT SLAB

The new Kiwi Rail Locomotive wash slab in Christchurch, New Zealand, was designed to be watertight without any joints and to resist the weight of the locomotive (Figure 14). The raft slab is generally 200 mm thick and needs to resist a design moment 45 kNm/m. Using 35kg/m³ of Dramix® 5D SFRC together with light conventional reinforcement, i.e. 16 mm diameter bars at 250 mm centres spacing, it provides a ultimate bending moment capacity of more than 65 kNm/m and the combined fibres and mesh was also used in the slab for achieving a nominal crack width of 0.2 mm. The solution results in lesser demand in conventional reinforcement, which made it easier and quicker to construct, and, therefore, more cost effective.

6 CONCLUSIONS

In June 2018, the new Australian Standard for Concrete Structures (AS 3600-2018) was released. This follows the release of the new Australian Standard Australian Standard for the design of Concrete bridges (AS5100.5-2017) in March 2017. These two Australian Standards are the first standard in Australia, and one of the few national standards in the world, to include design procedures for steel fibre reinforced concrete in a comprehensive way.

This paper provided some basic principles governing the structural design of SFRC based on the available design codes design rules, including

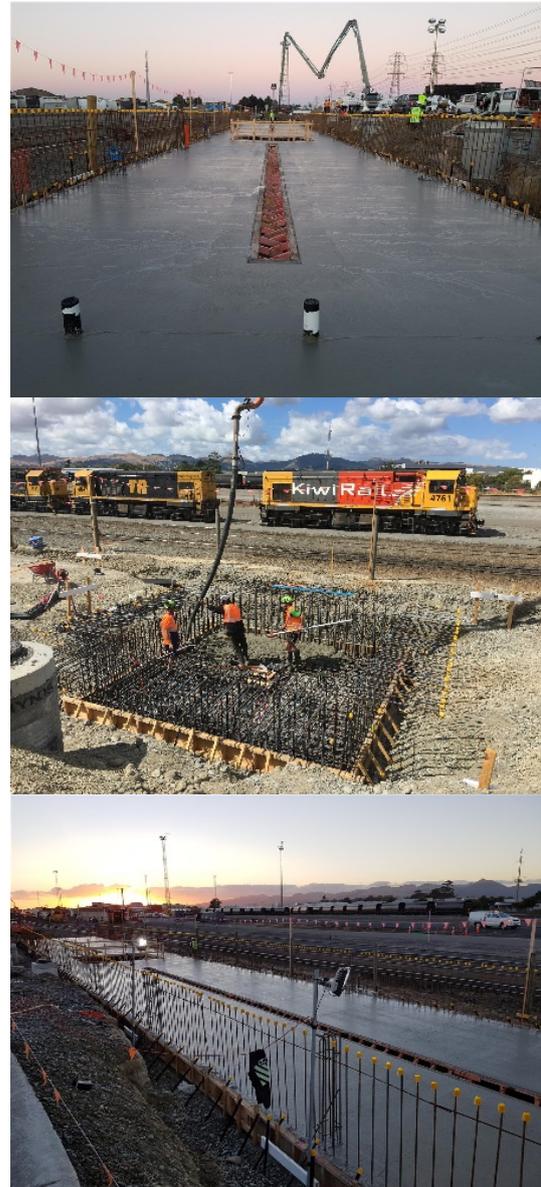


Figure 14: SFRC and conventional reinforcement for Kiwi Rail Locomotive Wash Raft Slab

the determination of the materials properties, design models for strength and serviceability and on quality control measures.

As designers, builders and owners look towards more economical, durable, robust and tough structures, SFRC will likely come to the force. Some examples of application of SFRC in Australia for structures are presented; giving insight information on where steel fibre only reinforcement and combined steel fibre and conventional reinforcement were used.

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