IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

EARLIEST DEDUCTION OF INTERNAL CRACKS OF REINFORECED CONCRETE WITH SILICA FUME BY USING FIBRE OPTIC CABLE

ASWINTH S
DINESH M S
PRASANNA S
NAVIN V
SHREE NAVEEN J B

SRI SHAKTHI INSTITUTE OF ENGINEERING AND TECHNOLOGY
(An Autonomous Institution)

ABSTRACT

In reinforced concrete structures, damage can occur due to heavy loads or prolonged stress. Currently, the tools available for inspections struggle to identify slow, subtle damage, particularly in hard-to-reach areas of the structure. In this context, we propose the use of advanced sensors to evaluate their effectiveness in detecting damage, though actual testing has not been conducted as of now.

To assess the potential of these sensors, a benchmark bending test on a typical concrete structure was considered. The objective was to determine whether these sensors could identify early signs of cracking and explore the possibility of utilizing silica fume as a remedy.

Various methods for analyzing fibre optic sensors were contemplated. By studying these signals,

the aim was to monitor the internal cracks in the structure. Several non- destructive evaluation methods were also considered to assess the condition of the concrete structure without causing any harm.

The result is that our fibre optic sensors can detect cracks with a 100% success rate, even before your eyes or using other methods. This should demonstrate that a sensor-based method can be used to detect cracks earlierby using this sensor thecnology.

CHAPTER 1 INTRODUCTION

1.1 GENERAL

Occurrence of various cracks patterns in the building during construction, and after completion when it is subjected to super imposed load or during the service life, is a common phenomenon. A building component develops cracks whenever the stress in the component exceeds its strength. Stress in the building component could be caused by externally applied forces, such as dead, live, wind and seismic loads, foundation settlement etc. or it could be induced internally due to thermal movement, moisture changes elastic deformation, chemical reaction etc.

Cracks in building could be broadly classified into two, as

- Structural cracks
- Non-Structural cracks.

1.1.1 Structural Cracks

These occur due to incorrect design, faulty construction or overloading and these may endanger the safety of the building eg extensive cracking of an RCC beam (rein force concrete course)

1.1.2 Non-Structural Cracks

These are mostly due to internally induced stresses in building but may look unsightly, or may create an impression of faulty work or may give a feeling of instability in some situation due to penetration of moisture through them, non- structural cracks may spoil the internal finishes thus adding to the cost of maintenance, or corrode the reinforcement, thereby adversely affecting the stability of the structure in long run e.g. vertical crack in a long compound wall due to shrinkage or thermal movement.

Cracks may appreciably vary in width from thin hair crack barely visible tonaked eye to gaping crack. Depending upon the crack width crack ar e classified as.

(a) Thin Crack — less than 1 mm in width

(b) Medium Crack — 1 to 2mm in width

(c) Wide Crack — more than 2mm in width

(d) Crazing — Occurrence of closely fine cracks at the surface of a material these is called crazing.

Cracks may be of uniform width throughout or may be narrow at one end gradually widening at the other end. Cracks may be straight, toothed, stepped, map pattern or random type and may be vertical, horizontal or diagonal.

Cracks may be only surface and extend to more than one layer of materials. Cracks due to different causes have varying characteristics and by the careful observations of these characteristics, one can diagnose the causes of cracking for adopting the appropriate reduced measures. Small magnitude causing tension and shear stresses can lead to cracking. Internal stress are induced in the building component on account of thermal movements, moisture change, elastic deformation, chemical reaction etc.

All these phenomenon causes dimensional changes in the building components, and whenever this movement is restraint due to interconnectivity of various member, resistance between the different layers of the components etc. stresses are induced and whenever these stresses (tensile or shear) exceed the strength of material cracks occurs.

Depending upon the cause and certain physical properties of building materials, these cracks may be wide, but further apart or may be thin but more closely space. As a rule, thin cracks even though closely spaced and greater in number, are 1ess damaging to the structures and are not so objectionable from aesthetic to the structure and other consideration as fewer number of wider cracks.

1.2 STATEMENT OF THE PROBLEM

The statement of the problem can as well be the causes of crack in building.

Which are as stated belowFor the structural cracks

- Incorrect design
- Faulty construction
- Overloading

Cracking of an RCC beam which can lead to extensive cracking of RCC beamwhich may endanger the building safety.

Non-structural cracks involved

- Moisture change
- Thermal movement
- Elastic deformation
- Creep
- Chemical reaction
- Foundation movement and settlement of soil
- Growth of vegetation

Those elements are mostly due to internally induced stresses in building materials and do not endanger safety of a building but may look unsightly, or may create an impression of faulty work or may give a feeling of instability in some situation due to penetration of moisture through them. Non-structural cracks may spoil the internal finishes thus adding to the cost of maintenance, or corrode the reinforcement thereby adversely affecting the stability of the structure in the long run e.g: vertical crack in a long compound wall due to shrinkage or thermal movement.

1.3 TYPES OF CRACKS & CAUSES

1.3.1 CRACKS

Investigation into the causes, effects, and prevention of cracks in building. This is an essential topic which need to be investigated in other not to cause fear with building user and building unsightly. There are many ways in which cracks may occur in reinforce concrete, block and brick wall structures. Some of the causes effects and remedies of cracks will be discoursed.

Crack in building are defects that may lead to collapse of building structure thus: there is need for adequate study into this topic to avoid the failure of the structure.

Types of cracks and their characteristic, building when designed should be checked for serviceability condition the following.

1.3.2 TYPES OF CRACKS

1. Thin – Hair cracks _ less than 1mm in width
2. Medium crack - between 1-2 mm width
3. Deep- wide crack _ ranges above 2mm width
4. Diagonal cracks
5. Vertical cracks
6. Horizontal cracks
7. Crazing _ occurrence of closely fine cracks at the fine Surface of material these is called crazing.

Cracks may of uniform width throughout or may be narrow at one end and gradually widening at the other end cracks may be straight toothed, stepped, map pattern or of random types and may be vertical horizontal or diagonal

1.3.3 CHARACTERISTIC OF CRACKS:

Cracks may be only surface or may extend to more than one layer of materials, cracks due to different causes have varying characteristics one can diagnose the causes of cracks for adopting an appropriate reduced measure. The characteristic of each crackis discussed below

1.3.3.1 Thin-Hair Crack

These are crack less or than 0.1mm in width hair thin cracks are difficulty to see with ordinary eyes unless the wall Are smoothly plastered the degree of damage to building structure is insignificant and does not have effects on both building and the users.

1.3.3.2 Medium Cracks

Fine cracks require close observation of brick or stone masonry to defect them theirwidth ranges from 1mm-2mm with the degree of damage is very slight and does not have any effects on the building structures and the users.

1.3.3.3 Deep-Wide Cracks

This type of crack can be more easily observed by tough as wall paper is likely to stretch, wrinkle or tear in clear light may be detected by carefully visual inspection from ground level when investigate upper elevation of two and possible three Storey building. The degree of damage may be affected towards the upper boundary, stability may also be at risk.

