

**EFFECT OF FOUNDRY SAND AND STEEL FIBRES ON THE STRENGTH  
CHARACTERISTICS OF PAVEMENT QUALITY CONCRETE**

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## DECLARATION

I, Ankit Kumar Abrol, hereby declare that this thesis entitled "**Effect of Foundry Sand and Steel Fibres on the Strength Characteristics of Pavement Quality Concrete**" is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering in Civil Infrastructure Engineering** in the Civil Engineering Department, Thapar University, Patiala under the supervision of **Dr. Maneek Kumar, Professor and Mr. Tanuj Chopra, Assistant Professor**, Department of Civil Engineering, Thapar University, Patiala during July 2012 to July 2014 . This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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## CERTIFICATE


This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

  
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## **ABSTRACT**

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The world's second largest road network of almost 3.5 million Km consisting of both paved and unpaved surfaces is in India. Roads in India are presently constructed not with the right choice of material. Bitumen and concrete are the two major types of materials used in road construction in the country. Construction of concrete roads in the country is of very small share. There is growing interest in the construction of concrete pavements, due to its high strength, durability, better serviceability and overall economy in the long run.

The thrust nowadays is to produce thinner and green pavement sections of better quality, which can carry the heavy loads. The high strength steel fibre reinforced concrete is a concrete having compressive strength greater than 40MPa, made of hydraulic cements and containing fine and coarse aggregates; and discontinuous, unconnected, randomly distributed steel fibres.

The present study aims at, developing pavement quality concrete mixtures incorporating waste foundry sand as partial replacement of fine aggregate as well as steel fibres. The aim is to design of slab thickness of PQC pavement using the achieved flexure strength of the concrete mixtures for different percentage of steel fibres and replacement of fine aggregates with waste foundry sand are reported. It is found out the maximum increase in flexure strength and compressive strength is for 30% waste foundry sand and 1% Steel fibre.

Due to this increase in the flexural strength it is possible to achieve a savings in cost of Pavement Quality Concrete construction. In this study it has been observed that with 30% replacement of fine aggregates with foundry sand and addition of 1% steel fibres, the maximum saving of 21.14% in cost per kilometre has been achieved for the 8.5m wide PQC carriageway by calculating the thickness required for the PQC slab as per IRC: 58-2002.

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**CHAPTER-1**  
**INTRODUCTION**

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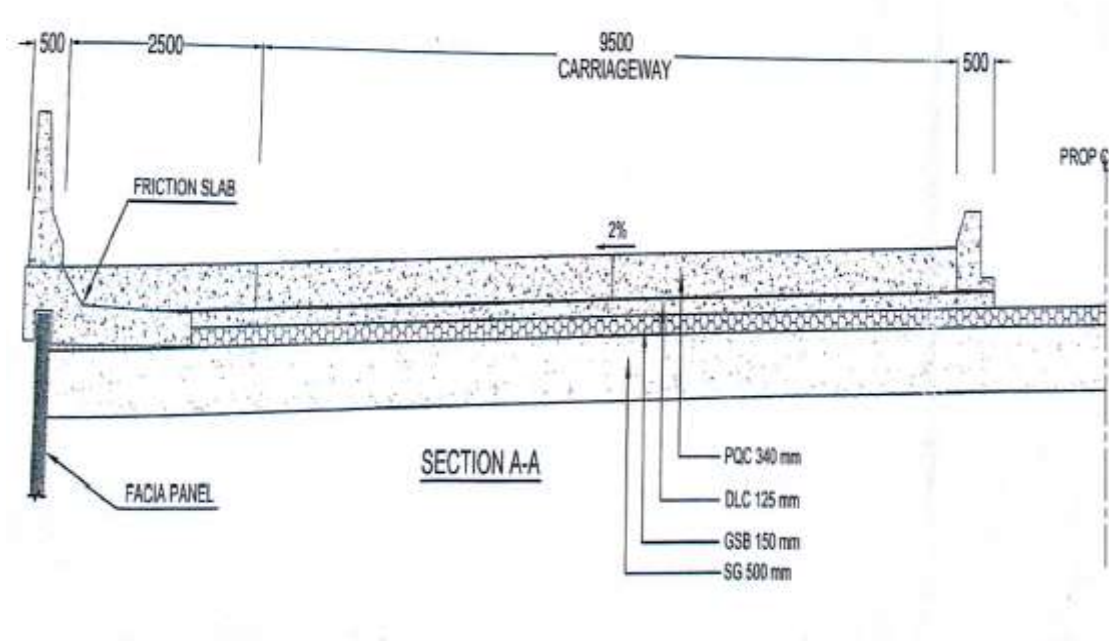
**1.1 RIGID PAVEMENT**

Rigid pavement is the technical term for any road surface made of concrete. Concrete roads are called rigid while asphalt-covered roads are flexible. These terms refer to the amount of deformation created in the road surface itself when in use or over time. The largest advantages of using concrete pavement are in its durability and ability to hold a shape.

The basic design of rigid pavement is very simple. A surface layer, made up of slabs of Portland cement concrete (PCC), sits on top of a handful of sub-layers. The layer directly under the PCC is more flexible than the concrete, but still quite rigid. This layer provides a stable base for the PCC as well as assists in drainage. Some roads have a second sub-layer under the first that is even more flexible, while some roads simply have the existing material.

**1.2 COMPONENTS OF CEMENT CONCRETE PAVEMENT**

A typical cross-section showing various components of cement concrete pavement is shown in figure 1.1.



**Fig. 1.1 Typical Rigid Pavement Section**

### **1.2.1 Sub-grade**

Sub grade is not formally a pavement layer. In order to design and construct a satisfactory pavement over it, its properties and function must be fully understood. Sub grade is the natural soil or made-up ground on which the pavement is built. The load of the whole pavement finally comes on the sub-grade.

The sub grade and sub base for lying of paving concrete slab shall comply with the following requirements: (IRC: 15-1991)

- a) No soft spots are present in the sub grade or sub base.
- b) The uniformly compacted sub grade or sub base extends at least 300 mm on either of width to be connected.
- c) It should be properly drained.
- d) The maximum modulus of sub grade reaction obtained with a plate bearing test shall be 5.5 kg/cm<sup>3</sup>.

### **1.2.2 Drainage Layer**

A geo-composite drainage layer is provided over a sub grade for improved pavement drainage. The geo-composite has advantage over natural drainage in maintaining its flow capacity and compressive stiffness under the construction and services besides unequal support. It is a sand/ graded gravel layer.

### **1.2.3 Sub-base Course/ Dry Lean Concrete (DLC)**

It is an important part of modern rigid pavement. It is a plain concrete with a large ratio of aggregate to cement than conventional concrete and generally used as a base/ sub base of rigid pavement (Central road research institute, 2010)

### **1.2.4 Pavement Quality Concrete (PQC)**

The IRC specifications of materials used for Pavement Quality Concrete (PQC) are discussed as below (MORTH section 600).

#### **a) Cement**

As per technical specifications- M.O.R.T&H Cl. 601.2.1, Ordinary Portland Cement of 43 grade conforming to IS: 8112 shall be used.

- i) Fly ash up to 20 percent by weight of cement may be used in ordinary Portland cement 53 Grade. No fly ash shall be used in any other grade of Cement other than 53 Grade. The fly ash shall conform to IS: 3812 (Part I).
- ii) Ground Granulated Blast Furnace Slag (GGBFS) obtained by grinding granulated slag conforming to IS: 12089. GGBFS shall not be used in any other grade of cement except 53 grade. The content of GGBFS shall be up to 50 percent by weight of Ordinary Portland Cement 53 grade.
- iii) Mix design will be done as per IRC: 44. The OPC content shall not be less than 310 kg/m<sup>3</sup> in case of blending at site. The curing period may be suitably enhanced by at least about 2 days.

**b) Coarse aggregates**

The maximum size of coarse aggregate shall not exceed 31.5 mm for pavement concrete. No aggregate which has water absorption more than 2 percent shall be used in the concrete mix. The aggregates shall be tested for soundness in accordance with IS: 2386 (Part-5). After 5 cycles of testing, the loss shall not be more than 12 percent if sodium sulphate solution is used or 18 percent if magnesium sulphate solution is used. The combined flakiness and elongation index of aggregate shall not be more than 35 percent.

**c) Fine aggregates**

The fine aggregates shall consist of clean natural sand or crushed stone sand or a combination of the two and shall conform to IS: 383.

**d) Cement content**

When Ordinary Portland Cement (OPC) is used the quantity of cement shall not be less than 360 kg/cu.m. In case fly ash grade I (as per IS:3812) is blended at site as part replacement of cement, the quantity of fly ash shall be up to 20 percent by weight of cement and the quantity of OPC in such a blend shall not be less than 310 kg/cu.m. The minimum of OPC content in case ground granulated portland blast furnace is used, shall also not be less than 310 kg/m<sup>3</sup>.

**e) Concrete strength**

The characteristic flexural strength of concrete shall not be less than 4.5 MPa (M 40 Grade).

#### **f) Separation Membrane**

Separation membrane shall be impermeable plastic sheeting of 125 micron thick laid flat without creases. Before placing the separation membrane, the DLC surface shall be swept clean of all the extraneous materials. Overlap of membrane if any shall be at least 300 mm and any damaged sheet shall be replaced immediately.



**Fig. 1.2 Laying of separation membrane**

#### **g) Joints**

Initial saw cut of 3mm wide, 100mm depth in transverse and longitudinal direction will be provided after initial set (approximately 6-8 hrs). Final saw cutting 10-12 mm wide, 20-25 mm depth will be provided after 14 days of curing at accommodated joint sealant. The staggering of transverse joint with reference to the base will be minimum 0.3 m.

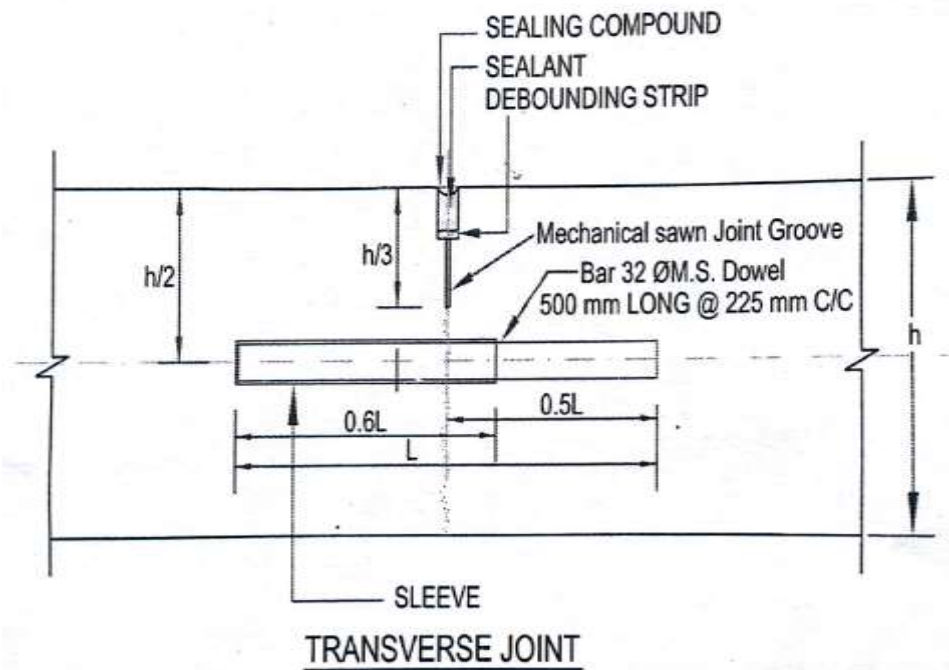
Contraction joints will be provided at every 4.5 m interval except where expansion joints are provided. Transverse construction joint shall be placed when concreting is done after a day's work. It will be provided at regular location of contraction joints using dowel bars.



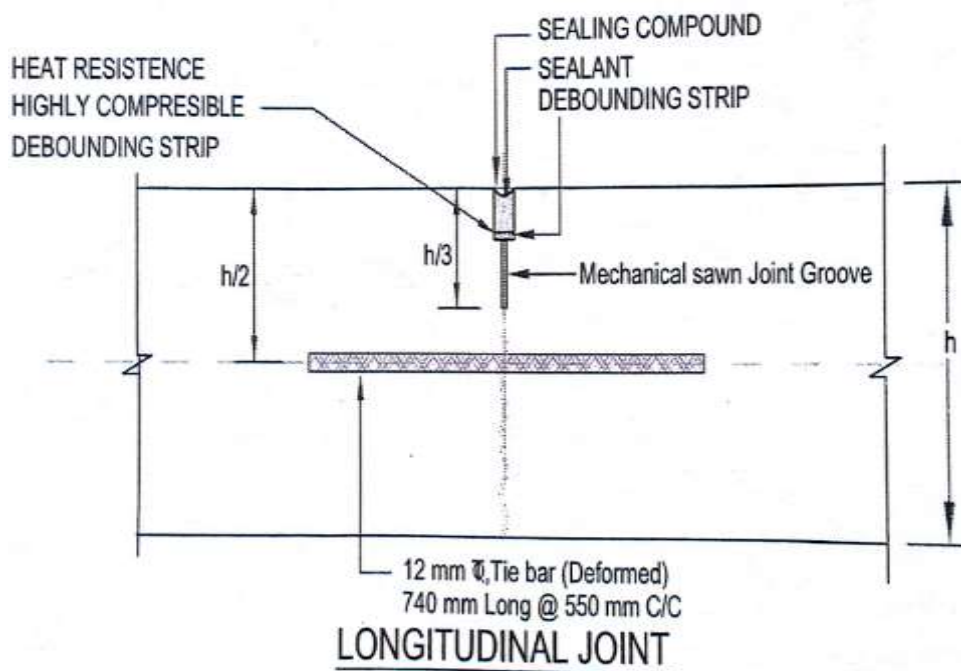
**Fig. 1.3 Longitudinal joint in Pavement Quality Concrete (PQC)**



**Fig. 1.4 Saw Cut in transverse direction**



**Fig. 1.5 Section of Transverse joint in Pavement Quality Concrete (PQC)**



**Fig. 1.6 Section of Longitudinal joint in Pavement Quality Concrete (PQC)**

### **h) Dowel Bars**

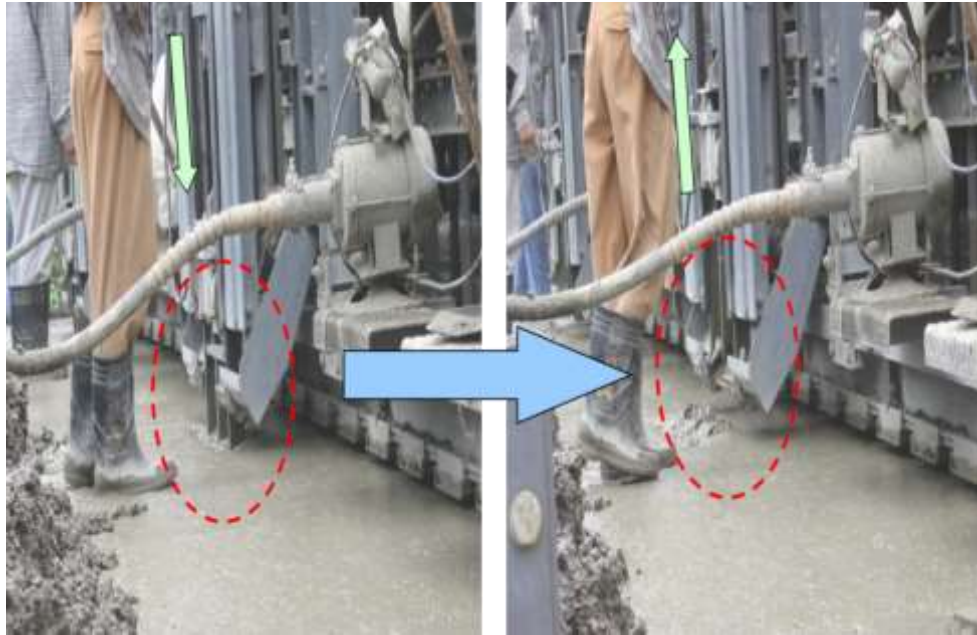
Dowel bars shall conform to the requirements of IS:432, IS:1139 and IS:1786. The dowel bars shall conform to Grade S 240 and tie bars to Grade S 415 of IS. It should be mild steel round, free from dirt, loose rust, scale straight and burring restricted slippage in the concrete. Dowel bars will be positioned at the mid depth of the slab with in a tolerance of +/- 20 mm. Dowel bars shall be covered by a thin plastic sheet for at least 2/3 of length from one end for dowel bars in contraction joint or half the length plus 50 mm for expansion joints. The sheet shall be tough, durable and of an average thickness not less than 1.23 mm. For expansion joints, a closely fitting cap 100 mm long cotton waste placed over sheet end of each dowel bar.



**Fig. 1.7 Dowel bars in Pavement Quality Concrete (PQC)**

### **i) Tie Bars**

Tie bars should be free from oil, dirt, loose rust and scale. In longitudinal joints shall be deformed steel bars of strength 415 MPa complying with IS: 1786. It should protect from corrosion for 75 mm on each side of the joint by applying bituminous paint. The coating shall be dry when Tie bars are used. It should be perpendicular to the line of joint, with the centre of each bar on the intended line of the joint within a tolerance of +/- 50 mm and with a minimum cover of 30 mm below joint groove.



**Fig. 1.8 Tie bars in Pavement Quality Concrete (PQC)**

**j) Surface Tolerance**

Surface tolerance shall be within the limits of  $+5/-6$  mm tolerance limit as per M.O.R.T.H Clause 902.3, surface levels shall be checked on a grid of points spaced at 6.25 m along the length and 3.5 m transversely between 0.5 m from the edges and at the centre of the pavement.



**Fig. 1.9 Laying of Pavement Quality Concrete (PQC) with Slip Form Paver**



**Fig. 1.10 Placing of Dowel bars manually and Laying of Pavement Quality Concrete with paver.**

### **1.3 WASTE FOUNDRY SAND**

A foundry produces metal castings by pouring molten metal into a performed mould to yield the resulting hardened cast. The metal casts include iron and steel from the ferrous family and aluminium, copper, brass and bronze from non-ferrous family. Foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a moulding material because of its thermal conductivity. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as foundry sand. The physical and chemical characteristics of foundry sand depend on the type of casting process and the industry sector from which it originates. In modern foundry practice, sand is typically recycled and reused through many production cycles. For example, in United States alone, Industry estimates that approximately 100 million tons of sand is used in production and approximately 6-10 million tons is discarded annually and is available to be recycled into other products and in industry. The automotive industries and its parts are the major

generators of foundry sand. Foundries purchase high quality size-specific silica sands for use in their moulding and casting operations. The raw sand is normally of a higher quality than the typical bank-run or natural sand used in fill construction sites. These sands normally rely upon a small amount of bentonite clay to act as the binder material. Chemical binders are also used to create sand “cores”. Depending upon the geometry of the casting, sands cores are inserted into the mould cavity to form internal passages for the molten metal. Once the metal has solidified, the casting is separated from the moulding and core sands in the shakeout process. In the casting process, moulding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. At that point, the old sand is displaced from the cycle as by-products, new sand is introduced, and the cycle begins again.

