STEEL FIBRE REINFORCED HIGH STRENGTH CONCRETE SLAB ON GROUND

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Introduction

Concrete is a brittle material, and its low tensile strength means that cracks are easily formed and open rapidly, leading to a slab collapse, at relatively low magnitudes of applied load. An addition of fibres to concrete prevents the cracks from opening and thus improves ductility and toughness of concrete, which eliminates the need for traditional reinforcement.

Design guidelines do not consider high strength concrete reinforced with steel fibres, however, the shortcoming of high strength concrete is its brittleness and lack of toughness, which can be enhanced by adding fibres to it. In industry, high strength concrete is being used increasingly in various applications due to the beneficiary effects in the reduction in element dimensions, such as slab thickness in warehouses or on airport fields. The other reason for focusing on high strength concrete is the observation by some researchers that the composite material can fail due to de-bonding of fibres and concrete. This has led to a recommendation of having a strong matrix around the steel fibres, which will give a good bond and failure will happen only after fibres reach their ultimate tensile capacity.

STRUCTURAL ELEMENTS OF GROUND FLOORS

***Sub-grade**: this is naturally occurring soil or imported fill material that supports the sub-base and slab construction. Some evaluation of the capacity of this material to sustain the applied loading is essential.*

***Sub-base:** building this layer is optional, it depends on the:*

- ***Type of sub-grade, in case of a higher k value there will be no need for this layer of sub-base.***
- ***Degree of levelness required from the layer under the slabs.***

***Slip membrane:** This is used to reduce friction under the slab and to prevent loss of cement fines from wet concrete into the sub-base material.*

***Concrete slab:** This is the main structural concrete element forming the ground floor system. It may be either reinforced or unreinforced, depending upon site conditions and design requirements.*

MATERIALS

- ### Steel fibres

Fibres can be divided into two main groups, these with elastic modulus lower than the cement matrix, such as cellulose, nylon and polypropylene and those with higher modulus such as asbestos, glass, steel, carbon and Kevlar. Fibres may require mechanical bonding to avoid pull out unless the specific surface area is very large. Thus steel fibres are commonly produced with varying cross-sections or bent ends to provide anchorage. Fibre length divided by fibre diameter generally ranges from ٣٠ to ١٠٠. Steel fibre lengths range from ١٣ to ٧٦ mm. Short steel fibres facilitate mixing and uniform dispersion in freshly mixed concrete. The main factors controlling the theoretical performance of the composite material are the physical properties of the fibres. Fibre properties can be found in manufacturers' literature, such as Dramix (١٩٩٦).The elongation at break of fibres is two or three orders of magnitude greater than the strain at failure of the matrix and hence the matrix will crack long before the fibre strength is approached. This fact is the reason for the emphasis on postcracking performance in the theoretical treatment. Normally, carbon steel fibres are used in Portland cement-based SFRC. However, various fibres using corrosion-resistant alloys are available. Their use is dictated by cost and exposure conditions. Stainless steel fibres are used for most high-temperature applications. The yield strengths of commercially available steel fibres vary from ٣٤٥ to ١٧٢٥MPa (ACI ٥٤٤ (١٩٩٤)).

- **Superplasticizer**

Most proprietary admixtures that can be used with conventional concrete can also be used with steel fibre concrete, with the exception of calcium chloride which when used at correct dosages tends to induce surface corrosion of the fibres under certain environmental conditions. In a continuing long-term study, however, it does not appear to affect the structural performance of the concrete, neither does corrosion of internal fibre occur, Beckett and Humphreys (١٩٨٩).

super-plasticizing admixtures are added at between ٣٠٠ and ٢٠٠٠ ml per ٥٠ kg of cement; it has added to a normal ٥٠ mm concrete slump to produce a flowing concrete with a slump in excess of ٢٠٠mm, which can be placed without the need of vibration. It was concluded that if a normal dose of the agent is added to a semi fluid concrete (of slump equal to ٥٠ to ١٠٠ mm), the consistency of the concrete is altered to approximately ٢٠٠ mm. Concrete designated as fluid has a slump equal to ١٠٠ to ١٥٠mm. Using manufacturers' recommended dosage of normal water-reducing admixture, it is possible to reduce the water content of a concrete mixture by ٥ to ١٠% higher than recommended dosages can be used to obtain a larger water reduction.