1.3.3.2 Diagonal cracks

Typically found at the of ends of lintel, junction between wall and ceilings; junction of difference materials for example where wall plate eaves are below ceiling line in upper room and over door in slender bricks or blocks partitions or not the door framing. Continuous up to ceiling level. The width of the diagonal crack. Various and the degree of damage are depending on the width size of the crack.

1.3.3.3 Vertical cracks

These may be hair-thin crack, or deep or medium cracks depend on the impact of the applied forces, they are erected when originates from the roof down to the foundation depend on the applied force. There width size varied and the degree of change effect on the building structure depends on the width size.

1.3.3.4 Horizontal Cracks

These are cracks which crosses the wall horizontally. They may be perpendicular to vertical fine or deep cracks depend on the impact to the applied force. Their width also varies and the degree of damage, effect on building structure depends on the width size.

1.3.3.4 Fine Crack-Crazing

Occurrence of closely fine cracks at the surface of a material these is called fine crack or crazing. Fine cracks require close observation of bricks, block or stone masonry too defect their width ranges from 1.0mm-3.3mm typically found as crazing patterns in plastering or rendered wall the degree of damage is very slight and does not have effect on the building structure and the user.

1.4 CRACKS RECORDING AND MEASUREMENT

Where inspecting walls which have crack pattern the following factor pertaining to the walls are important.

1. Length, Height, Thickness of the crack and wall
2. Changing or changed in environment. (tress and subsoil's)
3. Any alteration since completion (physically or in loading)
4. Original specification, bond, mortal designation etc.
5. Perforation
6. Subsequent maintenance

7. Physical life cycle of the building and element inquisition

1.5 FACTORS DISCUSSING

1.5.1 Length and thickness

The height length and thickness of cracks is very important to consider when inspecting walls with cracks. The wider the length, height, and thickness of the crack, the more it causes severe problem to the building structure, if a remedy is not taken at appropriate time: it may lead to total collapse of the building structure.

1.5.2 Changing or changed in environment

According to changes in the environment is also important to consider when inspecting walls with cracks for instance, if it alters since the completion of a structure, some tree with fibrous roots erected are likely to have an impact on the structure as time goes on if they were very close to the structure.

1.5.3 Any Alteration since completion

The new extension of a building or an adjoining house may also have an impact on the main building structure if it was not well planned designed and constructed.

1.5.3 Original specification, Bond, mortal Designation etc.

There are various types of bond used in construction e.g. stretcher bond, English bond header bond and Flemish bound should be avoided and the mortal to be used should not contain any element of clay in order to understand what is happening to a building which contain cracks recommend a simple method of recording cracks in a manner and relating the drawing to a floor plan it is possible to build up an accurate three dimension record of cracks for further analysis.

1.6 CONDITION FOR CRACK IN BUILDING

We identified two states for a concrete structure that cracks with reference to reinforced concrete member subjected to an axial force on a bending moment when the tensile does not exceeds the stress of the concrete intension, the member is free from cracks. Occurs the tensile zone is assumed to be full cracked.

Cracks are generally expected to occur in reinforce concrete structure without or with partial pre-stress, when the tensile stress exceeds the strength of the concrete in tension the weakest section in a cracked member is obviously at the location of a crack, away from a crack the concrete in tension zone can resist some tensile stress and this contributing to the stiffness of the members.

Two external states are considered. The un cracked condition in which concrete and steel are assumed to behaved elastically and exhibit compliable deformation and the fully cracked condition with the concrete intension ignored with those two assumptions the elongation or the curvature are calculated.

The actual deformation in a cracked member are predicated by interpolation between their two-extreme condition. A' dimension less, X-coefficient is used for the interpolation, and it present the extent of cracking.

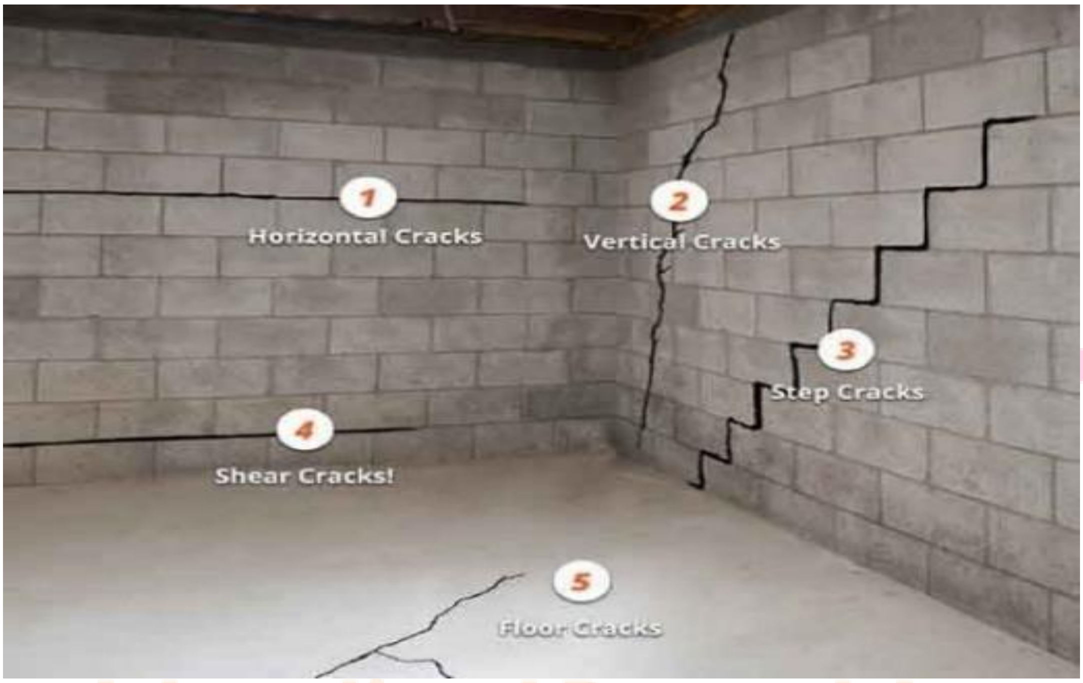


Figure 1.1 Types of Cracks

1.7 CAUSES OF CRACKS IN BUILDING STRUCTURE

Cracks in Building structure nowadays because of frequently overlapping factors, some of which includes the following. Complete absence of professionals during construction, overloading impact of door on wall, vibration of the structure, inadequate coming of concrete, fraudulent dealing between the projects sponsors and the relevant planning and approving authorities, use of poor materials, unacceptable, low standard of workmanship, absence of supervision, inadequate bonding, two much of clay in fine aggregate and lack of soil investigation before construction.

All those causes of cracks can be grouped into different heading;

- Environmental Problem
- Faulty design

- Faulty execution
- Faulty materials component
- Unexpected users' requirement
- Uneven settlement of foundation

1.7.1 Environmental Problem

The environment in which we live contribute immensely to failure in building structure. Thus, when designing for a structure the environment in which the structure is going to be located should be put into consideration. If not, the structure is prone to failure. The following environment factor are to be considered.

1.7.1.1 Rock Blasting Environment

If a structure is in a place very close to where blasting rock is taking place, the whole structure maybe weakens due to the vibration of the structure during blasting, if the environment in not put into consideration when designation of the structure there might be problem.