#### **1.4 TYPES OF FOUNDRY SANDS**

Classification of foundry sands depends upon the type of binder systems used in metal casting. Generally two types of binder systems are used and based on that foundry sands are classified as: clay-bonded systems (green sand) and chemically bonded systems. Both types of sands are suitable for beneficial use but they have different physical and environmental characteristics.

##### **1.4.1 Green sand**

Generally, green sand moulds are used to produce about 90% of casting volume. Green sand is composed of naturally occurring materials which are blended together; high quality silica sand (85-95%), bentonite clay (4-10%) as a binder, a carbonaceous additive (2-10%) to improve the casting surface finish and water (2-5%). Green sand is the most commonly used recycled foundry sand for beneficial reuse. It is black in colour due to carbon content.

##### **1.4.2 Chemically-bonded sand**

Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mould making. Most chemical binder systems consist of an organic binder that is activated by a catalyst although some systems use inorganic binders. Chemically bonded sands

are generally light in colour and in texture than clay bonded sands. Foundries produce recycled foundry sand (RFS) generally in their overall production volume although there are different sand to metal ratios employed in different casting processes and products. Most foundries have two sand systems one feeding the external moulding lines and the other feeding the internal core lines. After the metal is poured and the part is cooling, green sand is literally shaken off the casting, recovered and reconditioned for continual reuse. Used cores are also captured during this cooling and shake out process; these break down and are crushed and reintroduced into green sand system to replace a portion of sand lost in process. Depending on the projected end use, it may be important to segregate sand streams at the foundry as each stream can have different characteristics. Additionally, some sand is typically unrecoverable during shake off and finishing processes. These sands may be contaminated with metals or very large chunks of burnt cores and will need to undergo some type of segregation, crushing and screening before recycling.

## **1.5 PROPERTIES OF FOUNDRY SAND**

### **1.5.1 Physical characteristics**

Foundry sand is typically sun-angular to round in shape. After being used in the foundry process, a significant portion of sand is of agglomeration form. When these are broken down, the shape of individual sand grains is apparent. Green sands are typically black, or grey, not green and chemically bonded sand is typically a medium tan or off-white colour. The typical physical properties of spent foundry sand is uniform, with 85-95% of the material between 0.6mm and 0.15mm; 5-12% of foundry sand can be expected to be smaller than 0.075mm. Waste foundries sand gradations have been found to be too fine to satisfy some specifications for fine aggregate. Spent foundry sand has low absorption capacity and is non-plastic. The content of organic impurities (particularly from sea coal binder systems) can vary widely. The specific gravity of foundry sand varies between 2.39 and 2.55. The variation in specific gravity values could be due to the variability in fines and additive contents in different samples. In general, foundry sands are dry, with moisture contents less than 2%. A large fraction of clay lumps and friable particles are found, which are attributed to the lumps

associated with the moulded sand, which are easily disintegrated in the test procedure.

Its durability and soundness, chemical composition, and variability can quantify the quality of foundry sand. Various aspects of foundry sand production influence these three characteristics. Durability/soundness of foundry sand is important to ensure the long-term performance of civil engineering applications. Durability of the foundry sand depends on how the sand was used in the foundry. Physical properties of waste foundry as reported by Naik et al. (2001), Guney et al. (2010) and Siddique et al. (2011), are given in Table1.1.

**Table1.1 Physical Properties of waste foundry sand reported by various scientists**

<b>Property</b>	<b>Naik et al. (2001)</b>	<b>Guney et al. (2010)</b>	<b>Siddique et al. (2011)</b>
Specific Gravity	2.79	2.45	2.61
Fineness Modulus	2.32	-	1.78
Unit Weight (Kg/m <sup>3</sup> )	1784	-	1638
Absorption (%)	5.0	-	1.3
Moisture Content (%)	-	3.25	-
Clay Lumps and friable particles	0.4	-	0.9
Material finer than 0.075mm (%)	1.08	24	18

### **1.5.2 Chemical composition**

Chemical composition of the foundry sand relates directly to the metal moulded at the foundry. Chemical composition of the foundry sand depends on the type of metal moulded at the foundry, type of binder and combustible used. Generally, there is some variation in the chemical composition of the foundry sand and it varies from foundry to foundry. Sand produced by a single foundry, generally does not show significant variation over time. Moreover, blended sands produced by consortia of foundries often produce consistent sands. The chemical composition of the foundry sand may influence its performance. Spent foundry sand consists primarily of silica sand, coated with a thin film of burnt carbon,

residual binder (bentonite, sea coal, resins) and dust. Table 1.2 lists the chemical composition of a typical sample of spent foundry sand as determined by x-ray fluorescence. Silica sand is hydrophilic and consequently attracts water to its surface. This property could possibly lead to moisture-accelerated damage and associated stripping problems in an asphalt pavement. Anti-stripping additives may require counteracting such problems. Depending on the binder and the type of metal cast, the pH of spent foundry sand can vary between 4 and 8.

**Table 1.2 Chemical composition of foundry sand**

CONSTITUENT	VALUES (%)		
	Guney et al. (2010)	Etxeberria et al. (2010)	Siddique et al. (2011)
SiO <sub>2</sub>	98	95.10	78.81
Al <sub>2</sub> O <sub>3</sub>	0.8	1.47	6.32
Fe <sub>2</sub> O <sub>3</sub>	0.25	0.49	4.83
CaO	0.035	0.19	1.88
MgO	0.023	0.19	1.95
SO <sub>3</sub>	0.01	0.03	0.05
Na <sub>2</sub> O	0.04	0.26	0.10
K <sub>2</sub> O	0.04	0.68	-
TiO <sub>2</sub>	-	0.04	-
Mn <sub>2</sub> O <sub>3</sub>	-	-	-
SrO	-	-	-
LOI	-	1.32	2.15

## 1.6 STEEL FIBRES

In early 1990s Steel fibres have been used in concrete. Earlier the fibres were round and smooth and the wire was cut or chopped to required lengths. The use of straight, smooth fibre has largely disappeared and modern fibres have either rough surfaces, hooked ends or are crimped or undulated through their length. Modern commercially available steel fibres are manufactured from drawn steel wire, from slit sheet steel or by the melt-extraction process which produces fibres that have a crescent-shaped cross section. Steel fibres have been successfully used for pavement applications in many hundreds and thousands of square meters of concrete for roads and highways. Steel fibre Reinforced Concrete (SFRC) has extra strength in flexure and impact as compared to plain recycled concrete. Steel fibres distributed in the concrete delay the growth of

cracks thus improving the ductility of the matrix. The ability of steel fibres in improving the properties of concrete depends on the bond characteristics, aspect ratio of the fibre, surface friction and tensile strength of the fibre. Common applications of SFRC include paving applications such as in airports, highways, bridge decks and industrial floors, which endure significant cyclic loading during their service life. All these properties are the requirements needed for recycled concrete pavement for highways, bridge deck and runway or taxiway to maintain high quality and smooth riding surface without irregular depressions. The fatigue performance of SFRC is one of the important parameters to be considered in the design.

Fatigue is a process of progressive and permanent material damage under repeated loading. Fatigue failure takes place under the influence of repetitive or cyclic load, whose peak values are considerably smaller than safe loads estimated on the basis of static load tests. In concrete, these changes are mainly associated with the progressive growth of internal micro cracks, which result in a significant increase of irrecoverable strain. At the macro-level, this will manifest itself as changes in the material's mechanical properties.

Fatigue loading is usually divided into two categories i.e. low-cycle and high-cycle loading. Low-cycle loading involves the application of a few load cycles at high stress levels. On the other hand, high cyclic loading is characterized by a large number of cycles at lower stress levels.

## **1.7 STEEL FIBRE REINFORCED CONCRETE**

### **1.7.1 Definition**

Fibre reinforced concrete represented by combination of four different phases, like cement, water, coarse aggregate, fine aggregate and a dispersion of discontinuous, steel fibre. It can also contain admixtures and pozzolans which are commonly used with the conservative concrete. All admixtures under the ASTM specifications for use in concrete are desirable for use in Steel Fibre Reinforced Concrete (SFRC).

### 1.7.2 Fibre Content

Various amount of fibre is added in concrete which is generally measured as a fraction of total volume of mortar. Practically four ranges of Volume fractions ( $V_f$ ) can be identified as shown in Table 1.1

### 1.7.3 Types of Fibres

Fibre is manufactured from various materials in various shapes and sizes. The numerical parameter representing a fibre is its aspect ratio i.e.  $l/d$  ratio which means fibre length divided by diameter. Typical aspect ratio is used which have ranges from 30-150 for length dimensions of 1.0 to 76.2 mm. Various properties of commonly used steel fibres as shown in Table 1.2.

**Table 1.3 Typical Practical Ranges of Fibre Reinforcement of Concrete**

Approx. Vol. Fraction of Fibre	Matrix	Example
$V_f < 0.5\%$	Concrete	PP in pipe caps
$0.5 < V_f < 3\%$	Concrete (smaller size agg.)	Pavements, Joints
$3 < V_f < 8\%$	Mortar	Cement sheets, repairs
$8 < V_f < 20\%$	Paste, Slurry	Asbestos cement sheets, slurry

### 1.7.4 Properties of Fibre Reinforced Concrete

The properties of fibre reinforced concrete is regulate by fibre-matrix bond characteristics, volume fraction, material properties of fibres, type, geometry and matrix proportion in fresh as well as in hardened state. Steel fibres are uniformly distributed throughout the concrete mix as comparison to rebar or welded wire reinforcement, both which are specially located in a single plane. The foremost motive of the use of steel fibre is to modify micro and macro cracking. Steel fibres control the growing of cracks at their initial stages.

**Table 1.4: Physical and Mechanical Properties of Fibres**

<b>Fibre</b>	<b>Diameter (µm)</b>	<b>Specific Gravity</b>	<b>Young's Modulus (KN/mm<sup>2</sup>)</b>	<b>Tensile Strength (KN/mm<sup>2</sup>)</b>	<b>Elongation at break (%)</b>
Asbestos	0.02-20	2.55	165	3-3.5	2-3
Glass	9-15	2.60	70-80	2-4	2-3.5
Steel	5-500	7.84	200	1-3	3-4
Polypropylene	20-200	0.91	6-7	0.5-0.7	20
Rayon	20-200	1.5	7-8	0.4-0.6	10-25
Polyethylene	20-200	0.95	0.14-0.42	0.7	10
Cotton	-	1.5	5	0.42-0.70	3-10

## **1.8 APPLICATION OF FIBRE REINFORCED CONCRETE**

Steel fibre reinforced concrete (SFRC) is concrete containing dispersed steel fibres. The most important regulation of steel fibres in concrete is to control and retard the tensile cracking of the composite material. The steel fibre reinforced concrete improves the strength characteristics like flexural strength, split tensile strength, strain capacity, flexural toughness, compressive strength and crack arrest properties which lead to use in highway and airfield pavements, overlays and bridge deck slabs. Some of the practical applications of steel fibre reinforced concrete include usage in thin shells and walls, concrete pipes, highway pavements, partially pre-stressed composite concrete beams, airport runways, high velocity passages, blast resistance structures, water retaining structures, marine structures etc.

## **1.9 OBJECTIVES OF THE PROPOSED PROJECT**

The main objective of the proposed work is to study the effect of steel fibres on strength characteristics of Pavement Quality Concrete. Additionally, the effect of partial replacement of sand by waste foundry sand had also been proposed to be studied.

The relevant literature pertaining to the use of foundry sand, steel fibre in concrete carried out in India and abroad has been reviewed and presented as follows:

#### 2.1 FOUNDRY SAND

Foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a moulding material because of its thermal conductivity. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as foundry sand. Green sand is the most commonly used recycled foundry sand for beneficial reuse. It is black in colour due to carbon content. Different percentages of foundry sand are replaced with fine aggregates which are discussed as follows:

*Naik et al. (2003)*, studied the utilization of class F fly ash, coal-combustion bottom ash, and used foundry sand for the manufacture of bricks, blocks and paving stones. They replaced sand with either bottom ash or used foundry sand by 25% and 35%. Replacement rates, by mass, for Portland cement with fly ash were 25% and 35% for bricks and blocks, and 15% and 25% for paving stones. The result showed that partial replacement of cement with fly ash consistently improved the strength and durability of concrete masonry unit and up to 25% of sand in blocks could be replaced with either bottom ash (BA) or used foundry sand (UFS) in cold regions, and up to 35% of sand in bricks and blocks could be replaced with either BA or UFS for use where frost action is not concern.

*Bakis et al. (2006)*, investigated the use of waste foundry sand (WFS) in asphalt concrete. Asphalt concrete mixtures were prepared with 0%, 4%, 7%, 10%, 14%, 17% and 20% replacement of fine aggregate with WFS. Grain size of waste foundry sand ranged between 0.8 and 30 mm. The results showed that replacement of 10% aggregates with waste foundry sand was found to be more

suitable for asphalt concrete mixtures and waste foundry sand did not significantly affect the environment around the deposition.

*Koyuncu et al. (2006)*, undertaken a laboratory study regarding the reuse of waste foundry sand (WFS) in asphalt concrete production by replacing a certain proportion of aggregate with waste foundry sand. The replacement of 10% aggregates with waste foundry sand was found to be most suitable for asphalt concrete mixture. Also the physical and chemical properties of waste foundry sand were analysed in the laboratory to determine the potential effect on environment and the result indicated that the investigated waste foundry sand did not significantly affect the environment around the deposition area.

*Siddique et al. (2008)*, presented the results of an experimental investigation carried out to evaluate the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used foundry sand (UFS). Fine aggregate was replaced with three percentages (10%, 20% and 30%) of UFS by weight. Tests were performed for the properties of fresh concrete.

Compressive strength, Splitting-tensile strength, flexure strength and modulus of elasticity were determined at 28, 56, 91 and 365 days. Test results indicated a marginal increase in the strength properties of plain concrete by the inclusion of UFS as partial replacement of fine aggregate (sand) and that can be effectively used in making good quality concrete and construction material.

*Guney et al. (2010)*, investigated the potential re-use of waste foundry sand in high strength concrete production. The natural fine sand is replaced with waste foundry sand (0%, 5%, 10% and 15%). The findings from a series of test program has shown reduction in compressive and tensile strengths, and the elasticity modulus which is directly related to waste foundry inclusion of concrete. Nevertheless, the concrete with 10% waste foundry sand exhibits almost similar results to that of control one. The slump and the workability of the fresh concrete, decreases with the increase of the waste foundry sand ratio.

*Siddique et al. (2011)*, carried out an experimental investigation to evaluate the strength and durability properties of concrete mixtures, in which natural sand was partially replaced with waste foundry sand. Natural sand was replaced with

five percentages (0%, 5%, 10%, 15% and 20%) of waste foundry sand by weight. Compressive strength and splitting tensile strength test were carried out to evaluate the strength properties of concrete at the age of 7, 28 and 91 days. Test result indicate a marginal increase in strength properties of plain concrete by inclusion of waste foundry sand as a partial replacement of fine aggregate.

*Siddique et al. (2011)*, presents the design of concrete mixes with used foundry sand (UFS) as partial replacement of fine aggregate. Various mechanical properties are evaluated (compressive strength and splitting tensile strength). Test results indicate that industrial by-products can produce concrete with sufficient strength and durability to replace normal concrete. Compressive strength and split-tensile strength was determined at 28, 90 and 365 days along with carbonation and rapid chloride penetration resistance at 90 and 365 days. The replacement of fine aggregate with foundry sand was found to be optimum at 30% and should not exceed 50%. The rate of gain was closer to that of control mix at 90 days and at 365 days the rate of gain for all the mixes with foundry sand was higher than the CM mix. The compressive strength of cubes and cylinders, and split-tensile strengths were observed to increase with age.

*Wahab et al. (2013)*, investigated the effect of foundry sand as fine aggregate replacement on the compressive strength, split tensile strength and flexure strength having mix proportion of M30 was investigated. Fine aggregates were replaced with eleven percentages of foundry sand. The percentages of replacements were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 % by weight of fine aggregate. Tests were performed for compressive strength, split tensile strength and flexure strength tests for all replacement levels of foundry sand at different curing period (7-days, 28-days and 56-days). Maximum compressive strength and flexure strength was achieved with 50% replacement of fine aggregate with waste foundry sand at 28 days compared to normal concrete.

## **2.2 STEEL FIBRE REINFORCED CONCRETE**

Steel fibre reinforced concrete (SFRC) is concrete dispersed steel fibres. The most important regulation of steel fibre in concrete is to control and retard the tensile cracking of the composite material. The steel fibre reinforced concrete

improves the strength characteristics like flexural strength, flexural toughness, strain capacity, split tensile strength, compressive strength and crack arrest properties which lead to use in highway and airfield pavements, overlays and bridge deck slabs.

*Wang, et al. (1996)*, investigated the fibre reinforced concrete beams under impact loading. Impact tests were carried out on small concrete beams reinforced with different volumes of both polypropylene and steel fibres. The drop height of the instrumented drop weight impact machine was so chosen that some specimens failed completely under a single drop of the hammer, while others required two blows to bring about complete failure. It was found that, at volume fractions less than 0.5%, polypropylene fibres gave only a modest increase in fracture energy. Steel fibres could bring about much greater increase in fracture energy was also modest; above 0.75% fibre pull-out was the primary mechanism with a large increase in fracture energy.

*Furlan and Bento (1997)*, analyzed the influence of fibre on the structural performance in situations of different ratios of shear reinforcement, some aspects of the properties of fresh and hardened concrete are introduced. The main alterations resulting from the use of fibres were increased shear strength, stiffness (particularly after cracking stage) and ductility. Other parameters used in analyzing performance were the properties of the hardened concrete (compressive strength, tensile strength, and modulus of elasticity), and stresses in the stirrups, in the longitudinal reinforcement and in the concrete (at the web and compression zone).

*Chunxiang and Patnaikuni (1998)*, studied on the properties of high-strength steel fibre-reinforced concrete beams in bending. They investigated that the flexural rigidity before yield stage and the displacement at 80% ultimate load in the descending curve are improved and crack number and length at comparable loads is reduced after the addition of steel fibres. The descending part of the load-displacement curve of the concrete beams without steel fibres is much steeper than that with steel fibres, which shows that the addition of steel fibres makes the high strength concrete beams more ductile. The research results of

ten high-strength reinforced concrete beams and steel fibre-reinforced high strength concrete beams, with steel fibre content of 1% by volume. The enlarged ends of mild carbon steel fibres with three different dimensions were selected.