HOW STEEL FIBRES WORK

The mechanisms are as follows:

- Steel fibres, being randomly distributed in the concrete, intercept micro-cracks as they form, inhibiting the tendency for them to form into larger cracks.
- After cracking, the fibres spanning the crack will provide a degree of residual load-carrying capacity. This capacity can be considerable, depending on the dosage and the type of fibre used, and can be used in plastic design approaches.

GROUND SLABS APPLICATIONS

Ground slabs find use in construction as industrial floors, pavements, railway slabs, foundations and many other applications, which each require somewhat different designs, but the basic principles are the same. Their behaviour is affected by the load and the properties of soil and concrete and they are normally reinforced with steel fabric, or with steel or synthetic fibres.

In the UK, the main guidelines for design and analysis of industrial ground slabs are provided in TR ٣٤ (٢٠٠٣). In this Concrete Society's technical report material properties for concrete, soil, steel and fibres are described. Different loading types and distributions were specified including point loads from racking legs or truck wheels and uniformly distributed loads (Fig ٢.١ shows a typical warehouse). TR ٣٤ compared the merits of the use of plain concrete, steel fabric and steel fibre reinforced concrete for industrial ground floors. The importance of serviceability issues were highlighted including flatness, levelness, absence of cracks on the top surface, abrasion resistance.

Fig. ٢.١ the racking in a warehouse (TR٣٤ (٢٠٠٣))

Pavement applications of ground slabs include industrial or factory pavements, highways, roads, parking areas, bridge decks, and airport runways. The design parameters are; traffic loading, soil and concrete properties. The required thickness is determined so that the tensile stress level is low enough that no fatigue cracking will occur for the designed number of stress repetitions (Frazier and Rice (١٩٧٧)).Concrete ground slabs are used on railway lines, where they absorb the impact from the fast moving trains.

High strength concrete

There is a rapid adoption of high strength concrete in bridges, pavements, industrial floors and other slab structures under heavy or moving loads. In these applications, large slab thickness is needed due to the high rate and amount of moving loads, which makes HSC the best choice Yan et al. (١٩٩٩). Mehta and Aitcin (١٩٩٠) described the microstructure of high strength concrete and guidelines for selection of materials, and of proportioning of HSC. High strength concrete mixtures are generally characterized by low W/C ratio, high cement content, and presence of several admixture types, such as water–reducing, set retarding, and mineral admixtures. Compressive and tensile strength of concrete is related to the porosity, where strength decreases with increasing pore size and increasing grain size.They listed the general guidance for the selection of materials to make HSC mixtures. According to them, increasing maximum size of aggregate leads to a lower w/c ratio and higher strength, but, increasing MSA has other adverse effects on strength, so that ١٢mm is probably the optimum MSA, which does not mean that ٢٠mm cannot be used.

SOIL (SUBGRADE)

Sub-grade is considered as rows of closely spaced but independent elastic springs. The modulus of sub-grade reaction, k, is equivalent to the spring constant and is thus a measure of the stiffness of the sub-grade. The modulus of sub-grade reaction relates soil pressure and deflection and is widely used in the structural analysis of foundation members. Plate bearing test is commonly used to specify this parameter. However, the load deflection graph for a general soil is a curve rather than a straight line. The question is then whether to use a tangent or a secant modulus and at which point of load deflection curve.a supplementary theory was also proposed for the case of the internal load only. The theory allows for a sub-grade that acts as a continuous body (and thus overcomes the lack of continuity of the Winkler sub-grade) by decreasing the deflections near the load.

The following four values for the modulus of sub-grade reaction (k) was given ; k = ٠.٠١٣ N/mm^{٣}, very poor ground, K= ٠.٠٢٧ N/mm^{٣}, poor ground, K=٠.٠٥٤ N/mm^{٣}, good ground, K= ٠.٠٨٢ N/mm^{٣}, very good ground (no sub-base needed).

Chandler (١٩٨٢) gave modulus of sub-grade reaction (k) for typical British soils.Experimental programs with slabs on the ground used different ground conditions. Chen (٢٠٠٥) tested slabs cast on a sub-base of a cork giving value of the modulus of sub-base reaction k, of ٠.٠٤٤-٠.٠٥٥ N/mm^{٣}. The modulus of sub-grade reaction, was determined and measured before each slab casting, the plate load test performed by exerting load up to ٢٠ kN on the cork sub-grade through a rigid plate ٧٠٧x٧٠٧mm, and ٣٠mm in thickness, and the k value was derived by dividing the unit pressure by the vertical displacement.