1.7.1.2 Earth Quake Environment

Earth quake is produced by a sudden release of tremendous amount of energy within the earth by 5 sudden movement during earth quake, the building is moved up, down or horizontally and in any direction. The ground motion is usually much large in sand or clays then in rocky area. Reclaimed land or fills being the worst.

Building should be designed to meet modern earth quack resistance standard especially in areas that are prone to earth tremors and quakes. These building should be able to withstand minor earth quake without damage, but collapse should be avoided. In area subjected to earth movement, geologist and seismologist should be employed to carry a geodesic experiment in the site and the source of the problem should be incorporated at design stage.Faulty Design

This is an important source of crack in building, it is a source of error, which arise from improper professional direction and experience is the development of conceptual, detailed design and working drawings.

This result from incorrect loading assumption; incorrect assumption of values given in the design codes or its misinterpretation, of standard details and manufacturers claims without proper assessment of the value.

For instance, during design of an irregular shaped structure certain assumption analysis and design may be made which may not be consistent with the condition of load application and distribution.

1.7.2 Faulty Execution

These occur when there is complete absence of professional during construction, poor workmanship and poor supervision eventually lead to faulty execution include improper mixing of the aggregates, in adequate curing, lack of adequate bonding, in appropriate water/cement ratio, shrinkage of mortal etc.

1.7.2.1 Poor workmanship

There is a function of the labor force on site for instance if there are inexperienced workers on site during construction, they may use stronger mortal for bonding block to avoid voice cracking. However, experiences have shown that Mortal must made relatively weaker than the block. Weaker mortal also permits them to allow a relaxation of stresses more individually whereby by redistributing the force inside the wall, if crack occur despite the use of weaker mortal, they are usually fine and referred to as hair thin cracks which are centered around each block rather than being wide and more extensions.

1.7.2.2 Poor Supervision

During execution of project, a qualified professional should be appointed to supervise the project so that rules and regulation guiding the construction according to the standard code will be followed by the worker on site, otherwise poor supervision will lead to poor execution of the project (consultant duties).

1.7.2.3 Inadequate curing

Curing is the process of keeping the fresh concrete under uniform condition of temperature and moisture contents. Proper curing of fresh concrete should take 28days using water, nylon, or wet-sand to prevent the occurrence of cracking due to shrinkage during the hot weather but if there is complete absent of professional during construction, curing process may not take place after caste of concrete.

1.7.2.4 Inadequate of bonding of blocks

There are many ways of setting blocks during construction, out of which are stretcher bond, Flemish bond, English bond, and header bond.

- **Stretcher bond**

Each course consists of stretcher with exception of a half but which must be placed at the stopped end of a wall at each alternate coarse so that the work will break joint.

- **Flemish bond**

This comprises alternate header and stretcher each course. There are two kinds of Flemish bond, double Flemish bond and single Flemish bond.

- **English bond**

This consist of alternative course of headers and stretchers due to the lack of inadequate bonding in English bond, it gives English bond its characteristics strength.

- **Header's bond**

Each course of a wall consists of headers only it is used chiefly in the construction of footing wall which are shapely curved, where the long faces of stretcher would unduly, break the line of the curse stretchers bond is the most common type use in India.

- **Improper mixing of aggregates**

If inappropriate water cement ratio is used when mixing aggregates, it may lead to segregation or leaking which eventually produce a week hardened concrete. A well-mixed concrete must be able to stand in a leap slump test used to carry out on site before casting.

1.7.3 Faulty material component

This is another cause of cracks, is the material used during construction such as concrete, steel, timber and sandy. This material can fail due to inappropriate selection, improper treatment, and careless handling during construction. If this material should fail, the whole structure is bound to fail.

1.8 SILICA FUME

Silica fume, also known as microsilica, is a highly reactive pozzolan that is commonly used as a supplementary cementitious material in concrete mixes. Its fine particle size and amorphous nature make it an ideal candidate for improving the properties of concrete, particularly in terms of strength, durability, and resistance to cracking. In the context of detecting internal cracks in reinforced concrete structures using fiber optic cable technology, the use of silica fume plays a critical role in several ways:

1. Reduced Permeability: Silica fume particles have a high surface area and can fill in the gaps between cement particles, resulting in a denser concrete matrix. This densification reduces the

permeability of concrete, making it less susceptible to ingress of harmful substances such as water, chlorides, and sulfates. By minimizing moisture ingress, the risk of corrosion of steel reinforcement, which can lead to internal cracking, is mitigated.

2. Improved Strength and Durability: Silica fume reacts with calcium hydroxide in the presence of water to form additional calcium silicate hydrate (C-S-H) gel, which is the primary binder in concrete. This reaction produces a denser and more refined microstructure, enhancing the compressive strength, flexural strength, and overall durability of concrete. The increased strength and durability contribute to the prevention of crack formation and propagation within the concrete.

3. Mitigation of Alkali-Silica Reaction (ASR): Alkali-silica reaction is a chemical reaction between alkaline hydroxides in concrete pore solution and reactive silica present in certain aggregates, leading to the formation of expansive gel, which can cause internal cracking and deterioration of concrete over time. Silica fume can help mitigate ASR by providing additional reactive silica, thereby reducing the availability of reactive silica in the aggregates for the deleterious reaction.

4. Enhanced Bond Strength: Silica fume contributes to improved bond strength between cement paste and aggregate particles, as well as between cement paste and steel reinforcement. This enhanced bond strength helps to redistribute stress and prevent localized cracking, thereby improving the overall structuralperformance of reinforced concrete elements.

In the context of early detection of internal cracks using fiber optic cable technology, the incorporation of silica fume into concrete mixes helps to create a more durable and crack-resistant concrete matrix.

This, in turn, reduces the likelihood of internal cracking and enhances the effectiveness of the fiber optic cable sensors in detecting any early signs of crack initiation or propagation. Overall, the use of silica fume contributes to the improved performance and longevity of reinforced concrete structures, while also facilitating the early detection and mitigation of internal cracks.

1.9 ENSORS

Sensors are devices or instruments that can detect and measure physical properties, environmental conditions, or changes in their surroundings and convert this information into a readable or quantifiable output. Sensors are essential components in various fields, including science, engineering, technology, and everyday life. They play a crucial role in data collection, monitoring, control systems, and automation. Here are some key characteristics of sensors:

1.9.1 Classification of Sensors

- **Detection:** Sensors are designed to detect specific physical or environmental changes. This can include variables such as temperature, pressure, light, humidity, motion, chemical composition, and many others.
- **Transduction:** Sensors transduce or convert the detected physical property or condition into an electrical, digital, or analog signal that can be processed and analyzed by electronic systems or humans. This conversion process varies dependingon the type of sensor.
- **Output:** The output from a sensor can take various forms, including voltage, current, resistance, frequency, digital data, or visual indicators (e.g., a gauge, LED display, orscreen).
- **Accuracy:** The accuracy of a sensor refers to its ability to provide a measurement that is as close to the true value as possible. The accuracy of sensors can vary widely, and it's an important factor when selecting a sensor for a particular application.