*Nataraja et al. (1999)*, carried out the investigation on stress-strain curve for steel fibre reinforced concrete under compression. The complete stress-strain curve of the material in compression is needed for the analysis and design of structures. In this experimental investigation, an attempt has been made to generate the complete stress-strain curve experimentally for steel-fibre reinforced concrete for compressive strength ranging from 30 to 50 MPa. Round crimped fibres with three volume fractions of 0.5%, 0.75% and 1.0% (39, 59, and 78 kg/m<sup>3</sup>) and for two aspect ratios of 55 and 82 are considered. The effect of fibre addition to concrete on some of the major parameters namely peak stress, strain at peak stress, the toughness of concrete and the nature of the stress-strain curve is studied. A simple analytical model is proposed to generate both the ascending and descending portions of the stress-strain curve. There exists a good correlation between the experimental results and those calculated based on the analytical model. Equations are also proposed to quantify the effect of fibre on compressive strength, strain at peak stress and the toughness of concrete in terms of fibre reinforcing parameter.

*Elsaigh et al. (2005)*, carried out investigation on steel fibre reinforced concrete for road pavement applications. In this paper, they established that the use of SFRC for road pavements and compare its execution with plain concrete under traffic loading. The determining of SFRC properties on performance and design aspects of concrete roads are discussed. Results coming out from road trial sections, tested under in-service traffic, are used to validate the use of the material in roads.

*Wegian et al. (2011)*, studied on the influences of fly ash on behaviour of fibre reinforced concrete structures. The aim of this study was to measure the tensile and compressive strength of concrete with different steel fibre and fly ash percentage. Concrete specimens with different fibre contents like 0.50%, 1% and 1.5% by volume were tested. Fly ash contents in mixes ranged b/w 0 and 30% by weight. Sixteen concrete mixes were prepared. The result of this study confirmed

that the addition of steel fibre has a negligible effect on the compressive strength of concrete but it improves the flexural strength.

*Neophytou et al. (2011)*, studied on the proportioning of steel fibre reinforced concrete mixes for pavement construction and their impact on environment and cost. The innovative concept of the project is the use of recycled steel tyre-cord wire as concrete fibre reinforcement, which provides additional environmental benefits for tyre recycling over land filling. Within the project framework a demonstration of a steel-fibre-reinforced roller-compacted concrete (SFR-RCC) pavement was constructed in a rural area in Cyprus. In order to assess the economical and environmental picture of the demonstration pavement, life cycle cost analysis (LCCA) and life cycle assessment (LCA) studies were undertaken, which also compared the under study pavement design with four conventional alternatives. The main output of the studies is that SFR-RCC is more environmentally and economically sustainable than others.

The proposed SFR-RCC pavement design is well sustainable alternative to SFRC for use in road construction industry both in economical and environmental terms. Given available design methodology, existing laying and material production equipment, SFR-RCC pavement may be the ideal new approach in road construction.

However, further work can be done towards a more environmental and economical pavement design. Most importantly, the life cycle studies showed that the steel fibre type and dosage can greatly influence the environmental (emissions and energy consumption) and economical indicators of concrete pavement layer. This is because the pavement layer depth, required to support the traffic load, is affected by the mechanical properties of SFRC which in turn are influenced by fibre type and dosage. On the other hand, recycled concrete aggregates may replace natural aggregates used in concrete mix, achieving only a small reduction in air emissions. But, it is more environmentally sustainable to recycle wastes than to extract natural resources.

*Soulioti (2011)*, carried out investigation on effect of fibre geometry and volume fraction on the flexural behaviour of steel fibre reinforced concrete. In this paper the effect of fibre geometry and fibre volume fraction has been investigated for steel fibre reinforced concretes. Specifically the compression strength, the

flexural strength and toughness were studied as a function of the above parameters and compared to unreinforced concrete. The effect of the fibre inclusion on the slump and air content properties of fresh concrete has been also evaluated.

The test results led to the conclusion that the fibres play an important role, not only in the fresh state of the concrete, but also in the mechanical properties of hardened concrete specimens. Concerning fresh concrete, the addition of steel fibres in the concrete mixture reduced the slump in the range of 65–90 mm, compared to plain concrete.

The air content increased with the raising of fibre volume fraction. Mixtures with high fibre volume fraction (1 and 1.5% by concrete volume) presented higher air content than mixtures with smaller fibre volume fraction (0.5% by concrete volume).

Plain concrete specimens failed catastrophically by a single crack, and separation into two pieces. On the contrary, the fibre-reinforced concrete specimens, even those with small fibre volume fraction (0.5%), retained post-cracking ability to carry out loads.

*Vardhan et al. (2012)*, carried out laboratory investigation on the influence of steel fibre on concrete at a dosage of 0.8% volume of concrete. Experimental investigation was done using M20 mix and tests were carried out as per recommended procedures by relevant codes. The study parameters of this investigation included compressive strength, split tensile strength and flexural strength of conventional and fibre reinforced concrete. The results indicated that the compressive, split tensile and flexural strength of fibre reinforced concrete is increased by 32.14%, 52.38%, 12.68% respectively when compared to the conventional concrete.

*Patel et al. (2012)*, investigated that the shear strength of Steel Fibre Reinforced Concrete (SFRC) moderate deep beams without stirrups having span to depth ratio 2.0, 2.4, 3.0, 4.0. The 12 numbers of beams were tested. 12 numbers of beams were tested to failure under two point symmetrical loading. A complete shear deformational behaviour along with load-deflection response, crack patterns and modes of failure is studied experimentally. Shear strength is evaluated using empirical equations proposed here in this work for estimation of

ultimate shear strength of moderate deep beams without stirrups. Experimental results of ultimate shear strength are compared with theoretical results calculated from proposed equation proposed. The comparison shows that the equation proposed here provides the most accurate estimates of shear strength. In addition to concrete strength, the influence of other variation such as fibre factor, span to depth ratio, longitudinal steel ratio and size effect is considered. *Khan et al. (2013)*, performed on steel fibres to increase the load carrying capacity of concrete members. Fibres substantially reduce the brittleness of concrete and improve its engineering properties, such as tensile, flexural, impact resistance, fatigue, load bearing capacity after cracking and toughness. It shows a review of research performed on Steel Fibre reinforced concrete. The performance of the Steel Fibre Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete.

### **2.3 GAP FINDINGS**

The combined effect of the steel fibres and foundry sand had never been studied for the compressive and flexural strength characteristics of the Pavement Quality Concrete. In this study the fine aggregates has been replaced with foundry sand from 0% to 50% and steel fibres have been added as 0.5% and 1%.

**3.1 GENERAL**

The present chapter deals with the presentation of results obtained from various tests conducted on material used for developing concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of waste foundry sand, steel fibre and super plasticizer on compressive strength and flexure strength of concrete.

**3.2 MATERIAL USED**

The properties of material used for making concrete mix are determined in laboratory as per relevant code of practice. Different materials used in present study were cement, coarse aggregates, fine aggregates, and super-plasticizer, in addition to foundry sand and steel fibres. The aim of studying of various properties of material is used to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular strength. The description of various materials which were used in this study is given below:

**3.2.1 Portland Cement**

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cement offers many advantages

for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% saving in cement consumption and also they offer many hidden benefits. One of the most important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) of 43 Grade (Ultra-Tech cement) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standards IS: 8112:1989 are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

**Table 3.1 Properties of OPC 43 Grade Concrete**

<b>Sr. No.</b>	<b>Characteristics</b>	<b>Values Obtained Experimentally</b>	<b>Values Specified By IS 8112:1989</b>
1.	Specific Gravity	3.10	-
2.	Standard Consistency, percent	27	-
3.	Initial Setting Time, minutes	149	30 (minimum)
4.	Final Setting Time, minutes	257	600 (maximum)
5.	Compressive Strength		
	3 days	27.8 N/mm <sup>2</sup>	23 N/mm <sup>2</sup> (minimum)
	7 days	36.5 N/mm <sup>2</sup>	33 N/mm <sup>2</sup> (minimum)
	28 days	48.6 N/mm <sup>2</sup>	43 N/mm <sup>2</sup> (minimum)

### 3.2.2 Aggregate

Aggregates constitute the bulk of a concrete mixture and give dimensional stability to concrete. To increase the density of resulting mix, the aggregates are frequently used on two or more sizes. The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assist the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the possible segregation of paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to placement. The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean, hard, strong and well graded.

### a) Coarse Aggregates

The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types:-

- i) Crushed gravel or stone obtained by crushing of gravel or hard stone.
- ii) Uncrushed gravel or stone resulting from the natural disintegration of rocks.
- iii) Partially crushed gravel or stone obtained as product of blending of above two types.

The normal maximum size is gradually 10-20 mm; however particle sizes up to 40 mm or more have been used in Self Compacting Concrete. Gap graded aggregates are frequently better than those continuously graded, which might expensive grader internal friction and give reduced flow. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of interlocking of angular particles, while rounded aggregates improved the flow because of lower internal friction.

**Table 3.2 Properties of coarse aggregate**

Characteristics	Value
Colour	Grey
Shape	Angular
Maximum Size	20mm/10mm
Specific Gravity	2.71/2.75
Water Absorption	0.20% /0.35%

**Table 3.3 Sieve Analysis of Coarse Aggregate (20 mm)**

Weight of Sample Taken = 3000gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	28.00	0.93	99.07	0.93
4	10	2876.00	95.87	3.20	96.80
5	4.75	75.00	2.50	0.70	99.30
6	Pan	21.00	0.70	0.00	
	<b>Total</b>	<b>3000.00</b>		<b>Sum</b>	<b>197.03+500=697.03</b>
				F.M=	6.97

The coarse aggregate used were a mixture of two locally available crushed stone of 20 mm and 10 mm size in 60:40 proportion. The aggregates were washed to remove dirt, dust and then dried to surface dry condition.

Specific gravity and other properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done. Table 3.3 & Table 3.4 show the result of sieve analysis. Proportioning of coarse aggregate was done and fineness modulus was obtained.

**Table 3.4 Sieve Analysis of Coarse Aggregate (10 mm)**

<b>Weight of Sample Taken= 2000 gm</b>					
<b>Sr. No</b>	<b>IS-Sieve (mm)</b>	<b>Wt. Retained (gm)</b>	<b>%age retained</b>	<b>%age passing</b>	<b>Cumulative % retained</b>
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	447.00	22.35	77.65	22.35
4	10	415.00	20.75	56.90	43.10
5	4.75	1055.00	52.75	4.15	95.85
6	2.36	80.00	4.00	0.15	99.85
7	Pan	3.00	0.15	0.00	
	<b>Total</b>	<b>2000.00</b>		<b>Sum</b>	<b>161.16+500=661.16</b>
				F.M=	6.61

**b) Fine Aggregates**

The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:

- i) Natural sand, i.e. the fine aggregate resulting from natural disintegration of rocks.
- ii) Crushed stone sand, i.e. the fine aggregate produced by crushing hard stone.
- iii) Crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel.

According to size, the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to grading IV.

In this experimental program, fine aggregate (stone dust) were collected from Jhelum Stone Crusher, Mirthal, Pathankot and conforming to Grade Zone II. It was coarse sand light brown in colour. The sand was sieved through 4.75 mm sieve to remove particles greater than 4.75 mm size. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are shown in Table 3.5. Specific gravity of fine aggregates were experimentally determined as 2.58. Sieve analysis of fine aggregates was performed to get Fineness Modulus.

**Table 3.5 Sieve Analysis of Fine Aggregate**

Weight of sample taken = 1000 gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age passing	Cumulative % retained
1	4.75	5.00	0.50	99.50	0.50
2	2.36	59.00	5.90	93.60	6.40
3	1.18	136.00	13.60	80.00	20.00
4	600 $\mu$	243.00	24.30	55.70	44.30
5	300 $\mu$	415.00	41.50	14.20	85.80
6	150 $\mu$	122.00	12.20	2.00	98.00
7	Pan	20.00	2.00	0.00	
	<b>Total</b>	<b>1000.00</b>		<b>Sum</b>	<b>255.00</b>
				F.M=	2.55

**Table 3.6 Sieve Analysis of Waste Foundry Sand**

Weight of sample taken= 1000 gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (gm)	%age retained	%age passing	Cumulative % retained
1	4.75	4.00	0.40	99.60	0.40
2	2.36	4.00	0.40	99.20	0.80
3	1	16.00	1.60	97.60	2.40
4	600 $\mu$	18.00	1.80	95.80	4.20
5	450 $\mu$	170.00	17.00	78.80	21.20
6	300 $\mu$	229.00	22.90	55.90	44.10
7	150 $\mu$	442.00	44.20	11.70	88.30
8	75 $\mu$	80.00	8.00	3.70	96.30
9	Pan	37.00	3.70	0.00	
	<b>Total</b>	<b>1000.00</b>		<b>Sum</b>	<b>257.70</b>
				F.M=	2.57

The 84% particle size of foundry sand ranges between 150 $\mu$  to 450 $\mu$ .

### c) Foundry Sand

Foundry sand was collected from R.P Foundry, Focal Point, Mandi, Gobindgarh. It was black in colour and it was air dried. It was sieved through 4.75 mm sieve so as to find the percentage fineness as shown in Table 3.6. The specific gravity of foundry sand was experimentally determined as 2.59.

### d) Steel Fibre

Mild steel fibres having 30 mm length and 0.6 mm thickness i.e. aspect ratio ( $l/d$ ) 50 which are corrugated and obtained through cutting of steel wires have been used. The fibres have been cut by fibre cutting machine to an accurate size. Three different proportions of fibres i.e. 0%, 0.5% and 1% have been used. Properties of steel fibre used are tabulated in Table 3.7.

**Table 3.7 Properties of Steel Fibres**

Average Thickness	0.6 mm
Length	30 mm
Density	7850 kg/m <sup>3</sup>
Tensile Strength	8500 kg/m <sup>3</sup>
Shape	Crimped steel fibre

### 3.2.3 Super plasticizer

Super-plasticizers constitute a relatively new category and improved version of plasticizer. They are chemically different from normal plasticizers. Use of super-plasticizer permits the reduction of water to the extent up to 30 percent without reducing workability in contrast to possible reduction up to 15 percent in case of plasticizers. The mechanism of action of super-plasticizer is more or less same as in case of ordinary plasticizer. The super-plasticizers are more powerful as dispersing agents and they are high water reducers. It is use of super-plasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain compressive strength of the order of 120 MPa or more. It is the use of super-plasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

Super-plasticizers are also often used when pozzolanic ash is added to concrete to improve strength. This method of mix proportioning is especially popular when producing high-strength concrete and fibre reinforced concrete. Adding 1-

2% super-plasticizer per unit weight of cement is usually sufficient. However, note that most commercially available super-plasticizers come dissolved in water, so the extra water added has to be accounted for in mix proportioning. Adding an excessive amount of super-plasticizer will result in excessive segregation of concrete and is not advisable. Some studies also show that too much super-plasticizer will result in a retarding effect.

Super-plasticizers are chemical admixtures that can be added to concrete mixtures to improve workability. Unless the mix is “straved” of water, the strength of concrete is inversely proportional to amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water is added which makes the concrete mixture very unworkable and difficult to mix, necessitating the use of plasticizers, water reducers, super-plasticizer or dispersants.

The super-plasticizer “Conplast SP430” procured from FOSROC Limited was used in present study. The technical data provided by manufacturer is given in Table 3.8

**Table 3.8 Properties of Super-plasticizer**

<b>Sr.No.</b>	<b>Characteristics</b>	<b>Value</b>
1.	Appearance	Brown liquid
2.	Specific Gravity	Typically 1.20 at 20°C
3.	Chloride content	Nil to BS 5075
4.	Air entrainment	Typically less than 2% additional air is entrained at normal dosages.
5.	Alkali content	Typically less than 72.0 gm. Na <sub>2</sub> O equivalent/litre of admixture

The dosage of super-plasticizer recommended is 0.6% to 2% by weight of cementitious material. 0.8% super-plasticizer by weight of cementitious material was selected in this study to get the medium range of workability.

### **3.2.4 Water**

The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

### 3.3 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)

**Step 1** As per clause **602** of MORTH Specification

- Cement – 43 grade OPC as per **IS 8112** as per **602.2.2**
- Coarse aggregate – 20 mm and 10 mm as per **602.2.4**
  - Los angles Abrasion value not greater than 35%
  - Impact value not greater than 30%
- Fine aggregate – Natural sand as per **IS 383**
- Admixture – Conplast AEA (if required)
  - Air entrained concrete 5% maximum (optional)

**Step 2 Design Parameter:**

1. Characteristics flexural strength required at 28 days = 4.69 N/mm<sup>2</sup>
2. Maximum water cement ratio = 0.36 as per clause **602.3.3.1**
3. Maximum size of coarse aggregate = 25 mm
4. Degree of quality control = Good
5. Minimum cement content = 350 kg/m<sup>3</sup> as per clause **602.3.2**
6. Maximum cement content = 425 kg/m<sup>3</sup> as per clause **602.3.2**

**Step 3 Calculation of fine aggregate content:**

After determining the weight per cubic meter of cement, water, coarse aggregate and percentage of air content, the fine aggregate is calculated so as to produce one cubic meter of concrete using absolute volume method. On converting the weight per cubic meter into volume, we have

$$(a) \text{ Volume of cement} = \frac{\text{Weight of cement}}{\text{Specific gravity of cement} \times 1000}$$

$$(b) \text{ Volume of coarse aggregate} = \frac{\text{Weight of coarse aggregate}}{\text{Specific gravity of coarse aggregate} \times 1000}$$

$$(c) \text{ Volume of water} = \frac{\text{Weight of water}}{1000}$$

$$(d) \text{ Volume of fine aggregate} = 1 - \{\text{Volume of cement} + \text{coarse aggregate} + \text{water} + \text{Air Content}\}$$

$$(e) \text{ Weight of fine aggregate} = \text{Volume of fine aggregate} \times \text{specific gravity} \times 1000$$

Now by following the above steps for mix design, the mix proportion for different compressive strength are given by using following data:

Specific gravity of cement	= 3.10
Specific gravity of fine aggregate	= 2.58
Specific gravity of coarse aggregate, 20 mm	= 2.71
Specific gravity of coarse aggregate, 10 mm	= 2.75
Slump value	= 50 to 70

The proportions for pavement quality concrete mixtures are tabulated in Table 3.9

**Table 3.9 Mix Design Concrete**

Mean Target Flexure strength (MPa)	Max. Size of Aggregate, (mm)	Mix proportions (C:FA:CAI:CAII)	W/C Ratio	Materials for 1 m <sup>3</sup> in kg				
				Water	Cement	F.A	C.AI (20)	C.AII (10)
4.69	20	1:1.58:1.75:1.18	0.36	149	414	656.98	723.45	489.42
The estimated values of steel fibre contents are = 40 kg/m <sup>3</sup> (0.5%) and 80 kg/m <sup>3</sup> (1%)								

#### Step 4 Estimation of fibre content:

The fibre content is taking as 0.5 percent by volume. Therefore

$$0.5\% \text{ by volume} = \frac{0.005 \times \text{Unit weight of fibre}}{0.995 \times \text{Unit weight of concrete}} \times 100$$

$$= \% \text{ by weight}$$

We have, Unit weight of fibre = 7860 kg/m<sup>3</sup>

Unit weight of concrete = 2300 kg/m<sup>3</sup>

$$0.5\% \text{ by volume} = \frac{0.005 \times 7860}{0.995 \times 2300} \times 100 = 1.7173\% \text{ by weight}$$

$$0.5\% \text{ fibre by volume} = \frac{\% \text{ by weight}}{100} \times \text{unit weight of concrete in kg/m}^3$$

$$0.5\% \text{ fibre by volume} = \frac{1.7173 \times 2300}{100}$$

$$= 39.4979 \text{ kg/m}^3$$

$$= 40 \text{ kg/m}^3 \text{ (approx.)}$$

Fibre content = 40 kg/m<sup>3</sup>

**4.1 GENERAL**

This chapter deals with the presentation of results obtained from various tests conducted on material used for developing concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of foundry sand and steel fibre on flexural strength, compressive strength of concrete so as to assess its feasibility on highway pavement. The experimental program consists of casting, curing and testing of controlled and foundry sand concrete specimen at different ages. The details of material and experimental procedure adopted for various tests are shown in Figure 4.1.