GROUND SLABS REINFORCED WITH STEEL FIBRES

A brief review of the ground slabs literature indicated that the addition of steel fibres has significant beneficial effects on slab's structural response. The SFRC slabs were thus chosen for an in-depth study.

Advantages and applications

Steel fibres have been used to substitute conventional reinforcement in ground slabs for the last few decades. Apart from the already mentioned TR٣٤, the use of steel fibres in ground slabs has been the subject of the Concrete Society's technical report TR٦٣ (٢٠٠٦). It was shown in tests (Beckett and Humphreys (١٩٨٩), Beckett (١٩٩٠) that steel fibres increase the load capacity of ground slabs and improve the post cracking performance (toughness), compared to plain concrete slabs.

Several works reported the reduction in slab thickness made possible with the addition of steel fibres to concrete. Schrader (١٩٨٥) used ٣٠kg/m^{٣} of fibres to achieve the reduction in slab thickness from ٢٠٠ to ١٨٠mm. Barros and Figueiras (١٩٩٨) reported that SFRC pavements can be ٣٠-٤٠% thinner compared to plain concrete ones.

Fibres suppress crack initiation and progression, thus eliminating the problem of shrinkage cracks and making possible of inventing fewer large joint in slabs of several thousand square metres. The use of fibres instead of conventional reinforcement speeds up and simplifies construction process, as there is no need for placement of mesh reinforcement.

During the service life warehouse floors and pavements are subjected to cyclic and impact loads requiring an adequate fatigue flexural strength and energy absorption capacity, both of which can be achieved with the addition of steel fibres to concrete.

There are numerous examples of SFRC being used for external paving, such as major roads and junctions in Australia, in Spain, SFRC has been used where the loading was very high or where there was a particular need to reduce the slab thickness Huang (١٩٩٣). Fibres have been used to improve the cracking performance of concrete pavements, reduce the required slab thickness and increase the allowable joint spacing, Salah et al. (٢٠٠٤).

In pavements, break-off and spalling of corners, edges, and joints usually results from excessive stresses, loss of support and curling. Curling stresses are the stresses caused by the temperature differential through the depth of pavement. Investigations on SFRC airfield pavements in the U.S.A., found that although break-off was found in many locations, its effect on performance was minimal because the pieces remained held together through fibres with the rest of the slab, Schrader (١٩٨٥). Longitudinal cracks occurring parallel to the centrelines of pavement slab are either due to loss of support or to the fatigue of concrete. SFRC can result in a reduction in the formation of fatigue related cracks, as the fatigue endurance of SFRC is better than that of plain concrete. Also even if cracks occur, they will be much narrower in SFRC.In New Zealand, shearing of surfacing and pavement layers causing scabbing and rutting have been an ongoing maintenance problem with the regular replacement of the asphalt pavement programmed to maintain serviceability. To overcome these issues, a ٤٠ m section of high curvature was designed and constructed in FRC in May ٢٠٠٦, Hart and Johnson (٢٠٠٦).

The use of fibre-reinforced overlays for rehabilitating both concrete and asphalt roads in the USA was popular, because of the speed of installation and the reduced thickness of material required. SFRC has proven good performance in slabs suspended on piles, or columns, where they fully substitute traditional reinforcement. The dosages here are higher, at about ١٠٠kg/m٣ (TR ٦٣, ٢٠٠٦).

PROBLEMS AND UNKNOWNS

While for plain concrete and conventionally reinforced slabs, the material properties and structural behaviour are well known and set forth in standards, there is still lack of design rules for SFRC structures in building codes. For example, ACI Committee ٣٦٠ (٢٠١٠) recognized the potential benefits of fibres in concrete slabs on ground but did not provide specific design rules for this material. TR ٦٣ (٢٠٠٦) gave the industry guidance to this type of reinforcement, its design and application. However, although steel fibre reinforced concrete is used widely in the UK and elsewhere, clear information is still lacking about its nature, use and properties. The design methods for conventional reinforcement are not suitable because of a very different behaviour of fibre reinforcement, with pullout rather than yielding failure. Moreover, elastic analysis is not appropriate because SFRC behaviour is markedly non-linear.

Material stress-strain curve for SFRC is difficult to predict as it depends on fibre type, content, distribution, concrete bond strength etc. Material behaviour is nonlinear, with different stiffness's in different regions. In slabs on the ground, the interaction of soil and slab adds to complexity, even if it is assumed that soil response to load is linear.

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