1.9.2 Range: Sensors typically have a specific operating range, which defines the minimum and maximum values of the property they can detect. For example, a temperature sensor might have a range from -40°C to 100°C.

1.9.3 Types of Sensors

- Ultrasonic Sensors
- Strain Gauges
- Fibre Optic Sensors
- Acoustic Emission Sensors
- Resistive Sensors
- Crack Width Gauges
- Ground Penetrating Radar

All together there are three types of ultrasonic sensors, classified by frequency and shape: the drip-proof type, high-frequency type, and open structure type (lead type).

1.10 UNEXPECTED USER'S REQUIREMENT

If the correct load application of an undersized structural member which eventually will be over stressed and fail under service load. Although design loading, this may however not accommodate wrong and in accurate load estimation.

The structural design of building nowadays requires professional skill and in qualify of structural engineer is properly forecasting accurately. The design load application bears it in mind that many buildings are now being out to use for other purpose which they are originally designed without any proper engineering assessment.

1.10.1 Uneven settlement of foundation

The vertical downward movement of the base of structure is called settlement and its effect upon the structure depend largely on its magnitude. Its uniformity, the length of time over which it takes place or the nature of the structure itself.

- ➢ The imposed weight of the structure on the soil.
- ➢ Changed in moisture content of the soil.
- ➢ Subsidence due to mining or similar operation around the site.

Foundation settlement often results from poorly compacted soil and wrong choice of foundation type when settlement of foundation become uneven this would lead to cracks in a structure.

Before a structure is constructed, through investigation of the ground condition must be under taken to know the geotechnical capability of the soil, the nature and properties of the soil, the depth of water table etc. assessment of the consolidation or differential settlement must also be determined.

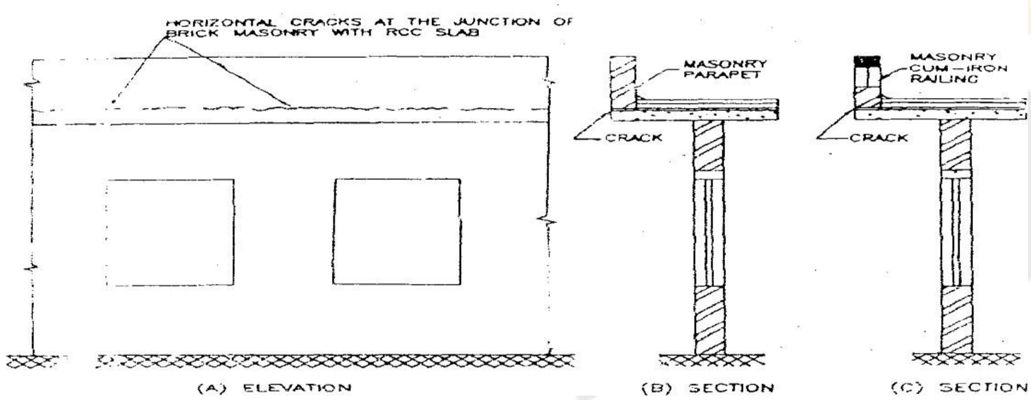


Figure 1.2 Horizontal crack at the base of brick masonry parapet (or masonry-cum-Iron Raing) supported on a projecting RCC slab.

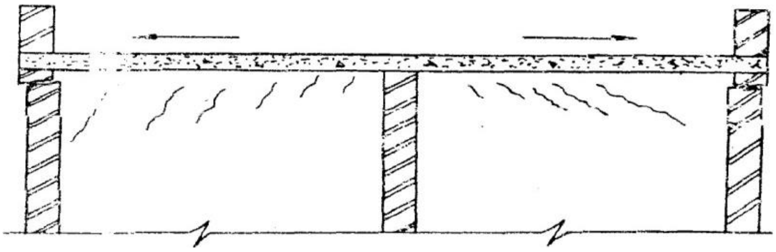


Figure 1.3 Cracking in cross walls of top most Storey of a load bearing structure

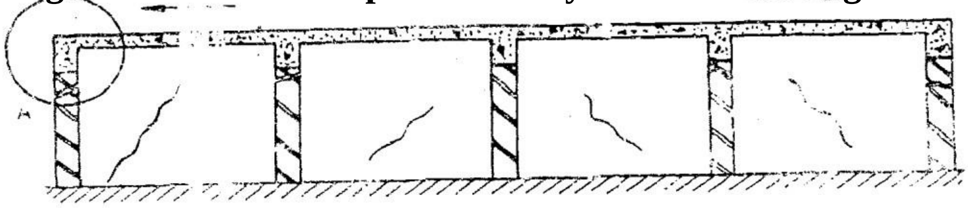


Figure 1.4 Typical cases of cracking due to vegetation are as under

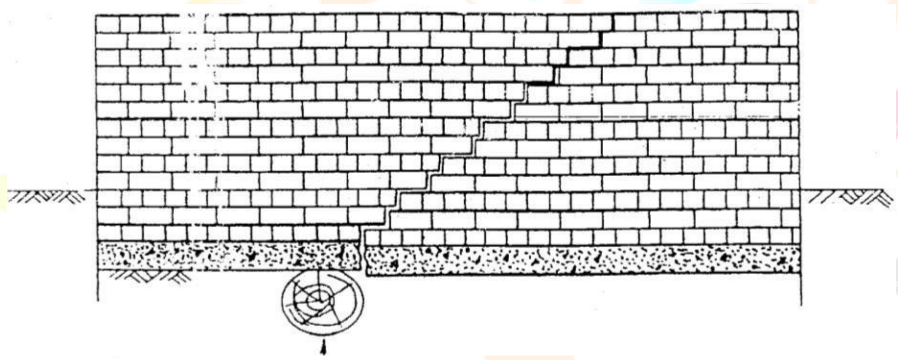


Figure 1.5 Cracking of a compound wall due to growing roots under thefoundation. (Wide at base & narrow upward)

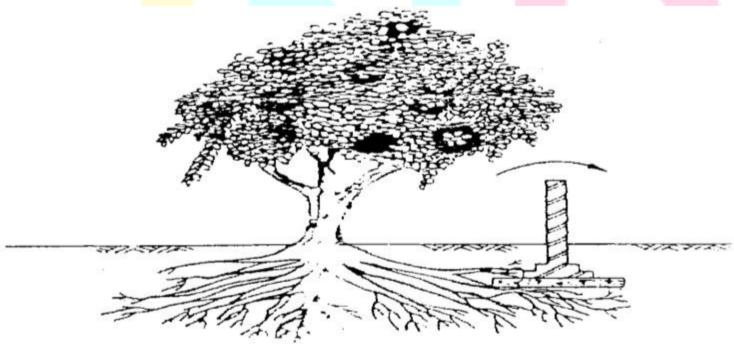


Figure 1.6 Roots of fast-growing tree under the foundation of compound wall maytopple down the wall.