The experimental program including the following:

- i) Testing of properties of materials used for making concrete.
- ii) Design of mixes for high strength concrete and high strength steel fibre reinforced concrete by making trials.
- iii) Casting and curing of specimens.
- iv) Tests to determine the flexural strength and compressive strength of high strength steel fibre reinforced concrete.

**4.2 COMPRESSIVE STRENGTH****4.2.1 General**

In most structural applications, concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains. If the concrete contains steel fibres, the crack propagation gets effectively arrested by the fibres oriented at the right angle to the axis of loading. The lateral tensile strain is resisted by the fibres and hence the compressive strength of the member is increased.

#### 4.2.2 Test Procedure and Results

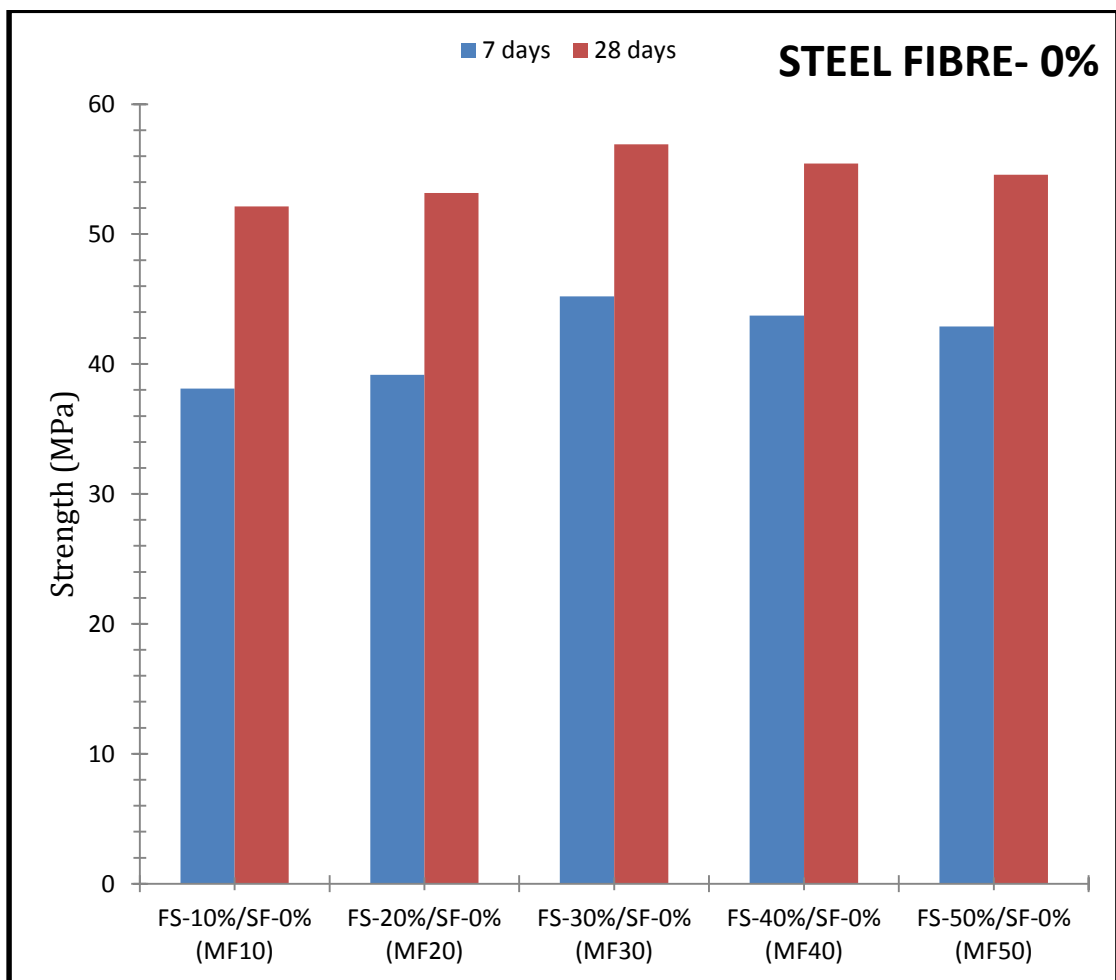
Test specimens of size 150 × 150 × 150 mm were prepared for testing the compressive strength of high strength steel fibre reinforced concrete. The mix for various percentage of steel fibre and replacement of foundry sand with fine aggregate was done.

**Table 4.1 Compressive Strength Test Results**

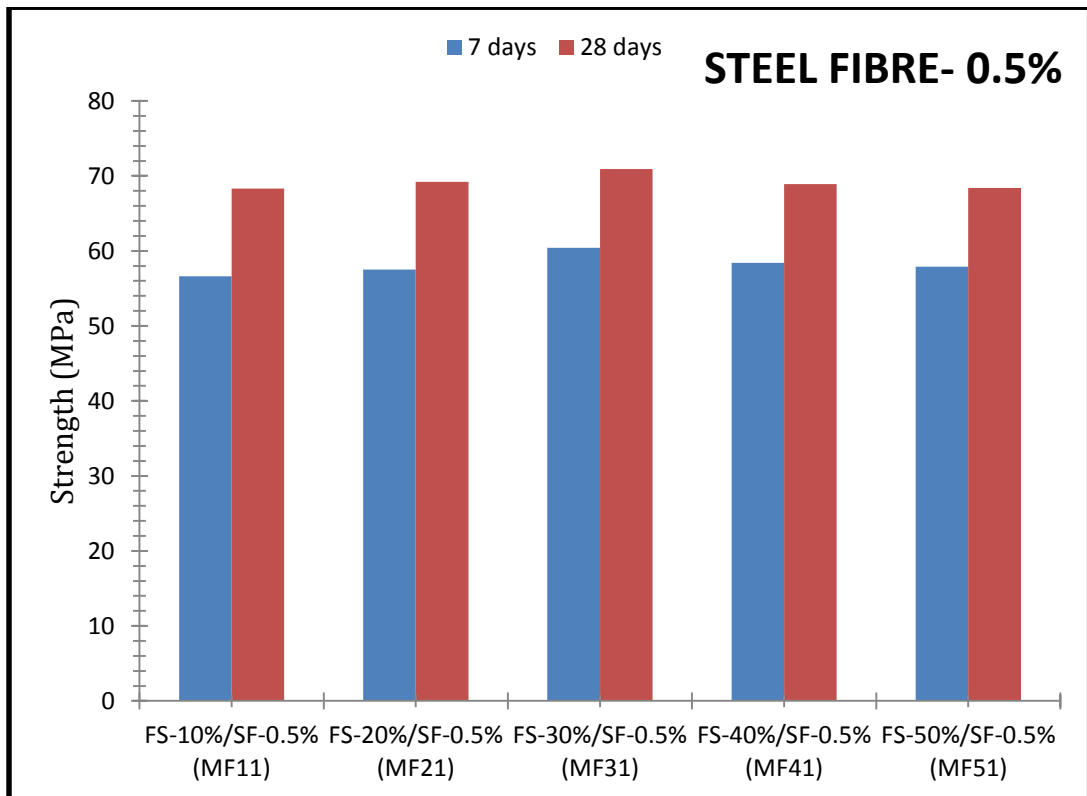
Cube Strength (MPa)		
Type of concrete	7days	28days
FS-0%/SF-0% (MF00)	39.8	53.8
FS-10%/SF-0% (MF10)	38.12	52.12
FS-20%/SF-0% (MF20)	39.16	53.16
FS-30%/SF-0% (MF30)	45.21	56.91
FS-40%/SF-0% (MF40)	43.73	55.43
FS-50%/SF-0% (MF50)	42.9	54.6
FS-10%/SF-0.5% (MF11)	56.6	68.3
FS-20%/SF-0.5%(MF21)	57.53	69.23
FS-30%/SF-0.5% (MF31)	60.42	70.92
FS-40%/SF-0.5% (MF41)	58.4	68.9
FS-50%/SF-0.5% (MF51)	57.9	68.4
FS-10%/SF-1% (MF12)	61.01	71.51
FS-20%/SF-1% (MF22)	61.7	72.3
FS-30%/SF-1% (MF32)	63.1	73.38
FS-40%/SF-1% (MF42)	62.37	72.87
FS-50%/SF-1% (MF52)	61.09	72.39
FS-0%/SF-0.5% (MF01)	45.65	56.81
FS-0%/SF-1% (MF02)	62.76	72.52

In this study, the mix was done by manually. The cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine aggregates. Water was then added and the whole mass mixed. In case of HS SFRC the fibres were added just before

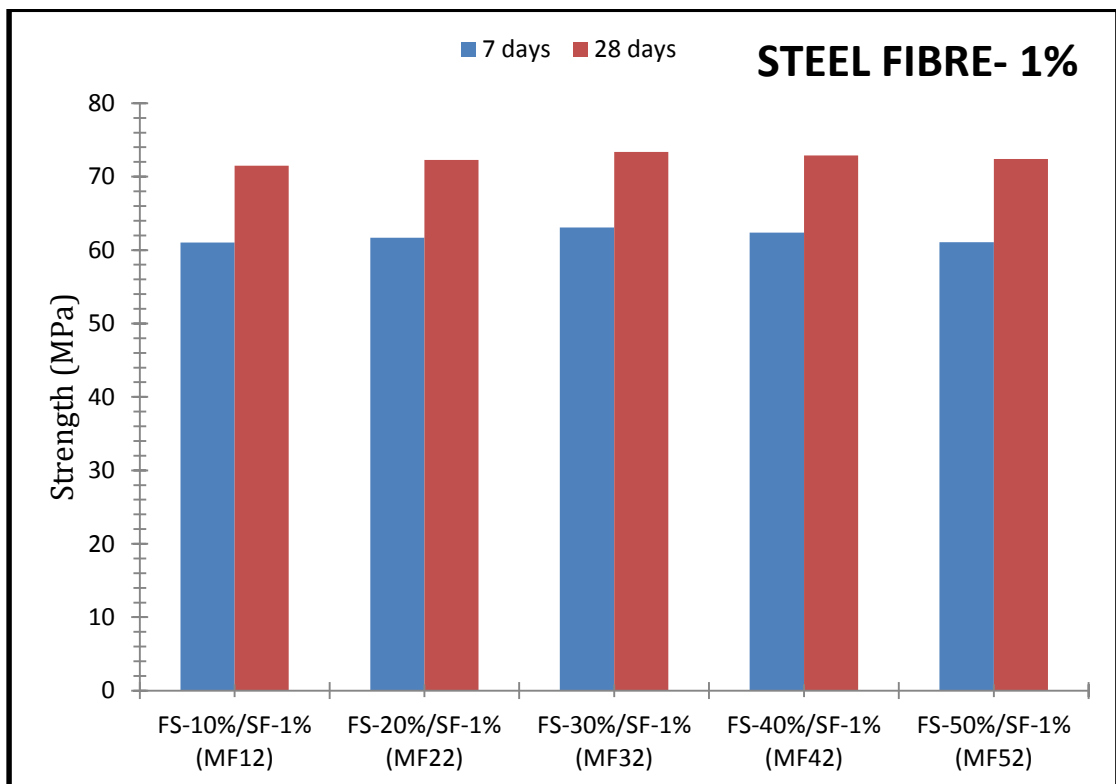
adding water and mixed dry thoroughly. Same in the case of foundry sand, foundry sand was replaced with fine aggregate with different percentage and added before adding water. The interior surface of the moulds and the base plate were highly oiled before concrete was placed. After this the specimens were removed from the moulds and placed in clean fresh water at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$  for 28 days curing. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Test results of compressive strength test at the age of 7 and 28 days are given in the Table 4.1. The cube strength results of concrete mix are also shown graphically.



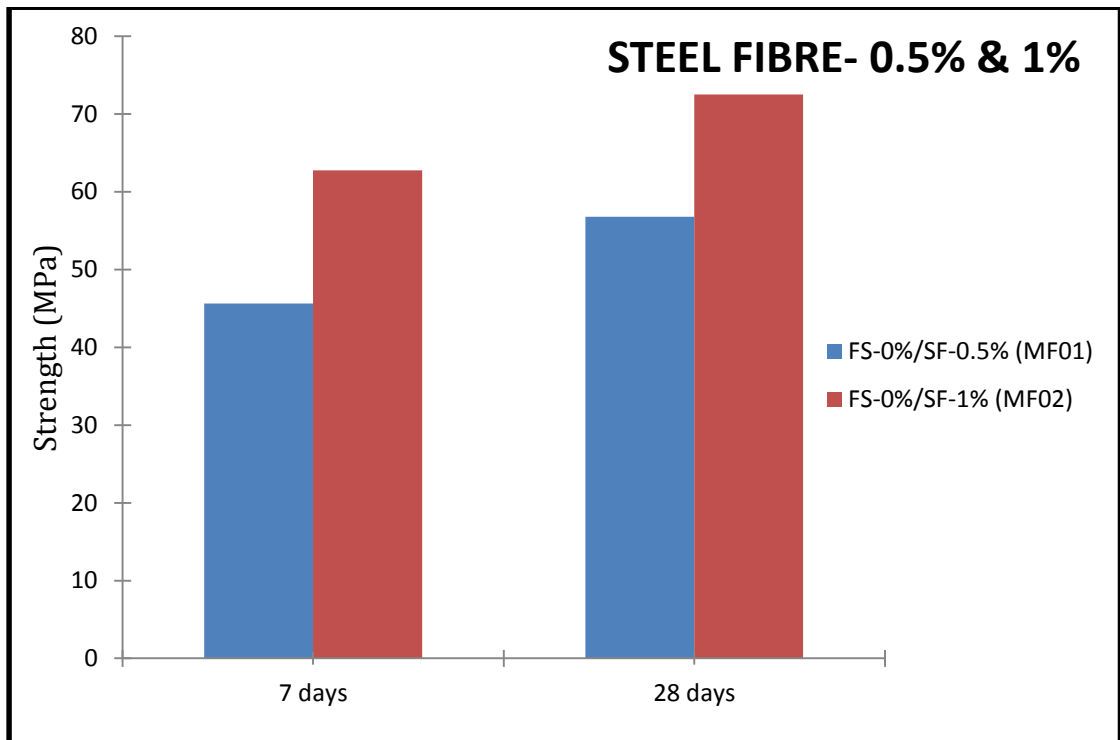
**Fig. 4.1 Variation of compressive strength of concrete for 0% S.F and different percentage of F.S**



**Fig. 4.2 Variation of compressive strength of concrete for 0.5% S.F and different percentage of F.S**



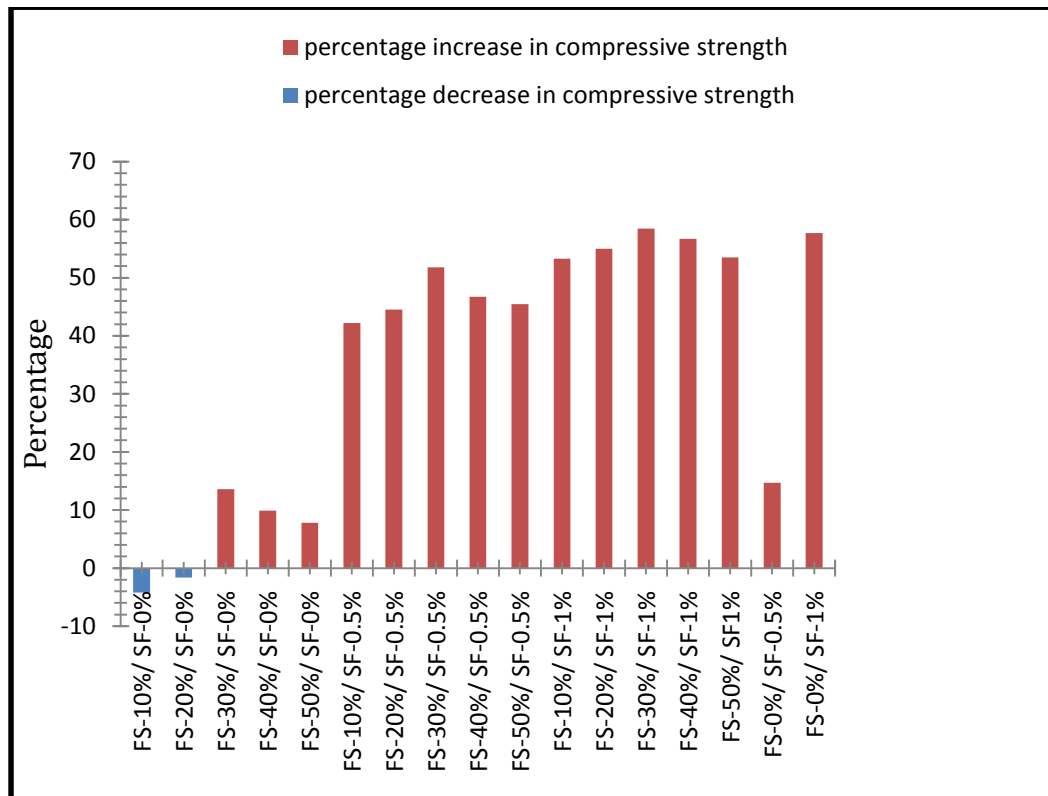
**Fig. 4.3 Variation of compressive strength of concrete for 1% S.F and different percentage of F.S**