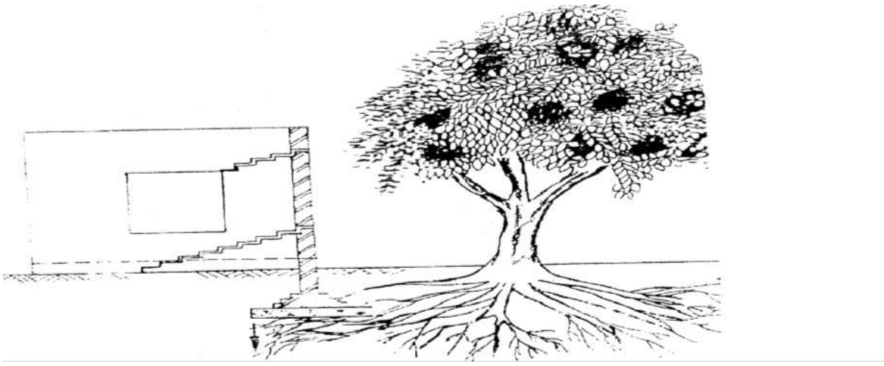


Figure 1.7 Cracks in the walls due to shrinkage of soil (Narrow at base and wideupward)

Trees growing close to building on shrinkable soil may cause

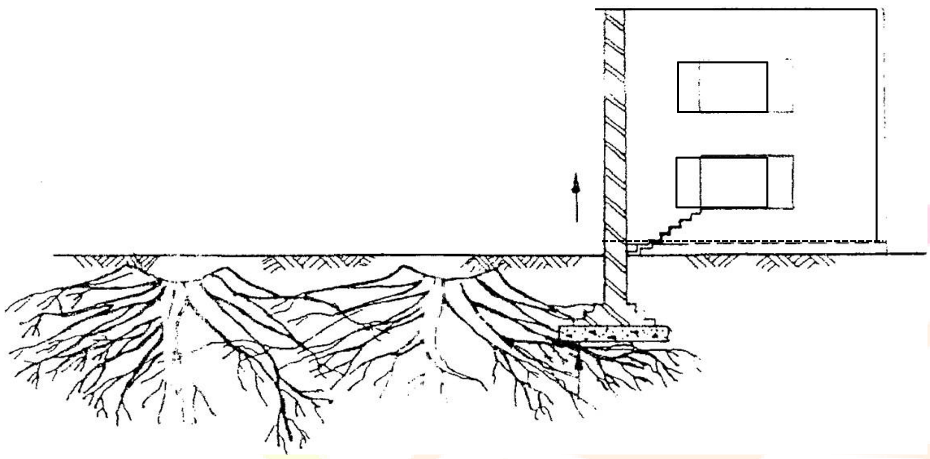


Figure 1.8 Cracking due to expansion, on moisture absorption if construction istaken-up soon after removal of trees. (Wide at base and narrow upward)

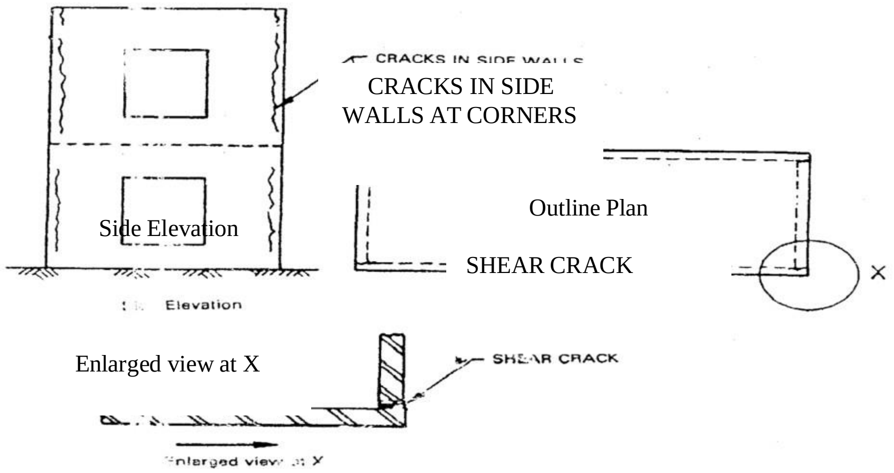


Figure 1.9 Vertical cracks at corners in the side walls of a long building due tothermal movement

1.10.2 Horizontal cracks at lintel/sill level in top Storey

These cracks are caused due to pull exerted on the wall by the slab on account of drying shrinkage and thermal contraction. Such cracks generally occur when window and room spans are large. These cracks could be prevented by providing slip joint at supporting walls.

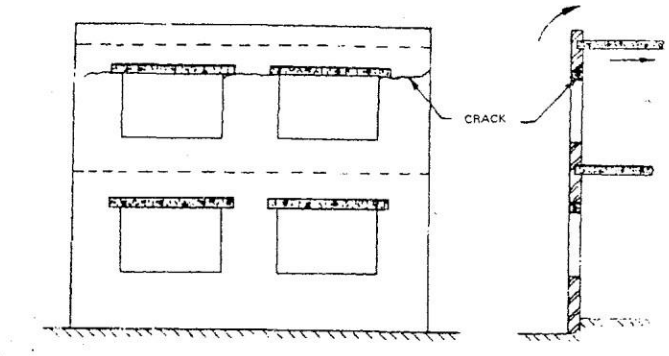


Figure 1.10 Horizontal cracks at window Lintel level in top most Storey

1.10.3 Diagonal cracks over RCC Lintels spanning large opening

These cracks are caused due to drying shrinkage of in-situ RCC Lintel and are observed during the 1st dry spell after construction. These cracks could be prevented by using low shrinkage and low slump concrete or using pre-cast lintels.

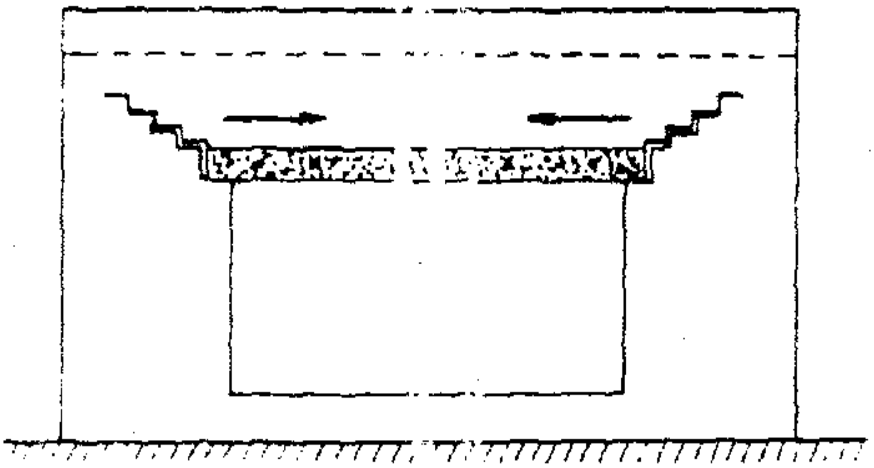


Figure 1.11 Diagonal cracks in brick masonry wall over Lintel of long spanopenings.

1.11 RCC FRAMED STRUCTURES

1.11.1 Cracking of panel walls

The external non-load bearing walls in a framed structure are termed as panel walls.

1.11.1.1 Horizontal cracks

Brick panel wall of a framed structure supported on a bear and built right up to the soffit of the upper beam. Due to shortening of columns, caused by elastic deformation, creep and drying shrinkage, or due to comparatively greater deflection of upper beam under heavy loads, wall is subjected to a large compressive force, with the rest that it gets bucked and horizontal flexural cracks occur as illustrated in.

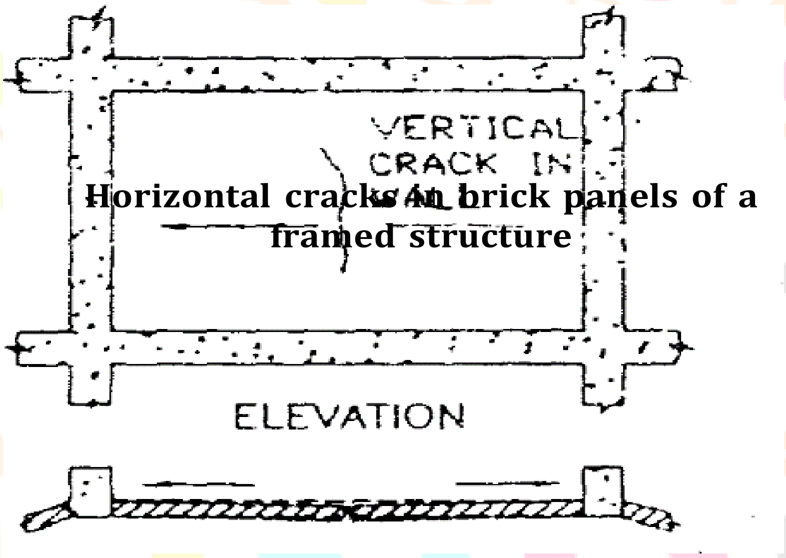


Figure 1.12 Horizontal cracks in brick panel of framed structure

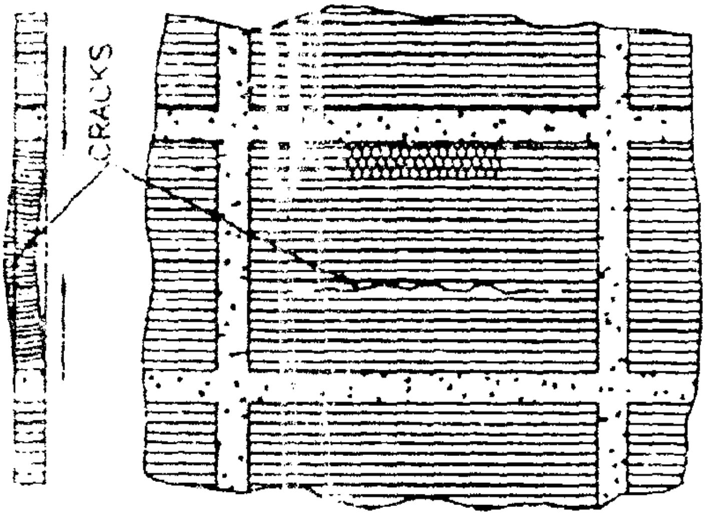


Figure 1.13 Vertical cracks in brick panel of framed structure

1.11.1.2 Vertical cracks

These cracks generally become apparent a few years after construction and are accompanied by bowing of the wails. Likelihood of damage due to these cracks is more if time interval between casting of the frame and building up of masonry wall hasbeen small.

1.12 OBJECTIVES

- To explore the potential of silica fume-enhanced concrete.
- To detect internal cracks in reinforced concrete early to prevent structural degradation, ensuring long-term durability and safety of infrastructure.

1.13 To implement a proactive maintenance strategy by utilizing Fiber Optic Cable technology, reducing long-term repair costs associated with structural damage anddowntime.SCOPE

This project is based on crack in building and due to time constraints, this study is limited to causes, effect, and prevention of crack in RC structures to prevent the occurrence of cracks and solution to the existing difference, types, and forms of cracks in building. Our project focuses on improving concrete building from cracks. We are exploring advanced sensors to detect damage, particularly in hard-to-reach areas where current tools struggle. We aim to use a benchmark bending test to assess the fibre optic cable ability to detect early cracks and explore the use of silica fume for repairs. Our preliminary results indicate that these sensors can detect cracks with high accuracy, offering the potential for early crack detection and remediation.

1.14 GENERAL CAUSES FOR FAILURE/DEFECTS IN STRUCTURE:

The following are the major causes of failures of concrete structures:

- Damages triggered due to fire, floods, earthquakes etc.

- Chemical deterioration & marine environments.
- Damages caused due to abrasion, wear & tear, impact, dampness, etc.
- Movement of concrete produced due to the settlement of foundation, etc.
- Structural deficiency due to faults in construction, use of inferior & substandard materials, poor workmanship & negligence in quality control & supervision.
- Structural deficiency results from faulty design & detailing as well as wrong assumptions in the loading criteria.

1.15 RCC STRUCTURES TYPES OF FAILURES:

1.15.1 Structural Failure: This failure is basically due to design deficiency, that is, when the applied load exceeds the design if serviceability aspect is not considered then the structure fails due to cracking, deflection or corrosion, deterioration.

1.15.2 Non-Structural Failure: This failure in structure is basically due to external factors such as improper utility, improper drainage, chemical damage, and physical. The major cause of such failure is improper quality of material used and poor workmanship.

1.16 FAILURES AT VARIOUS STAGES

Structure shows failure symptoms in every stage of life. Even the construction stage exhibits certain failure symptoms, which is basically due to improper curing, workmanship, and material quality. Such minor failures must be rectified by certain repair methods and taking some preventive measures during construction.

During serviceability period of the structure, the structure must be monitored at certain interval for its maintenance. Some preliminary failure symptoms such as hairline cracks, honeycomb in concrete is observed. The diagnosis of failure at preliminary stage is necessary so that it may not lead to secondary failures. Repair and in certain cases rehabilitation may fix the problem. But, if at this phase the failures is not rectified them these may lead to the catastrophic failure of the structure; and only rehabilitation or reconstruction is only possible solution.

CONSTRUCTION STAGE	UTILITY PHASE		FAILURE OF STRUCTURE
MINOR FAILURES /DAMAGES	PRELIMINARY FAILURE	SECONDARY FAILURE	FATAL FAILURE
REPAIR		REHABLITATION	NOT POSSIBLE

Figure 1.14 Failure at various stages in RCC Structure

CHAPTER 2 LITERATURE REVIEW

Anitya S. Zanke (2007), tells in his Study, cracks can cause major structural problems depending on their size and intensity, some cracks do not cause any structural issue. Though cracks formation cannot be completely prevented, but it can be controlled by using the proper methods and techniques. Causes of cracks in detail whether they are due to shrinkage, elastic deformation, earthquakes, and poor construction practices. proper work plan of every part of construction considering the environmental factors, using a proper mix of concrete and motor, using maximum size aggregate to lower the water content, creating expansion joints and slip joints where needed in the building. Dry packing should be taken into act if there are large number of cracks in the structure. It is always better to take care and follow safety measures for a crack free construction. To ensure the safety of a structure, it is important to monitor its condition. The cracks can always be avoided by using adequate construction material and technique, proper design, and efficient supervision.