**Fig. 4.4 Variation of compressive strength of concrete for 0.5% and 1% S.F**

**Table 4.2 Percentage Variation of Compressive strength at 7days**

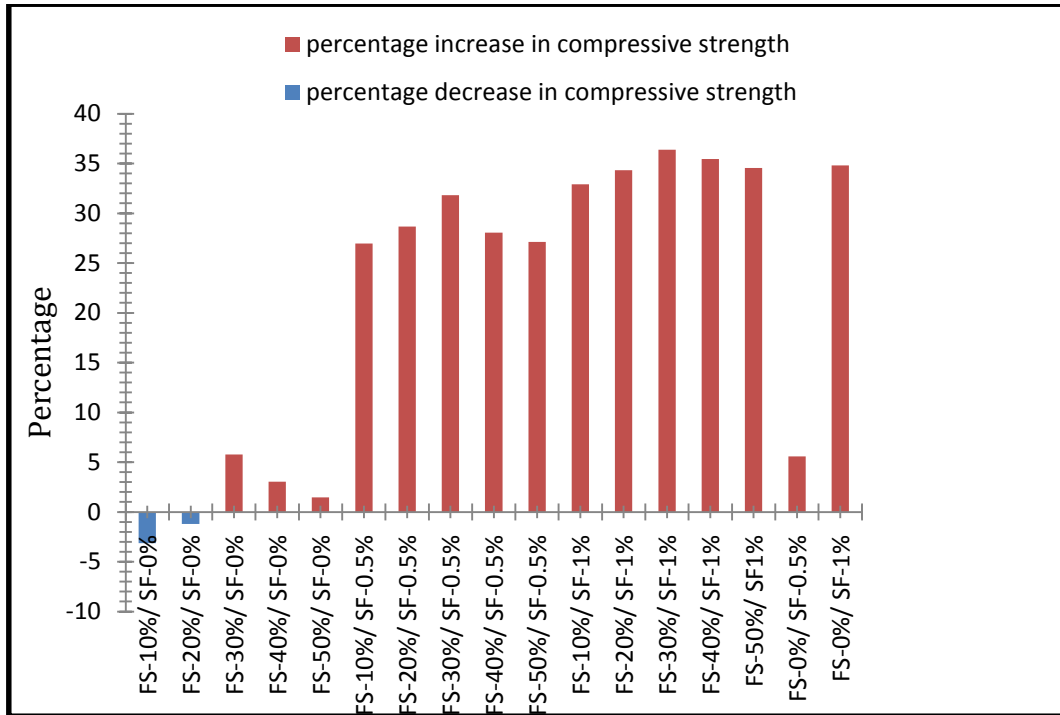
Sample ID	Compressive Strength	
	Percentage decrease in compressive strength	Percentage increase in compressive strength
FS-10%/SF-0%	-4.22	
FS-20%/SF-0%	-1.60	
FS-30%/SF-0%		13.59
FS-40%/SF-0%		9.90
FS-50%/SF-0%		7.78
FS-10%/SF-0.5%		42.21
FS-20%/SF-0.5%		44.54
FS-30%/SF-0.5%		51.80
FS-40%/SF-0.5%		46.70
FS-50%/SF-0.5%		45.47
FS-10%/SF-1%		53.29
FS-20%/SF-1%		55.02
FS-30%/SF-1%		58.50
FS-40%/SF-1%		56.70
FS-50%/SF-1%		53.49
FS-0%/SF-0.5%		14.69
FS-0%/SF-1%		57.68



**Fig 4.5 Percentage variation of compressive strength at 7days**

**Table 4.3 Percentage Variation of Compressive strength at 28days**

Compressive Strength		
Sample ID	Percentage decrease in compressive strength	Percentage increase in compressive strength
FS-10%/SF-0%	-3.12	
FS-20%/SF-0%	-1.18	
FS-30%/SF-0%		5.78
FS-40%/SF-0%		3.02
FS-50%/SF-0%		1.40
FS-10%/SF-0.5%		26.95
FS-20%/SF-0.5%		28.68
FS-30%/SF-0.5%		31.82
FS-40%/SF-0.5%		28.10
FS-50%/SF-0.5%		27.13
FS-10%/SF-1%		32.91
FS-20%/SF-1%		34.30
FS-30%/SF-1%		36.39
FS-40%/SF-1%		35.44
FS-50%/SF-1%		34.55
FS-0%/SF-0.5%		5.594
FS-0%/SF-1%		34.79



**Fig 4.6 Percentage variation of compressive strength at 28days**

#### 4.2.3 Discussion of Results for compressive strength

From the Table 4.3, 4.4 and Figures 4.5, 4.6, shows the variation of compressive strength at different ages. It is observed here that with the increase in percentage of waste foundry sand (replacing fine aggregate) there is marginal decrease in the compressive strength (up to 20% replacement) of the concrete mixes. The maximum strength was obtained at 30% foundry sand in all the replacement mixes and was more than control mix. The strengths of MF30, MF40 AND MF50 mixes were observed to be more than the strength of MF00 mix (nominal mix). The increase in compressive strength with the replacement of used foundry sand may be probably due to the fact that used foundry sand was finer than regular sand which resulted in denser concrete mix, and also due to the silica content present in use foundry sand. On the other hand, when steel fibre is added in concrete mix there is widely increase in compressive strength as compared to nominal mix. Maximum compressive strength of pavement quality concrete incorporating waste foundry sand and steel fibres both is achieved for 30% waste foundry sand and 1% steel fibres. However if the waste foundry sand

content is increased to 50%, even with 1% steel fibre, the strength increases but less as in 30% waste foundry sand and 1% steel fibre.

#### **4.2.4 Effect of steel fibre on compressive strength**

From the Table 4.1 and Figures 4.1 to 4.4, showing the variation of compressive strength, it is observed that with the increase in percentage of steel fibre the strength increases. This happens because when steel fibres are added to concrete, the propagation of cracks was restrained due to the bonding of fibres into the concrete (ductile failure). Also it is observed that one of the most desirable benefits of adding fibres to concrete is to increase its energy absorbing capability or saying more precisely ductility. Referring to above graph, it is observed that for addition of 1% steel fibre and replacement of fine aggregate with 30% waste foundry sand, the compressive strength increases the most when compared to nominal mix. Also on addition of 1% steel fibre without waste foundry sand the strength is almost equal to maximum strength.

### **4.3 FLEXURAL STRENGTH**

#### **4.3.1 General**

The most common concrete structure subjected to flexure is a highway or airway pavement and strength of concrete for pavements is commonly evaluated by means of bending tests. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are developed.

When fibre reinforced concrete and composite beams are loaded in pure bending, then the tensile strains develop. The load at first crack would increase with respect to high strength concrete due to crack arresting mechanism of the closely spaced fibres. After the concrete matrix cracks, the fibres continue to take higher load which is provided. Thus the ultimate flexural strength is increased.

#### **4.3.2 Test Procedure and Results**

Test specimens of beam size 150 mm × 150 mm × 700 mm were prepared for testing the flexural strength of high strength steel reinforced concrete and replacement of foundry sand with fine aggregate with different percentage.

The beam moulds containing the test specimens were placed in moist air for at least 90% relative humidity and a temperature of  $27^{\circ} \pm 2^{\circ} \text{C}$  for 24 hours  $\pm 1/2$  hour from the time of addition of water to the dry ingredients. After this the

specimens were removed from the moulds and placed in clean fresh water at a temperature of  $27^0 \pm 2^0$  C for 28 days curing. After 28 days of curing the specimens were tested in flexure on a Universal Testing Machine. Loads were applied at the one third points at a constant rate of 30 kg/minute. The distance between the centres of two rollers was kept 20 cm.

If the fracture occurred within the central one-third of the beam, the flexural strength was calculated on the basis of ordinary elastic theory using the following equations:

$$F_b = \frac{PL}{BD^2}, \text{ when 'a' is greater than 20 cm for 15 cm specimen}$$

$$F_b = \frac{3Pa}{BD^2}, \text{ when 'a' is less than 20 cm but greater than 17 cm for 15 cm specimen}$$

**Table 4.4 Flexure Strength Results**

<b>Beam Strength (MPa)</b>	
<b>Type of concrete</b>	<b>28days</b>
FS-0%/SF-0% (MF00)	5.09
FS-10%/SF-0% (MF10)	4.91
FS-20%/SF-0% (MF20)	5.03
FS-30%/SF-0% (MF30)	5.21
FS-40%/SF-0% (MF40)	5.17
FS-50%/SF-0% (MF50)	5.11
FS-10%/SF-0.5% (MF11)	6.1
FS-20%/SF-0.5%(MF21)	6.17
FS-30%/SF-0.5% (MF31)	6.29
FS-40%/SF-0.5% (MF41)	6.24
FS-50%/SF-0.5% (MF51)	6.15
FS-10%/SF-1% (MF12)	6.55
FS-20%/SF-1% (MF22)	6.79
FS-30%/SF-1% (MF32)	7.1
FS-40%/SF-1% (MF42)	6.89
FS-50%/SF-1% (MF52)	6.8
FS-0%/SF-0.5% (MF01)	5.95
FS-0%/SF-1% (MF02)	6.61

Where,

$F_b$  = Flexural Strength of the specimen in N/mm<sup>2</sup>

B = Width of the specimen (= 150 mm)

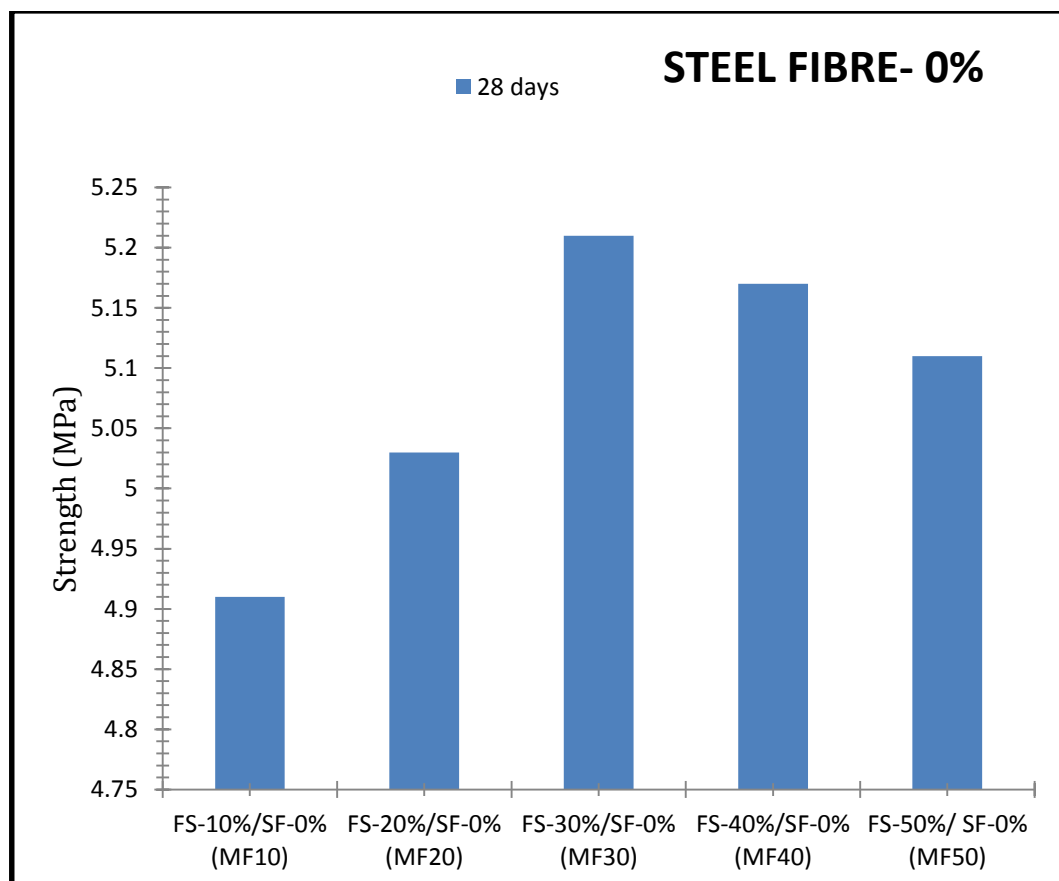
D = Depth of the specimen (= 150 mm)

L = Span of the specimen (= 700 mm)

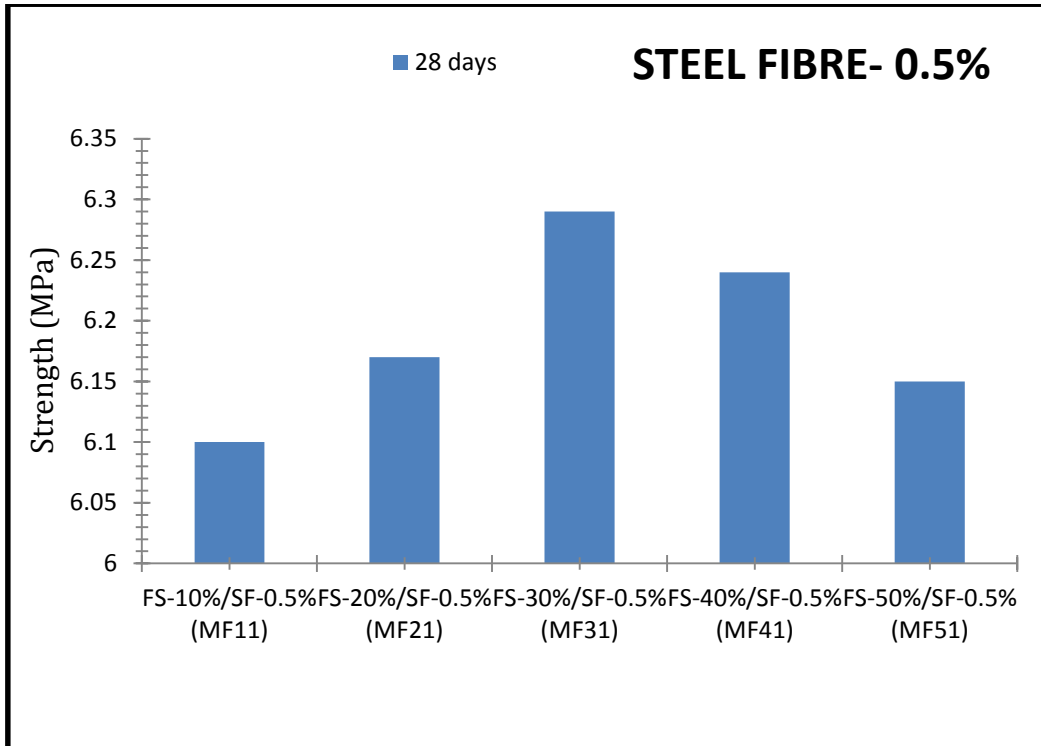
P = Maximum load in Newton (N) applied to the specimen

A = Distance b/w the line of fracture and nearer support, measured on the centre line of the tensile side of the specimen in cm, shall be calculated to the nearest 0.5 kg/cm<sup>2</sup>.

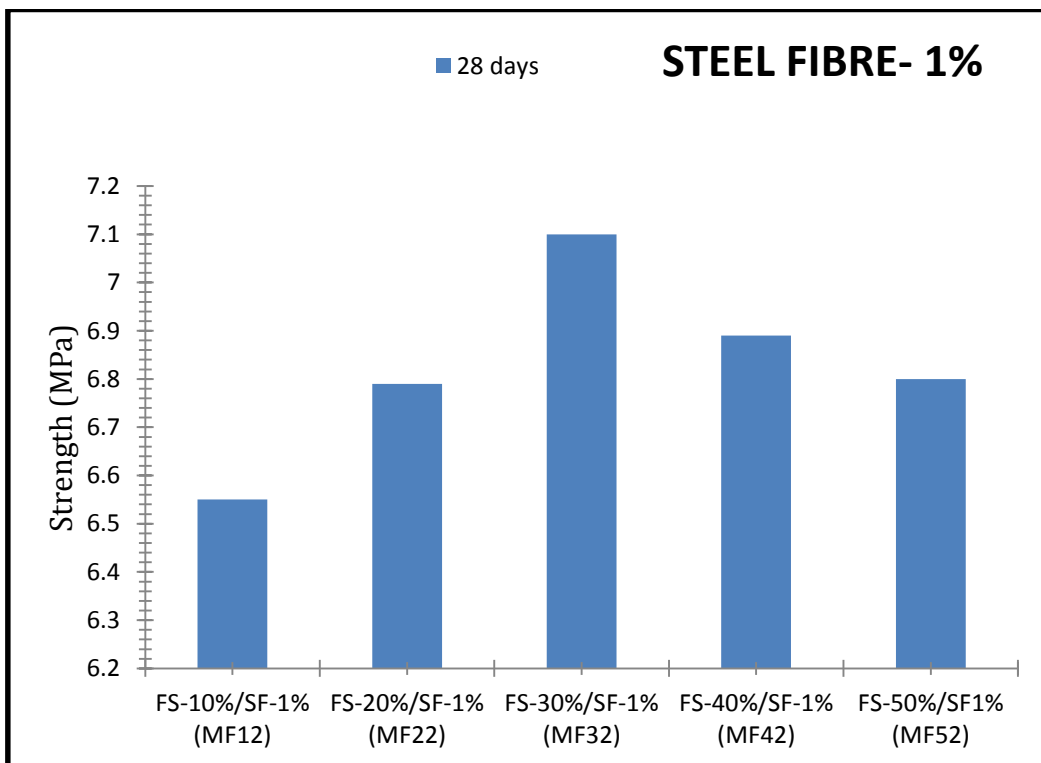
If 'a' is less than 17 cm the results of a test shall be discarded. Test results of flexural test at the age of 28 days curing are given in Table 4.4. The flexural strength results of concrete mix are also shown graphically.