Chetan J. Chitte, Yogesh N. Sonawane (2007), tells in their Study, Cracks are developed due to deterioration of concrete or corrosion in reinforcement bars due to poor construction or inappropriate selection of constituent material and by temperature and shrinkage effects. All type of cracks requires same level of consideration. Thermal fluctuations, elastic deformation, creep, chemical reaction, or reason related to the foundation soil such as its movement or settlement or unhindered vegetation. Some faulty steps during construction and some unavoidable reasons different type of cracks starts to appear on various structural and non- structural parts of the building. Identification of such cracks and adopting preventive measure are essential. Though cracks in concrete cannot be prevented entirely but they can be controlled by using adequate material.

Grishma Thagunna (2007), tells in his Study, the cracks may be classified based on their activeness, time of occurrence, their width, and the components of building on which they are developed. Based on activeness cracks are of two types; active crack and dormant crack. According to IS: 456 2000, the surface width of crack should not exceed 0.3mm in members where cracking is not harmful and does not have any serious adverse effects upon the preservation of reinforcing steel, nor upon the durability of the structures. Cracking in reinforced concrete structures of various types can be divided into two main groups: Non-structural cracks and Structural cracks. Permeability of concrete, Thermal movement Corrosion of Reinforcement, Moisture Movement, Creep, Poor Construction practices, Poor structural design and specifications, Poor Maintenance, Movement due to Chemical reactions, Indiscriminate addition and alterations, Foundation settlement are some causes of Cracks in Buildings.

Mr. Shyam Doshi & Et Al.tells (2008),in their Study, Cracks in building are a common occurrence. It affects the stability and appearance of buildings. So, it is important to understand the cause of cracks and the effective measures should be taken for prevention. Though cracks in concrete cannot be prevented entirely but they can be prevented by using proper material and technique of construction and considering criteria. Cracking are early indication of failure of structure. Light weight concrete shrinks more any lack of attentiveness can lead to a cause for damage in the building in its future, which can also lead to the failure of structure. And, not all type of crack requires same level of attention.

Cracks may occur due to various reasons. The potential causes of crack can be controlled if proper consideration is given to construction material and technique to be used. In case of existing cracks, after detail study and analysis of crack parameters, most appropriate method of correction should be adopted for effective and efficient repair of crack.

Disha Salgiya, Utkarsh Jain, Shruti Tongiya (2009) tells about in their study, A building is a place where people accommodate or come to work together, the major purpose of the building is to give a comfortable and healthy surrounding for people to conduct activities, to provide security, sustain load and environmental shelter. Proper and timely maintenance will help to extend functioning by offering protection against degradation. Development of cracks in a structure is very common phenomenon. Crack is a line along which a material is broken into two parts. Most of the building materials such as brick, mortar and concrete contain enough water. Some things are aesthetically defective example – quality of finished surface, plaster, or paint. This can be matter of relative judgment or relative experience. All the buildings are subjected to one or the other defects, failure, deterioration. This research has brought into consideration effect of various factors and agencies on the building.

Shivani More & **Tejas Hirlekar** (2010), talks about in their study, Cracking is the most difficult and puzzling problem for the engineers today. Many designers are trying to eliminate the problems of cracking, but cracking is unavoidable response of any structure. The formation of cracks cannot be eliminated nor completely stopped but several measures can be undertaken to prevent their consequences. Several cracks and tendency of cracking we also concluded that not all type of cracks require same level of attention.

Taking into consideration proper repair and maintenance, adequate construction materials, proper techniques, the potential causes of crack can be largely minimized. Different types of cracks for gaining the most effective and efficient structure.

Pooja Nama, **Ankush Jain**, **Rajat Srivastava** and **Yash Bhatia** (2011), talks about in their study, a crack is a complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing. Concrete structure has been started applying since the mid-19th century, because of the low quality of cement and at that time the development of concrete structure was slow. The potential causes of crack can be controlled if proper consideration is given to construction material and technique to be used. the problem engineers are facing i.e. of cracking after construction and what preventive measures should be taken along with the techniques to cure cracks. Due to some faulty designs and other unavoidable factors cracks start developing on various structural and non-structural parts of the building. Hence, timely measures should be adopted to prevent and control cracks and its formation. Not all the cracks developed are harmful but there are some types of cracks which can be severely structurally hazardous.

Agu Ransford Teethe, Ye Liang (2011), talks about in their study, Cracks in concrete structures have many causes. They can affect the appearance or indicate significant structural loads or lack of durability. Cracks can represent the full extent of the damage or indicate serious problems. Its importance depends on the type of structure and the type of cracking. For example, cracks that are acceptable for buildings may not be acceptable for water retention structures. Correct crack repair depends on knowledge of the causes and selection of repair procedures that take these causes into account.

Otherwise, the repair can only be temporary. Cracks are a typical defect that are unavoidable in concrete. If cracks exceed the allowable widths defined in the codes of practice, they considerably reduce the strength, stiffness and durability of the concrete structure and therefore need to be repaired.

Mr. Harshal Shankarrao Khode (2012), talks about in his study, Cracking is a common problem in concrete structures in real-life service conditions all over the worlds. In fact, crack-free concrete structures are very rare to find in real world. Concrete can undergo early-age cracking depending on the mix composition, exposure environment, hydration rate, and curing conditions. Understanding the causes and consequences of cracking thoroughly is essential for selecting proper measures to resolve the early-age cracking problem in concrete. This paper will help to identify the major causes and consequences of the early-age cracking in concrete. Also, this paper will be useful to adopt effective remedial measures for reducing or eliminating the early-age cracking problem in concrete. Factors affecting the initiation and growth of early-age cracks, the causes of early-age cracking, and the modelling of early-age cracking are discussed.

Cracks are inherent and detrimental elements of building detailed investigation should be carried out regularly to ensure the accessibility and serviceability of the building. For rehabilitation of cracks, it is important to understand the causes and the types of cracks appeared in the structure. Non-destructive testing methods are used to access the strength of the structure at a first instance to know the actual state of the structure whether it will be serviceable/workable or to be demolished.

P Velumani, **K Mukilan**, **G Varun**, **S Divakar**, **R Muhil Doss** and **P Ganesh Kumar** (2012) talks about in their study, Analyzing and identifying cracks is the most vital step in the construction process. The manual crack detection process will take longer and will be subjectively assessed by the inspectors. This research provides a conceptual base for the image processing methodology for the automated identification and examination of cracks. This model uses the Gray Intensity Correction Method (i.e.) Min Max Gray Level Differentiation (M2GLD) for Image Improvement and the Otsu Image Binarization Process. The experimental result of the M2GLD method and the Otsu test will effectively detect crack defects in images. This model can therefore be a useful tool for building construction agencies and structural maintenance engineers.

Kishor Kunal, **Namesh Killemsetty** (2013), talks about in their study, Structural Cracks are a common occurrence in all types of buildings. To ensure the longevity of the structure, engineers are often required to investigate their causes and carry out suitable repairs and remedial measures. For repairs and remedies to be effective, it is essential that the engineer should have a proper understanding of various causes of occurrence of cracks. For investigating the causes, it is necessary to observe carefully the location, shape, size, depth, behavior, and other characteristics of the cracks, and to collect information about specifications of the job and time of construction. It is also necessary for the engineer to keep track of when the cracks first came to notice.