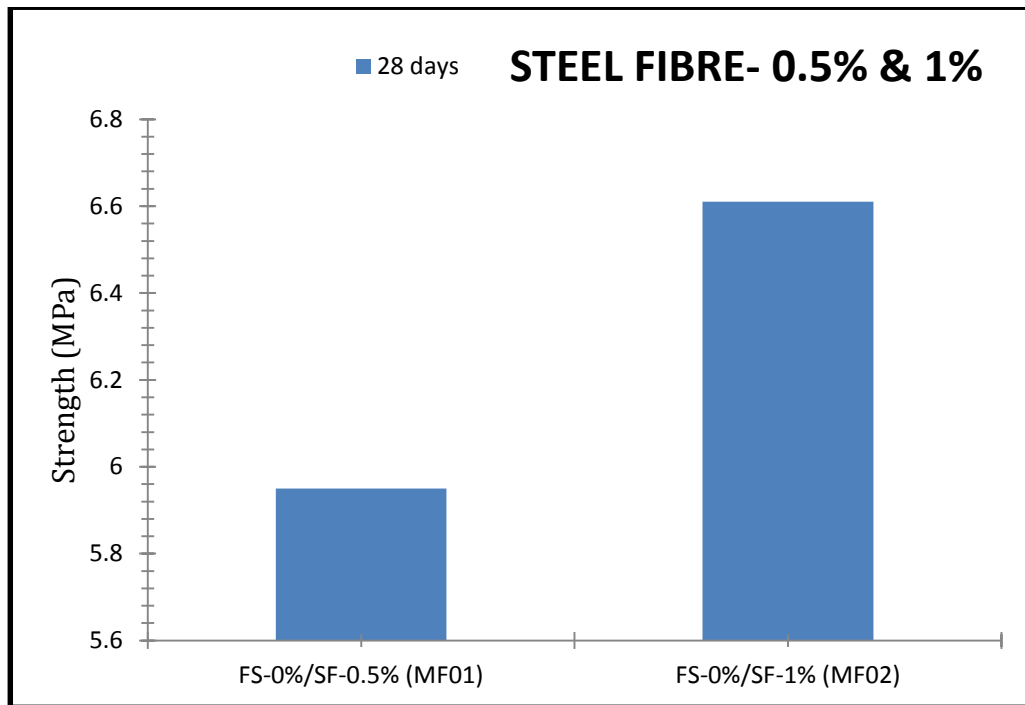
**Fig. 4.7 Variation of flexure strength of concrete for 0% S.F and different percentage of F.S**



**Fig. 4.8 Variation of flexure strength of concrete for 0.5% S.F and different percentage of F.S**



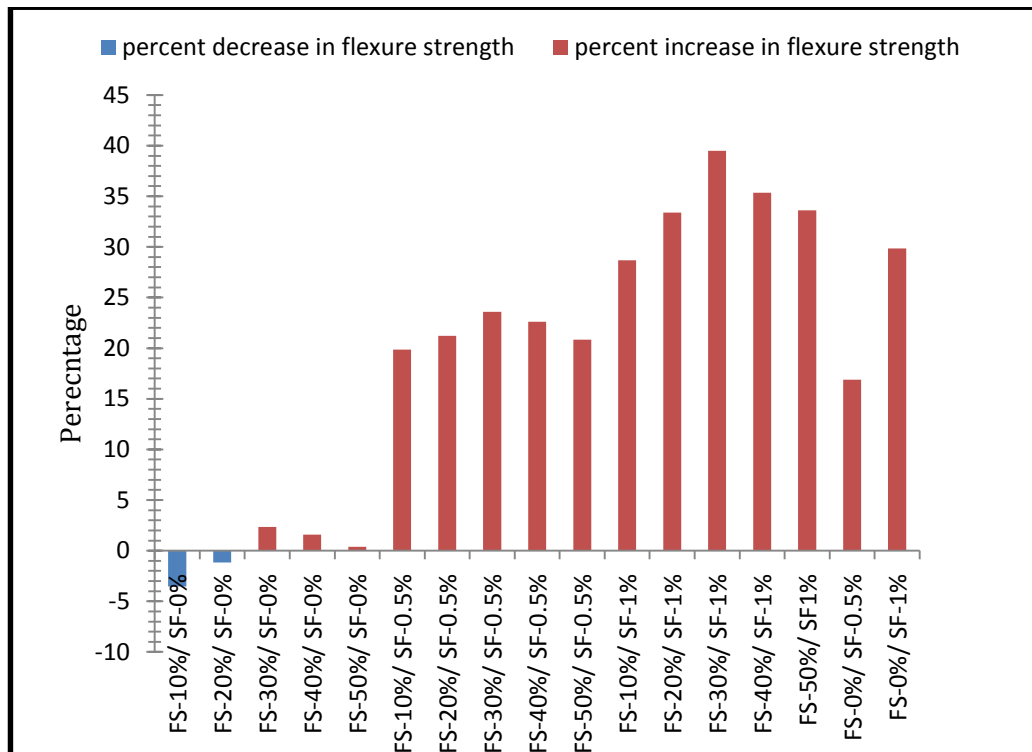
**Fig. 4.9 Variation of flexure strength of concrete for 1% S.F and different percentage of F.S**



**Fig. 4.10 Variation of flexure strength of concrete for 0.5% and 1% S.F**

**Table 4.5 Percentage Variation of Flexure strength at 28 days**

Flexure Strength		
Sample ID	Percentage decrease in Flexure strength	Percentage increase in Flexure strength
FS-10%/SF-0%	-3.53	
FS-20%/SF-0%	-1.17	
FS-30%/SF-0%		2.35
FS-40%/SF-0%		1.57
FS-50%/SF-0%		0.39
FS-10%/SF-0.5%		19.84
FS-20%/SF-0.5%		21.21
FS-30%/SF-0.5%		23.57
FS-40%/SF-0.5%		22.59
FS-50%/SF-0.5%		20.82
FS-10%/SF-1%		28.68
FS-20%/SF-1%		33.39
FS-30%/SF-1%		39.48
FS-40%/SF-1%		35.36
FS-50%/SF-1%		33.59
FS-0%/SF-0.5%		16.89
FS-0%/SF-1%		29.86



**Fig 4.11 Percentage variation of flexure strength**

#### 4.3.3 Discussion of Results for flexure strength

From the Table 4.5 and figures 4.11 shows the variation of flexure strength at 28 days. It is observed here that with the increase percentage of waste foundry sand (replacing fine aggregate) the flexure strength increase and is more than the control mix (MF00). The maximum flexure strength is attained at 30% waste foundry sand (replacing fine aggregate) further increase in waste foundry sand (upto 50%) the increase is not significant. On the other hand, when the steel fibre is added in the concrete mix, there is significant increase in flexure strength as compared to controlled mix. Maximum flexure strength of pavement quality concrete incorporating waste foundry sand and steel fibre both is achieved for 30% waste foundry sand and 1% steel fibres. However, if the waste foundry sand content is increased to 50%, even with 1% steel fibre, the strength increases but less as in 30% waste foundry sand and 1% steel fibre .

#### 4.3.4 Effect of steel fibre on Flexure Strength

From the Table 4.4 and Figures 4.7 to 4.10, showing the variation of flexure strength, it is observed here that with the increase percentage of steel fibre the flexure strength follows a pattern similar to that of compressive strength. This

happens because when the steel fibres are added to the concrete, the propagation of cracks was restrained due to the bonding of fibres into the concrete (ductile failure). However maximum flexure strength is attained at 30% replacement further increase in percentage replacement beyond 30%, the value of flexure strength increases but less as in 30% replacement. On the other hand, when steel fibre is added in the concrete mix, there is significant increase in flexure strength, as well, when compared to controlled mix.

### DESIGN AND ANALYSIS OF PAVEMENT QUALITY CONCRETE

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#### 5.1 DESIGN OF PAVEMENT QUALITY CONCRETE (PQC) FOR INDIAN HIGHWAYS

##### 5.1.1 Introduction

Guidelines for the design of rigid pavements for highways were first approved by the Cement Concrete Road Surfacing Committee in March 1973 and published subsequently in the IRC: 58-2002 editions. In view of the recent upward revision of the legal limit on the maximum laden axle loads of commercial vehicle from 8160 kg to 10200 kg, appropriate modifications have become necessary in some sections of the Guidelines of IRC:58-1988, which resulted in the publication of IRC:58-2002, "Guidelines for the Design of Plain Jointed Rigid Pavements for Highways". The early approach to the Design of Rigid Pavement was based on Westergaard's analysis. Recent advance in knowledge have led to vast changes in the design methodology.

##### 5.1.2 Factor Governing Design

###### a) *Factor Governing Design*

It considered single and tandem axle loads, their repetition, tyre pressure and lateral placement characteristics of commercial vehicles.

###### b) *Wheel Load*

The legal axle load limits in India have been fixed as 10.2, 19 and 24 tonnes for single axles, tandem axles and tridem axles respectively, a large number of axles operating on National Highways carry much higher loads than the legal limits. Data on axle load distribution of the commercial vehicles is required to compute the number of repetitions of single and tandem axles of different weights expected during the design period. For most of the commercial highways vehicles, the tyre pressure ranges from 0.7 to 1.0 MPa but it is found that stresses in concrete pavements having thickness of 20 cm or more are not affected significantly by the variation of tyre pressure in the range mentioned earlier. A tyre pressure of 0.8 MPa may be adopted for design.

For computation of stresses in the pavements, the magnitude of axle loads should be multiplied by Load Safety Factor (LSF). For important roads, like, Expressways, National Highways and other roads where there will be uninterrupted traffic flow and high volume of truck traffic, the value of LSF is taken as 1.2. For roads of lesser importance having lower proportion of truck traffic, LSF may be taken as 1.1. For residential and other streets that carry small number of commercial traffic, the LSF may be taken as 1.0.

**c) Design Period**

Normally, cement concrete pavements have a life span of 30 years and should be designed for this period. When the traffic intensity cannot be predicted accurately for a long period of time, and for low volume roads, a design period of twenty years may be considered. However, the design engineer should use his judgement about the design life taking into consideration the factors, like, traffic volume, the traffic growth rate, the capacity of the road.

**d) Design Traffic**

Assessment of average traffic should normally be based on 7 × 24 hours count made in accordance with IRC: 9 “Traffic Census on Non-Urban Roads”. The actual value of growth rate ‘r’ of heavy commercial vehicles should be determined. However, if actual data is not available, an average annual growth rate of 7.5 percent may be adopted.

The cumulative number of repetitions of axles during the design period may be adopted from the following formula:

$$C = \frac{365 \times A \{ (1+r)^n - 1 \}}{r}$$

Where

C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r = Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

In most of design problems, it is expected that the weights and number of trucks travelling in each direction are fairly equal. This may not be true for roads, like, Haul roads in mine areas where many of the trucks haul full loads in one direction and return empty in the other direction. In such cases, a suitable adjustment should be made.

### **e) *Temperature Differential***

Temperature differential between the top and the bottom of concrete pavements causes the concrete slab to warp, giving rise to stresses. The temperature differential is a function of solar radiation received by the pavement surface at the location, losses due to wind velocity and thermal diffusivity of concrete and is thus affected by geographical features of the pavement location. As far as possible, values of actually anticipated temperature differentials at the location of the pavement should be adopted for pavement design.

## **5.2 CHARACTERISTICS OF SUBGRADE AND SUB BASE**

### **5.2.1 Strength**

The strength of sub grade is expressed in terms of modulus of sub grade reaction  $k$ , which is defined as pressure per unit deflection of the foundation as determined by plate bearing tests. As the limiting design deflection for cement concrete pavements is taken as 1.25 mm, the  $k$ -value is determined from the pressure sustained at this deflection. As  $k$ -value is carried out by test plate diameter, the standard test is to be carried out with a 75 cm diameter plate. IS:9214-1974, "Method of Determination of Modulus of Sub grade Reaction of Soil in the field" may be referred. A frequency of one test per km per lane is recommended for assessment of  $k$ -value, unless the foundation changes with respect of sub grade soil, type of sub-base or the nature of formation i.e. cut or fill when additional tests may be conducted. An approximate idea of  $k$ -value of a homogenous soil sub grade may be obtained from its soaked CBR value using Table 5.1. It is advisable to have a filter layer above the sub grade for drainage of water to prevent (i) excessive softening of sub grade and (ii) erosion of the sub grade particularly under adverse moisture condition.

The approximate increases in  $k$ -values of sub grade due to different thickness of sub-bases made up of untreated granular, cement treated granular and dry lean concrete (DLC) layers may be taken from Table 5.2. 7-day unconfined compressive strength of cement treated granular soil should be a minimum of 2.1 MPa. Dry Lean Concrete should have a minimum compressive strength of 7 MPa at 7 days.

**Table 5.1 Approximate k-value corresponding to CBR values for Homogenous Soil Sub grade.**

<b>Soaked CBR value %</b>	2	3	4	5	7	10	15	20	50	100
<b>k-value (kg/cm<sup>2</sup>/cm)</b>	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14.0	22.2

**Table 5.2 K-Values with Dry Lean Concrete Sub-Base**

<b>k-value of sub grade kg/cm<sup>2</sup>/cm</b>	2.1	2.8	4.2	4.8	5.5	6.2
<b>Effective k over 100 mm DLC, kg/cm<sup>2</sup>/cm</b>	5.6	9.7	16.6	20.8	27.8	38.9
<b>Effective k over 150 mm DLC, kg/cm<sup>2</sup>/cm</b>	9.7	13.8	20.8	27.7	41.7	----

The maximum value of effective k will be 38.9 kg/cm<sup>2</sup>/cm for 100 mm of DLC and 41.7 kg/cm<sup>2</sup>/cm for 150 mm of DLC.

### 5.2.2 Separation layer between sub-base and pavement

Foundation layer below concrete slabs should be smooth to reduce the inter layer friction. A separation membrane of minimum thickness of 125 micron polythene is recommended to reduce the friction between concrete slabs and dry lean concrete slab-base (DLC).

## 5.3 CHARACTERISTICS OF CONCRETE

### 5.3.1 Design Strength

The concrete pavements fail due to bending stresses, it is necessary that their design is based on the flexural strength of concrete. The relationship b/w the flexural strength and compressive strength may be worked out. The mix should be so designed that the minimum structural strength requirement in the field is met at the desired level. Thus,

$S^1$  = Characteristics flexural strength at 28 days.

$S$  = Target average flexural strength at 28 days.

$Z_a$  = Tolerance factor for the desired confidence level, known as the standard normal variate.

$\sigma$  = Expected standard deviation of field test samples; if it is not known, it may be initially.

Assumed as per IS: 456-2000

Then the target average flexural strength is given as:

$$S = S^1 + Z_a \sigma$$

For pavement construction, the concrete mix should preferably be designed and controlled on the basis of flexural strength. Flexural strength should be determined by modulus of rupture tests under third point loading. The preferred size of the beam should be 15 cm × 15 cm × 70 cm when the size of the aggregate is more than 19 mm. When the maximum size of aggregate is less than 19 mm, 10 cm × 10 cm × 50 cm beams may be used. IS: 516 should be referred for the test procedure.

### 5.3.2 Fatigue behaviour of cement concrete

Due to repeated application of flexural stresses by the traffic loads, progressive fatigue damage takes place in the cement concrete slab in the form of gradual development of micro-cracks especially when the applied stress in terms of flexural strength of concrete is high. The ratio b/w the flexural stress due to the load and the flexural strength of the concrete is known as stress ratio (SR). If the stress ratio is less than 0.45, the concrete is expected to sustain infinite number of repetitions. As the stress ratio increases, the number of load repetitions required to cause cracking decreases. The relation b/w fatigue life (N) and stress ratio is given as:

N = unlimited for SR < 0.45

$$N = \left( \frac{4.2577}{SR - 0.4325} \right)^{3.268} \quad \text{When } 0.45 \leq SR \leq 0.55$$

$$\log_{10} N = \frac{0.9716 - SR}{0.0828} \quad \text{for } SR > 0.55$$

The values of fatigue life for different values of stress ratio are given in Table 5.3.

## 5.4 DESIGN OF SLAB THICKNESS

Step by step procedure of Design of Slab Thickness Pavement as per IRC 58-2002.

Step1. As per IRC 58-2002, Axle load (AL) in Single Axle and Tandem Axle (Tonnes) is given.

Step2. From the given data, cumulative repetition in 20 yrs. can be calculated from the formula which is given below:

$$C = \frac{365 \times A \{ (1+r)^n - 1 \}}{r}$$

Where,

C= Cumulative number of axles during the design period.

A= Initial number of axles per day in the year when the road is operational.

r= Annual rate of growth of commercial traffic (expressed in decimals).

n=Design period in years.

Step3. After calculating cumulative repetition, Design traffic can be calculated by 25% of cumulative repetition.

Step4. The Single and tandem Axle load is multiplied with a factor of 1.2 respectively.

Step5. Stress ( $\text{kg}/\text{cm}^2$ ) is calculated from the given graphs as mentioned in IRC 58:2002 (Graph between Slab thickness and flexure strength).

Step6. Stress Ratio is calculated from  $\frac{\text{Stress}}{\text{Flexure Strength}}$ .

Step7. Expected Repetition is calculated from the Design Traffic which is multiplied with a percentage of respective Axle loads.

Step 8.Allowable Repetition is calculated from the Table which is mentioned in IRC 58:2002 which is also shown below in Table 5.3.

Step9. Fatigue life consumed is calculated which is the ratio of fatigue life (N) and expected repetition (n). The design is unsafe if the cumulative fatigue life consumed is greater than 1.0.

The slab design process as per IRC 58-2002 for the pavement quality concrete tested in the laboratory is presented in Table 5.6. The Table 5.4 and 5.5 contains the input traffic data in terms of the expected repetitions for the single and tandem axles, for which the slab thickness have been calculated.

Table 5.7 to 5.24 presents the design of slab thickness by calculating the fatigue life consumed for the given axle load traffic (Table 5.5) and flexure strength of PQC achieved in the laboratory. Subsequent the following table presents the design for flexure strengths achieved by varying the percentages of waste foundry sand and steel fibres in the concrete mix.

**Table 5.3 Stress Ratio and Allowable Repetitions in Cement Concrete**

<b>Stress Ratio</b>	<b>Allowable Repetitions</b>	<b>Stress Ratio</b>	<b>Allowable Repetitions</b>
0.45	$6.279 \times 10^7$	0.66	$5.83 \times 10^3$
0.46	$1.4335 \times 10^7$	0.67	$4.41 \times 10^3$
0.47	$5.2 \times 10^6$	0.68	$3.34 \times 10^3$
0.48	$2.4 \times 10^6$	0.69	2531
0.49	$1.287 \times 10^6$	0.70	1970
0.50	$7.62 \times 10^5$	0.71	1451
0.51	$4.85 \times 10^5$	0.72	1099
0.52	$3.26 \times 10^5$	0.73	832
0.53	$2.29 \times 10^5$	0.74	630
0.54	$1.66 \times 10^5$	0.75	477
0.55	$1.24 \times 10^5$	0.76	361
0.56	$9.41 \times 10^4$	0.77	274
0.57	$7.12 \times 10^4$	0.78	207
0.58	$5.4 \times 10^4$	0.79	157
0.59	$4.08 \times 10^4$	0.80	119
0.60	$3.09 \times 10^4$	0.81	90
0.61	$2.34 \times 10^4$	0.82	68
0.62	$1.77 \times 10^4$	0.83	52
0.63	$1.34 \times 10^4$	0.84	39
0.64	$1.02 \times 10^4$	0.85	30
0.65	$7.7 \times 10^3$		

**Table 5.4 Design of Rigid Pavement as Per IRC: 58-2002**

Design Life	N	30 years
Design Wheel Load	P	7000 kg
Present Traffic Intensity	T <sub>b</sub>	474 CVD
28 days Compressive Strength of Concrete	f <sub>ck</sub>	450 kg/cm <sup>2</sup>
Flexure Strength of concrete	F <sub>ck</sub>	50.90 kg/cm <sup>2</sup>
Modulus of Elasticity of Concrete	E	300000 Kg/cm <sup>2</sup>
Poission's Ratio of concrete	μ	0.15
Coefficient of Thermal Expansion of Concrete	A	10.0×10 <sup>-6</sup> per °c
Subgrade CBR	%	7.000
K value of Subgrade	K <sub>sg</sub>	4.800 kg/cm <sup>3</sup>
Subbase Type		3
Thickness of Dry Lean Concrete >= 10 cm		15 cm
K Value of Subbase	K <sub>sb</sub>	27.700 kg/cm <sup>3</sup>
Zone of Project Corridor for Temperature		1 No.
Concrete Slab Thickness	H	22.7 cm
Temp. Difference b/w Top And Bottom Layer	D <sub>t</sub>	13.748 °C
Spacing of Contraction Joints	L	4.5 m
Length of Slab (Lane Width)	W	3.5 m
Tyre Pressure	P	8 kg/cm <sup>2</sup>
c/c Distance Between two Tyres	S	31 cm
Load Safety Factor For Fatigue analysis	LSF	1.2

**Table 5.5 Axle Load Spectrum**

Single Axle Load		Tandem Axle Load	
Load in Tones	Expected Repetitions	Load in Tones	Expected repetitions
27-29	0.00		
25-27	0.00		
23-25	0.00	42-46	0.00
21-23	0.00	38-42	0.00
19-21	0.00	34-38	0.00
17-19	0.00	30-34	0.00
15-17	2.08	26-30	0.00
13-15	6.25	22-26	1.74
11-13	18.06	18-22	7.99
09-11	17.71	14-18	12.50
< 09	26.04	< 14	7.64
Total	70.14	Total	29.86

Cumulative Repetitions in 30 Years = 45978340 CVD

Design Traffic = 11494585 CVD

Radius of Relative Stiffness (l) = 57.326 cm

**Table 5.6 Fatigue Analysis (Slab Design for Mix MF00)**

Flexure Strength = 50.9 kg/cm <sup>2</sup> Slab thickness = 22.7 cm						
Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm <sup>2</sup> (from Charts)	Stress Ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
Single Axle						
20	24.0	31.782	0.62	0	15692.810	0.00
18	21.6	29.280	0.58	0	61562.128	0.00
16	19.2	26.657	0.52	239471	284931.685	0.84044890
14	16.8	23.948	0.47	718412	4989856.127	0.14397440
12	14.4	21.153	0.42	2075411	∞	0.00
10	12.0	18.261	0.36	2035499	∞	0.00
8	9.6	15.221	0.30	2993382	∞	0.00
6	7.2	12.02	0.24	8062174	∞	0.00
Tandem Axle						
36	43.2	26.10	0.51	0	433996.691	0.00
32	38.4	20.92	0.41	0	∞	0.00
28	33.6	18.89	0.37	0	∞	0.00
24	28.8	16.78	0.33	199559	∞	0.00
20	24.0	14.59	0.29	917970	∞	0.00
16	19.2	12.39	0.24	1436823	∞	0.00
12	14.4	10.26	0.20	878059	∞	0.00

Cumulative Fatigue Damage/ Life Consumes

**0.9844**

Check for Fatigue Life

**SAFE**

Check for Temperature Stress:		
	L/I	7.850
	B/I	6.105
Bradbury's Coefficient	C	1.107
Edge warping stress	$S_{te}$	22.06 kg/cm <sup>2</sup>
Maximum Load stress		26.66 kg/cm <sup>2</sup>
Total Temperature stresses		48.72 kg/cm <sup>2</sup>
Check for Temperature stress		<b>SAFE</b>
Check for corner Stress:		
Radius of load contact Area	A	25.32 cm
Radius of equivalent distribution of pressure	B	23.93 cm
Corner Stress	$S_c$	17.59 kg/cm <sup>2</sup>
Check for Corner Stress		<b>SAFE</b>

**The Assumed Slab Thickness is Safe**

**Table 5.7 Slab Design for Mix (MF10)**

Flexure Strength =49.1 kg/cm <sup>2</sup> Slab thickness = 23.3 cm						
Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm <sup>2</sup> (from Charts)	Stress Ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	30.659	0.62	0	15681.702	0.00
18	21.6	28.245	0.58	0	61530.871	0.00
16	19.2	25.708	0.52	239471	286142.591	0.83689227
14	16.8	23.087	0.47	718412	5114938.584	0.14045360
12	14.4	20.384	0.42	2075411	∞	0.00
10	12.0	17.588	0.36	2035499	∞	0.00
8	9.6	14.652	0.30	2993382	∞	0.00
6	7.2	11.56	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	25.23	0.51	0	415125.244	0.00
32	38.4	20.18	0.41	0	∞	0.00
28	33.6	18.22	0.37	0	∞	0.00
24	28.8	16.16	0.33	199559	∞	0.00
20	24.0	14.04	0.29	917970	∞	0.00
16	19.2	11.93	0.24	1436823	∞	0.00
12	14.4	9.87	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9773

Check for Fatigue Life **SAFE**

**Table 5.8 Slab Design for Mix (MF20)**

Flexure Strength = 50.3 kg/cm <sup>2</sup> Slab thickness = 22.9 cm						
Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm <sup>2</sup> (from Charts)	Stress Ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	31.400	0.62	0	15756.806	0.00
18	21.6	28.928	0.58	0	61796.406	0.00
16	19.2	26.334	0.52	239471	286671.007	0.83534963
14	16.8	23.655	0.47	718412	5082456.621	0.14135124
12	14.4	20.892	0.42	2075411	∞	0.00
10	12.0	18.032	0.36	2035499	∞	0.00
8	9.6	15.027	0.30	2993382	∞	0.00
6	7.2	11.86	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	25.80	0.51	0	429749.712	0.00
32	38.4	20.67	0.41	0	∞	0.00
28	33.6	18.66	0.37	0	∞	0.00
24	28.8	16.57	0.33	199559	∞	0.00
20	24.0	14.40	0.29	917970	∞	0.00
16	19.2	12.23	0.24	1436823	∞	0.00
12	14.4	10.13	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9767

Check for Fatigue Life **SAFE**

**Table 5.9 Slab Design for Mix (MF30)**

Flexure Strength = 52.1 kg/cm <sup>2</sup> Slab thickness = 22.35 cm						
Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm <sup>2</sup> (from Charts)	Stress Ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	32.470	0.62	0	16213.585	0.00
18	21.6	29.914	0.58	0	63436.293	0.00
16	19.2	27.238	0.52	239471	294333.828	0.81360176
14	16.8	24.475	0.47	718412	5303834.968	0.13545134
12	14.4	21.625	0.42	2075411	∞	0.00
10	12.0	18.674	0.36	2035499	∞	0.00
8	9.6	15.571	0.30	2993382	∞	0.00
6	7.2	12.30	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	26.63	0.51	0	463601.650	0.00
32	38.4	21.38	0.41	0	∞	0.00
28	33.6	19.30	0.37	0	∞	0.00
24	28.8	17.15	0.33	199559	∞	0.00
20	24.0	14.93	0.29	917970	∞	0.00
16	19.2	12.68	0.24	1436823	∞	0.00
12	14.4	10.51	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9491

Check for Fatigue Life **SAFE**

**Table 5.10 Slab Design for Mix (MF40)**

Flexure Strength =51.7 kg/cm <sup>2</sup> Slab thickness = 22.45 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	32.271	0.62	0	15782.653	0.00
18	21.6	29.730	0.58	0	61882.899	0.00
16	19.2	27.070	0.52	239471	286087.383	0.83705376
14	16.8	24.323	0.47	718412	5000530.905	0.14366706
12	14.4	41.489	0.42	2075411	∞	0.00
10	12.0	18.554	0.36	2035499	∞	0.00
8	9.6	15.470	0.30	2993382	∞	0.00
6	7.2	12.22	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	26.47	0.51	0	445234.123	0.00
32	38.4	21.24	0.41	0	∞	0.00
28	33.6	19.18	0.37	0	∞	0.00
24	28.8	17.05	0.33	199559	∞	0.00
20	24.0	14.83	0.29	917970	∞	0.00
16	19.2	12.60	0.24	1436823	∞	0.00
12	14.4	10.44	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9807

Check for Fatigue Life

**SAFE**

**Table 5.11 Slab Design for Mix (MF50)**

Flexure Strength = 51.1 kg/cm <sup>2</sup> Slab thickness = 22.65 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	31.879	0.62	0	15934.848	0.00
18	21.6	29.369	0.58	0	62435.588	0.00
16	19.2	26.739	0.52	239471	289572.883	0.82697840
14	16.8	24.022	0.47	718412	5160529.183	0.13921277
12	14.4	21.220	0.42	2075411	∞	0.00
10	12.0	18.319	0.36	2035499	∞	0.00
8	9.6	15.270	0.30	2993382	∞	0.00
6	7.2	12.06	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	26.17	0.51	0	443736.826	0.00
32	38.4	20.99	0.41	0	∞	0.00
28	33.6	18.94	0.37	0	∞	0.00
24	28.8	16.83	0.33	199559	∞	0.00
20	24.0	14.64	0.29	917970	∞	0.00
16	19.2	12.43	0.24	1436823	∞	0.00
12	14.4	10.30	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9662

Check for Fatigue Life **SAFE**

**Table 5.12 Slab Design for Mix (MF11)**

<b>Flexure Strength =61.0 kg/cm<sup>2</sup>      Slab thickness = 20.00 cm</b>						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	37.843	0.62	0	17545.180	0.00
18	21.6	34.866	0.58	0	68175.973	0.00
16	19.2	31.782	0.52	239471	314224.365	0.76210042
14	16.8	28.605	0.47	718412	5715091.528	0.12570430
12	14.4	25.321	0.42	2075411	∞	0.00
10	12.0	21.912	0.36	2035499	∞	0.00
8	9.6	18.316	0.30	2993382	∞	0.00
6	7.2	14.51	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	30.76	0.51	0	624416.838	0.00
32	38.4	24.91	0.41	0	∞	0.00
28	33.6	22.51	0.37	0	∞	0.00
24	28.8	20.11	0.33	199559	∞	0.00
20	24.0	17.58	0.29	917970	∞	0.00
16	19.2	14.93	0.24	1436823	∞	0.00
12	14.4	12.42	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.8878

Check for Fatigue Life **SAFE**

**Table 5.13 Slab Design for Mix (MF21)**

Flexure Strength =61.7 kg/cm <sup>2</sup> Slab thickness = 19.80 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	38.371	0.62	0	16819.778	0.00
18	21.6	35.353	0.58	0	65570.583	0.00
16	19.2	32.229	0.52	239471	299289.127	0.80013104
14	16.8	29.011	0.47	718412	5111695.326	0.14054272
12	14.4	25.685	0.42	2075411	∞	0.00
10	12.0	22.231	0.36	2035499	∞	0.00
8	9.6	18.587	0.30	2993382	∞	0.00
6	7.2	14.73	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	31.16	0.51	0	601457.033	0.00
32	38.4	25.26	0.41	0	∞	0.00
28	33.6	22.83	0.37	0	∞	0.00
24	28.8	20.40	0.33	199559	∞	0.00
20	24.0	17.84	0.29	917970	∞	0.00
16	19.2	15.15	0.24	1436823	∞	0.00
12	14.4	12.61	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9407

Check for Fatigue Life **SAFE**

**Table 5.14 Slab Design for Mix (MF31)**

Flexure Strength =62.9 kg/cm <sup>2</sup> Slab thickness = 19.50 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	39.187	0.62	0	16308.258	0.00
18	21.6	36.105	0.58	0	63724.923	0.00
16	19.2	32.919	0.52	239471	288505.090	0.83003915
14	16.8	29.640	0.47	718412	4685020.981	0.15334223
12	14.4	26.248	0.42	2075411	∞	0.00
10	12.0	22.725	0.36	2035499	∞	0.00
8	9.6	19.006	0.30	2993382	∞	0.00
6	7.2	15.07	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	31.79	0.51	0	593842.170	0.00
32	38.4	25.80	0.41	0	∞	0.00
28	33.6	23.32	0.37	0	∞	0.00
24	28.8	20.85	0.33	199559	∞	0.00
20	24.0	18.24	0.29	917970	∞	0.00
16	19.2	15.50	0.24	1436823	∞	0.00
12	14.4	12.90	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9834

Check for Fatigue Life **SAFE**

**Table 5.15 Slab Design for Mix (MF41)**

Flexure Strength =62.4 kg/cm <sup>2</sup> Slab thickness = 19.65 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	38.776	0.62	0	17053.514	0.00
18	21.6	35.725	0.58	0	66406.445	0.00
16	19.2	32.571	0.52	239471	303421.118	0.78923485
14	16.8	29.323	0.47	718412	5240534.202	0.13708747
12	14.4	25.963	0.42	2075411	∞	0.00
10	12.0	22.476	0.36	2035499	∞	0.00
8	9.6	18.795	0.30	2993382	∞	0.00
6	7.2	14.90	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	31.47	0.51	0	611107.852	0.00
32	38.4	25.53	0.41	0	∞	0.00
28	33.6	23.07	0.37	0	∞	0.00
24	28.8	20.62	0.33	199559	∞	0.00
20	24.0	18.04	0.29	917970	∞	0.00
16	19.2	15.32	0.24	1436823	∞	0.00
12	14.4	12.75	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9263

Check for Fatigue Life **SAFE**

**Table 5.16 Slab Design for Mix (MF51)**

Flexure Strength =61.5 kg/cm <sup>2</sup> Slab thickness = 19.85 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	38.238	0.62	0	16886.793	0.00
18	21.6	35.230	0.58	0	65812.291	0.00
16	19.2	32.116	0.52	239471	300747.957	0.79624987
14	16.8	28.909	0.47	718412	5173176.838	0.13887242
12	14.4	25.593	0.42	2075411	∞	0.00
10	12.0	22.151	0.36	2035499	∞	0.00
8	9.6	18.519	0.30	2993382	∞	0.00
6	7.2	14.67	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	31.06	0.51	0	601838.313	0.00
32	38.4	25.17	0.41	0	∞	0.00
28	33.6	22.75	0.37	0	∞	0.00
24	28.8	20.32	0.33	199559	∞	0.00
20	24.0	17.77	0.29	917970	∞	0.00
16	19.2	15.10	0.24	1436823	∞	0.00
12	14.4	12.56	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9351

Check for Fatigue Life **SAFE**

**Table 5.17 Slab Design for Mix (MF12)**

Flexure Strength =65.5 kg/cm <sup>2</sup> Slab thickness = 19.00 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	40.616	0.62	0	17687.320	0.00
18	21.6	37.421	0.58	0	68662.206	0.00
16	19.2	34.129	0.52	239471	313877.030	0.76294376
14	16.8	30.740	0.47	718412	5524179.392	0.13004856
12	14.4	27.234	0.42	2075411	∞	0.00
10	12.0	25.591	0.36	2035499	∞	0.00
8	9.6	19.742	0.30	2993382	∞	0.00
6	7.2	15.66	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	32.88	0.51	0	694645.284	0.00
32	38.4	26.74	0.41	0	∞	0.00
28	33.6	24.17	0.37	0	∞	0.00
24	28.8	21.63	0.33	199559	∞	0.00
20	24.0	18.95	0.29	917970	∞	0.00
16	19.2	16.10	0.24	1436823	∞	0.00
12	14.4	13.41	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.8930

Check for Fatigue Life **SAFE**

**Table 5.18 Slab Design for Mix (MF22)**

Flexure Strength =67.9 kg/cm <sup>2</sup> Slab thickness = 18.45 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	42.295	0.62	0	16361.739	0.00
18	21.6	38.968	0.58	0	63894.254	0.00
16	19.2	35.550	0.52	239471	286461.168	0.83596155
14	16.8	32.034	0.47	718412	4469523.871	0.16073559
12	14.4	28.394	0.42	2075411	∞	0.00
10	12.0	24.609	0.36	2035499	∞	0.00
8	9.6	20.608	0.30	2993382	∞	0.00
6	7.2	16.36	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	34.16	0.51	0	660352.901	0.00
32	38.4	27.85	0.41	0	∞	0.00
28	33.6	25.18	0.37	0	∞	0.00
24	28.8	22.56	0.33	199559	∞	0.00
20	24.0	19.79	0.29	917970	∞	0.00
16	19.2	16.81	0.24	1436823	∞	0.00
12	14.4	14.02	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9967

Check for Fatigue Life **SAFE**

**Table 5.19 Slab Design for Mix (MF32)**

Flexure Strength = 71.0 kg/cm <sup>2</sup> Slab thickness = 17.9 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	44.096	0.62	0	17210.806	0.00
18	21.6	40.629	0.58	0	66929.360	0.00
16	19.2	37.076	0.52	239471	300979.206	0.79563809
14	16.8	33.424	0.47	718412	4871850.759	0.14746173
12	14.4	29.641	0.42	2075411	∞	0.00
10	12.0	25.705	0.36	2035499	∞	0.00
8	9.6	21.540	0.30	2993382	∞	0.00
6	7.2	17.11	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	35.52	0.51	0	749516.517	0.00
32	38.4	29.03	0.41	0	∞	0.00
28	33.6	26.26	0.37	0	∞	0.00
24	28.8	23.56	0.33	199559	∞	0.00
20	24.0	20.69	0.29	917970	∞	0.00
16	19.2	17.58	0.24	1436823	∞	0.00
12	14.4	14.67	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9431

Check for Fatigue Life **SAFE**

**Table 5.20 Slab Design for Mix (MF42)**

Flexure Strength = 68.9 kg/cm <sup>2</sup> Slab thickness = 18.3 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	42.773	0.62	0	17342.658	0.00
18	21.6	39.409	0.58	0	67411.752	0.00
16	19.2	35.955	0.52	239471	304838.138	0.78556615
14	16.8	32.403	0.47	718412	5071547.724	0.14165529
12	14.4	28.725	0.42	2075411	∞	0.00
10	12.0	24.900	0.36	2035499	∞	0.00
8	9.6	20.855	0.30	2993382	∞	0.00
6	7.2	16.56	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	34.52	0.51	0	726068.868	0.00
32	38.4	28.16	0.41	0	∞	0.00
28	33.6	25.47	0.37	0	∞	0.00
24	28.8	22.83	0.33	199559	∞	0.00
20	24.0	20.03	0.29	917970	∞	0.00
16	19.2	17.01	0.24	1436823	∞	0.00
12	14.4	14.19	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9272

Check for Fatigue Life **SAFE**

**Table 5.21 Slab Design for Mix (MF52)**

Flexure Strength =68.0 kg/cm <sup>2</sup> Slab thickness = 18.45 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	42.295	0.62	0	16783.887	0.00
18	21.6	38.968	0.58	0	65411.607	0.00
16	19.2	35.550	0.52	239471	294521.651	0.81308291
14	16.8	32.034	0.47	718412	4737524.585	0.15164281
12	14.4	28.394	0.42	2075411	∞	0.00
10	12.0	24.609	0.36	2035499	∞	0.00
8	9.6	20.608	0.30	2993382	∞	0.00
6	7.2	16.36	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	34.16	0.51	0	683505.101	0.00
32	38.4	27.85	0.41	0	∞	0.00
28	33.6	25.18	0.37	0	∞	0.00
24	28.8	22.56	0.33	199559	∞	0.00
20	24.0	19.79	0.29	917970	∞	0.00
16	19.2	16.81	0.24	1436823	∞	0.00
12	14.4	14.02	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9647

Check for Fatigue Life **SAFE**

**Table 5.22 Slab Design for Mix (MF01)**

Flexure Strength = 59.5 kg/cm <sup>2</sup> Slab thickness = 20.3 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	37.075	0.62	0	16267.393	0.00
18	21.6	34.158	0.58	0	63593.898	0.00
16	19.2	31.132	0.52	239471	289958.918	0.82587741
14	16.8	28.014	0.47	718412	4848450.938	0.14817342
12	14.4	24.791	0.42	2075411	∞	0.00
10	12.0	21.447	0.36	2035499	∞	0.00
8	9.6	17.922	0.30	2993382	∞	0.00
6	7.2	14.19	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	30.17	0.51	0	550619.594	0.00
32	38.4	24.41	0.41	0	∞	0.00
28	33.6	22.05	0.37	0	∞	0.00
24	28.8	19.68	0.33	199559	∞	0.00
20	24.0	17.20	0.29	917970	∞	0.00
16	19.2	14.61	0.24	1436823	∞	0.00
12	14.4	12.14	0.20	878059	∞	0.00
<b>Cumulative fatigue Damage/ Life Consumed</b>						<b>0.9741</b>

Check for Fatigue Life

**SAFE**

**Table 5.23 Slab Design for Mix (MF02)**

Flexure Strength = 66.1 kg/cm <sup>2</sup> Slab thickness = 18.3 cm						
<b>Axle load(AL), tonnes</b>	<b>A.L × 1.2</b>	<b>Stress kg/cm<sup>2</sup> (from Charts)</b>	<b>Stress Ratio</b>	<b>Expected repetition, n</b>	<b>Fatigue life, N</b>	<b>Fatigue life consumed</b>
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	41.062	0.62	0	17144.020	0.00
18	21.6	37.833	0.58	0	66713.170	0.00
16	19.2	34.506	0.52	239471	302731.488	0.79103275
14	16.8	31.084	0.47	718412	5086378.625	0.14124225
12	14.4	27.542	0.42	2075411	∞	0.00
10	12.0	23.861	0.36	2035499	∞	0.00
8	9.6	19.972	0.30	2993382	∞	0.00
6	7.2	15.85	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	33.22	0.51	0	675724.359	0.00
32	38.4	27.03	0.41	0	∞	0.00
28	33.6	24.44	0.37	0	∞	0.00
24	28.8	21.88	0.33	199559	∞	0.00
20	24.0	19.18	0.29	917970	∞	0.00
16	19.2	16.29	0.24	1436823	∞	0.00
12	14.4	13.57	0.20	878059	∞	0.00

Cumulative fatigue Damage/ Life Consumed 0.9323

Check for Fatigue Life **SAFE**

**Table 5.24 Slab Design for Mix (MF02) (UNSAFE)**

Flexure Strength = 66.1 kg/cm <sup>2</sup> Slab thickness = 18.8 cm						
Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm <sup>2</sup> (from Charts)	Stress Ratio	Expected repetition, n	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
<b>Single Axle</b>						
20	24.0	41.213	0.62	0	16091.344	0.00
18	21.6	37.972	0.58	0	62928.615	0.00
16	19.2	34.634	0.52	239471	282359.222	0.84810589
14	16.8	31.200	0.47	718412	4384158.744	0.16386532
12	14.4	27.646	0.42	2075411	∞	0.00
10	12.0	23.953	0.36	2035499	∞	0.00
8	9.6	20.050	0.30	2993382	∞	0.00
6	7.2	15.91	0.24	8062174	∞	0.00
<b>Tandem Axle</b>						
36	43.2	33.33	0.51	0	623752.351	0.00
32	38.4	27.13	0.41	0	∞	0.00
28	33.6	24.53	0.37	0	∞	0.00
24	28.8	21.96	0.33	199559	∞	0.00
20	24.0	19.25	0.29	917970	∞	0.00
16	19.2	16.35	0.24	1436823	∞	0.00
12	14.4	13.63	0.20	878059	∞	0.00

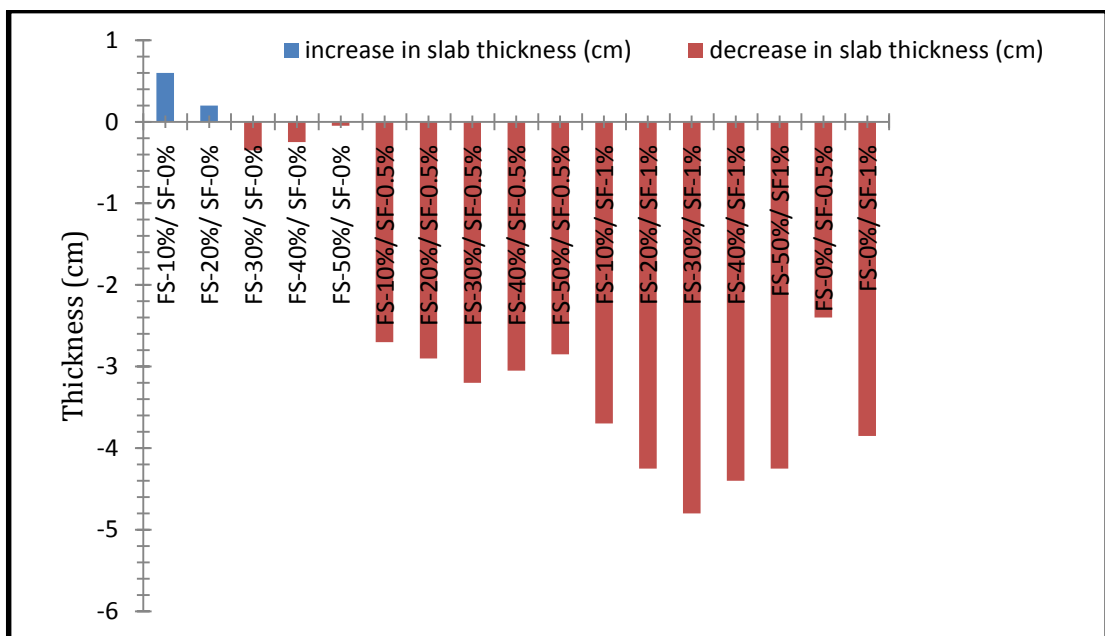
Cumulative fatigue Damage/ Life Consumed 1.0120

Check for Fatigue Life

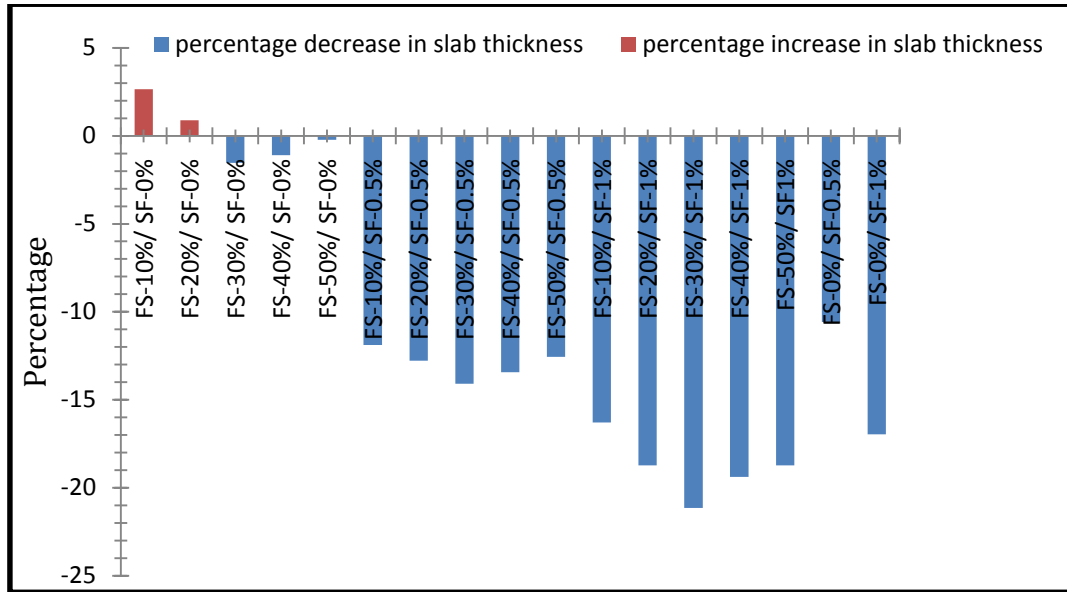
**UNSAFE**

**Table 5.25 Thickness of Concrete Slab**

Sample ID	Concrete Slab Thickness			
	Increase in slab thickness (cm)	Decrease in slab thickness (cm)	Percentage increase in slab thickness	Percentage decrease in slab thickness
FS-10%/SF-0%	0.6		2.64	
FS-20%/SF-0%	0.2		0.88	
FS-30%/SF-0%		-0.35		-1.54
FS-40%/SF-0%		0.25		-1.10
FS-50%/SF-0%		-0.05		-0.22
FS-10%/SF-0.5%		-2.7		-11.89
FS-20%/SF-0.5%		-2.9		-12.78
FS-30%/SF-0.5%		-3.2		-14.10
FS-40%/SF-0.5%		-3.05		-13.44
FS-50%/SF-0.5%		-2.85		-12.56
FS-10%/SF-1%		-3.7		-16.30
FS-20%/SF-1%		-4.25		-18.73
FS-30%/SF-1%		-4.8		-21.15
FS-40%/SF-1%		-4.4		-19.38
FS-50%/SF-1%		-4.25		-18.72
FS-0%/SF-0.5%		-2.4		-10.57
FS-0%/SF-1%		-3.85		-16.96



**Fig. 5.1 Variation of slab thickness (cm)**

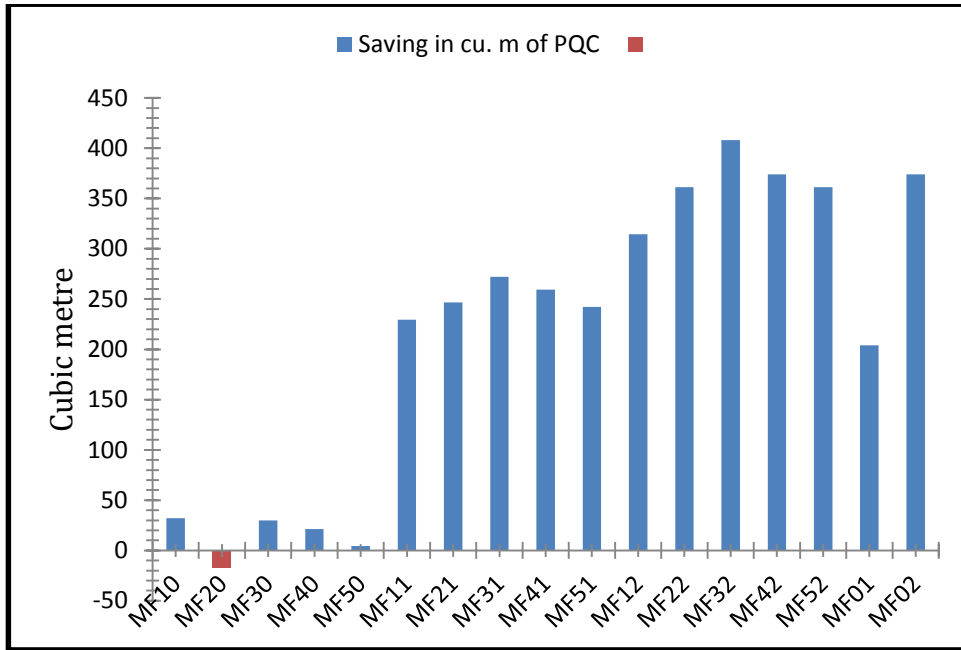


**Fig. 5.2 Percentage variation of slab thickness**

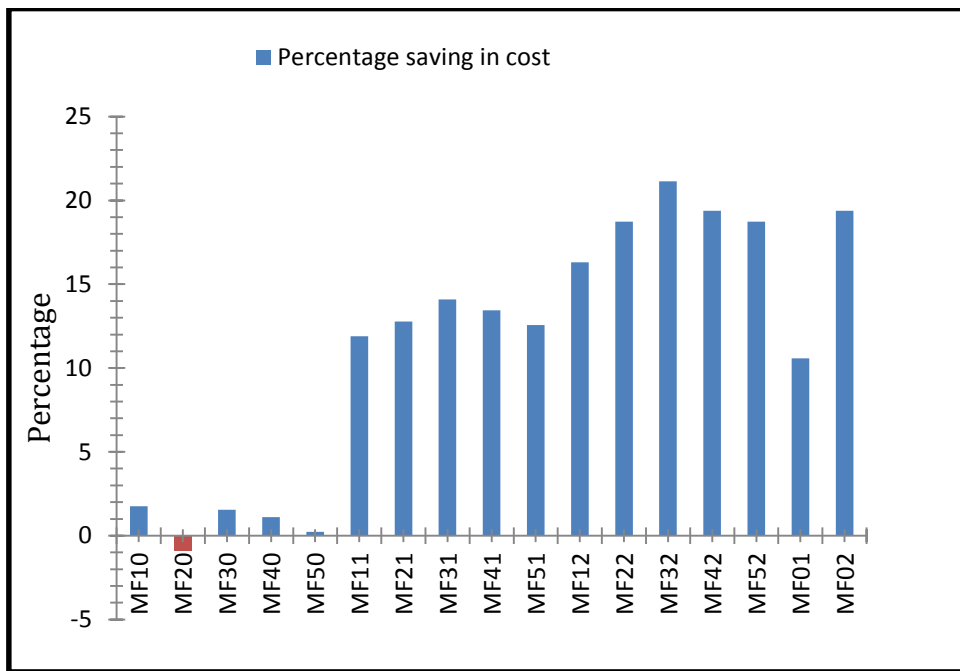
Table 5.25 and fig. 5.1, 5.2 shows the variation in slab thickness and it has been found that maximum percentage in slab thickness is 21.14 on replacing 30% waste foundry sand and 1% steel fibre.

**Table 5.26 Saving in cubic metre of PQC and Cost**

Mix ID	Length=1000m & Width=8.5m		
	cu.m of PQC	Saving in cu.m of PQC	Percentage saving in cost
(MF00)	1929.50		
(MF10)	1895.50	34.00	1.76
(MF20)	1946.50	-17.00	-0.88
(MF30)	1899.75	29.75	1.54
(MF40)	1908.25	21.25	1.10
(MF50)	1925.25	4.25	0.22
(MF11)	1700.00	229.50	11.89
(MF21)	1683.00	246.50	12.76
(MF31)	1657.50	272.00	14.10
(MF41)	1670.25	259.25	13.44
(MF51)	1687.25	242.25	12.56
(MF12)	1615.00	314.50	16.30
(MF22)	1568.25	361.25	18.72
(MF32)	1521.50	408.00	21.14
(MF42)	1555.50	374.00	19.38
(MF52)	1568.25	361.25	18.72
(MF01)	1725.50	204.00	10.57
(MF02)	1555.50	374.00	19.38



**Fig. 5.3 Saving in cubic metre of PQC**



**Fig. 5.4 Percentage saving in cost**

Table 5.26 and fig. 5.3, 5.4 shows savings in cu.m of PQC and percentage savings in cost and maximum savings in cost and cu.m of PQC is found on replacing 30% waste foundry sand and 1% steel fibre. Also it is found than on replacing of waste foundry sand and addition of steel fibre the results are very significant.

### CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

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#### 6.1 GENERAL

The present study was undertaken to investigate the compressive strength and flexure strength of concrete with different level of replacement of fine aggregates with waste foundry sand and addition of steel fibres in the concrete mix. Fine aggregates was partially replaced by waste foundry sand at six different levels of replacement i.e. 0%, 10%, 20%, 30%, 40% and 50% and steel fibre is added in concrete mix at different percentages i.e. 0%, 0.5% and 1%. Tests were performed after 7 days and 28 days of curing of concrete. 9 samples of reference mix i.e. with 0% waste foundry sand and 0% steel fibre and 153 samples of waste foundry sand and steel fibre in concrete with different percentage were prepared for determining compressive strength and flexure strength of concrete with water-cement ratio as 0.36 for 4.69 N/mm<sup>2</sup> (Target Mean Flexure Strength). Super plasticizer was used in all the mixes at 0.8% level by weight of cementitious material.

#### 6.2 CONCLUSION

From the experimental results, the following conclusion can be drawn:

##### **Strength Characteristics**

- ❖ Concrete mix with 30 percent waste foundry sand as replacement of fine aggregates and 1% addition of steel fibre is the optimum level and it has been observed to show a significant increase in compressive strength at 7days and 28 days when compared with nominal mix.
- ❖ The flexure strength also tends to increase with the increase percentage of steel fibre, a trend similar to increase in compressive strength.
- ❖ On increasing the percentage replacement of fine aggregate with waste foundry sand beyond 30%, there is decrease in compressive and flexure strength value.

- ❖ Maximum strength (compressive and flexure strength) of pavement quality concrete incorporating waste foundry sand and steel fibres, both, is achieved for 30% waste foundry sand and 1% steel fibres. However, if the waste foundry sand content is increased to 30%, even with 1% steel fibre, the strength increases but less than as in 30% waste foundry sand and 1% steel fibre.

### **6.3. SAVING IN DESIGN OF SLAB THICKNESS AND COST IN PQC**

According to the results of the study, compiled for various mixes incorporating waste foundry sand and steel fibre other than nominal mix, there is significant decrease in thickness of slab. The first two mixes (10% waste foundry sand & 0% steel fibre and 20% waste foundry sand & 0% steel fibre) shows an increase in slab thickness and in rest of the mixes slab thickness decreases. The maximum decrease in thickness of slab is 4.8 cm. From all the mixes, 408 cubic metre of PQC is saved on replacing 30% waste foundry sand and adding 1% steel fibre also maximum percentage saving in cost is 21.14 is achieved.

### **6.4 SCOPE FOR FUTURE WORK**

- ❖ In the present study experimental program was devised to study the strength characteristics of mixes containing waste foundry sand and steel fibre. The work can be extended to study the durability characteristics as well.
- ❖ The performance of the pavement quality concrete slabs containing waste foundry sand and steel fibre can be evaluated by constructing the trial stretches. The behaviour of these Pavement Quality Concrete (PQC) slabs can be analysed under repetitive loading for the fatigue life consumed.

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