Cracks are commonly found on and in structures and are usually undesirable features naturally occurring due to age, workmanship, and other natural and environmental causes. This study is set to characterize cracks with the principal aim of recommending proper maintenance and efficient repair actions. Crack occurrence in an office building (storey with basement) was investigated as a case study. Reconnaissance survey was carried out to locate and note the tools that would be required for the investigation of the cracks. The nature of the cracks showed that 91% are dormant cracks, while 9% are active cracks. Some of the cracks extended to the plastered surface, while the rest extended to the structural element's region. Therefore, the cracks in this building were found to be caused by the drying shrinkage at the wall section, the compressive force from the beams exceeding the ultimate strength of the affected blocks, foundation settlement at the courtyard was also discovered through topographical survey, due to underground erosion of the foundation wall footing. The results of the non-destructive test (NDT) indicated that, the average strength of the structural elements is within acceptable limit.

Saurabh Wankhade, **Prajyot Pardhi**, **Aniket Khawas**, **Aditya Satpute**, **Nikhil Rathod** (2014), talks about in their study, the building cracks are the most common problem in any structure. We all want a home that is both technically sound and appealing, but this isn't always achievable. Natural disasters, soil collapse, construction defects, poor design, and inadequate joints are all factors that lead to the formation of structural cracks. Although concrete fractures cannot be totally prevented, they can be handled with the right materials, construction techniques, and design requirements. It's vital to spot such cracks as soon as possible and take precautions. Active cracks are a major problem that needs to be addressed right away since they are structurally unsafe.

As a result, it is critical to comprehend the many sorts of fractures, their patterns, and their causes Based. The building cracks are the most common problem in any structure. We all want a home that is both technically sound and appealing, but this isn't always achievable. Natural disasters, soil collapse, construction defects, poor design, and inadequate joints are all factors that lead to the formation of structural cracks. Although concrete fractures cannot be totally prevented, they can be handled with the right materials, construction techniques, and design requirements.

Sheerin Sitara.N, Kavitha. S, Raghuraman.G (2014), talk about in their study, in real time scenario, cracks are very common in building, bridge, road, pavement, railway track, automobile, tunnel and aircraft. The presence of crack diminishes the value of the civil infrastructure and hence it is necessary to estimate the severity of crack. Crack detection and classification techniques with quantitative analysis play a major role in finding the severity of crack. The various quantitative metrics are length, width and area. Due to the rapid development in technology, number of images acquired for analysis is growing enormously. The limitations are inferred and a new design is proposed to address the limitations such as false crack the analysis is carried out on the basis of image processing and machine learning techniques.

Faizan I.Kagdi & **Mitesh J. Mungla** (2015),tell about in their study, the presence and propagation of crack damage in mechanical and civil structures can cause catastrophic failure. Crack damage identification is of important concern to the structural engineering community. Traditional methods also called as conventional NDT methods like ultrasonic methods, magnetic field methods, x-ray methods and radiography need the vicinity of the damage, and the portion of the structure being inspected should be readily accessible.

Crack detection methodologies given by various researchers clearly shows that several approaches have been developed to locate crack in slender beams. The inverse problem, genetic algorithm is used to search optimal solution for detection of multiple cracks locations and their intensities in Timoshenko beam.

Nidhi Pise, **Trupti Meshram**, **Yash Doijad**, **Rahul Gathe**, **Ayush Bobade**, **Anup Kutemate**, **Swapnil Patil**, **Pranay Raut** (2015), talk about in their study, building cracks are one form of regularly occurring trouble that occur in any form of concrete shape. In fact, crack-free concrete systems are very uncommon to find in actual global. Cracks in undeniable and bolstered concrete possess a hard to civil engineers from the six decades. All of us want our building structurally safe but it isn't so simple. A crack is to be impacts the building artistic and destroys the wall integrity, influences the shape protection, and reduce the sturdiness of concrete. Certain flawed steps during construction and other inevitable causes of various types of cracks begin to emerge structural and non-structural components of a building. The repair materials and restore technique are exceptional depending upon kinds of cracks in accordance to their positions in shape. A few types of cracks significantly need attention as they're structurally hazardous.

P.Swapna (2016), tell about in their study, Building splits are most normal issue found in a structure. We as a whole love to have a house which fundamentally protected and excellent yet it is not so natural, one needs to conquer regular disaster, soil disappointment, development deficiencies, inappropriate structure, and lacking joints causing is to create breaks on the structure. Although the splits in cement can't be averted completely yet they can be constrained by utilizing satisfactory material and method of development and explicit structure criteria.

On opportune distinguishing proof of such breaks and receiving preventive measure are basic. Dynamic splits cause genuinely issue and they need uncommon consideration as they are basically unsafe. The fix materials and fix method are distinctive relying on types of breaks as indicated by their situations in structure. A few sorts of splits truly need consideration as they are basically perilous. Splitting is an unavoidable reaction of any structure while planners are attempting to take out huge numbers of the reasons for breaking and plan resistance for different components. We as a whole need our structure fundamentally protected yet it is not so natural.

Rajveer Singh Narwaria, **Archana Tiwari** (2016), talk about in their study, Cracks in the building is the most common problem that occur in any type of concrete structure such as beams, column, etc. So, it is important to understand the cause and the measures to be taken for prevention. Though cracks in concrete cannot be prevented entirely but they can be controlled by using adequate material and technique of construction and considering design criteria. But due to some faulty steps taken during construction or due to some unavoidable reasons different cracks starts to appear on various structural and non- structural parts of the building with due course of time. There are cracks which need to be identified at appropriate time, so proper care of such cracks can be taken.

Mulla Fayaz (2017), talk about in his study, a crack is a complete or incomplete separation of concrete in two or more parts by breaking or fracturing. It is an inherent feature in concrete which cannot be prevented but controlled and reduced. Structural Cracks are a common occurrence in all types of buildings. To ensure the longevity of the structure, engineers are often required to investigate their causes and carry out suitable repairs and remedial measures.

For repairs and remedies to be effective, it is essential that the engineer should have a proper understanding of various causes of occurrence of cracks. For investigating the causes, it is necessary to observe carefully the location, shape, size, depth, behavior and other characteristics of the cracks, and to collect information about specificationsof the job and time of construction.

Rajendra P. Srivastava et.al (2017), this article performs two types of analysis using Dempster-Shafer theory of belief functions for evidential reasoning. The first analysis deals with the impact of the structure of audit evidence on the overall belief at each variable in the network, variables being the account balance to be audited, the related transaction streams, and the associated audit objectives. The second analysis deals with the impact of the relationship (logical "and" and "algebraic relationship") among various variables in the network on the overall belief. For our first analysis, we change the evidential structure from a network to a tree and determine its impact.

Constantinos A. Balaras et.al. (2018), A total of 349 residential building audits were performed in seven European countries to collect data on the degradation of building elements (architectural and installations). The buildings cover typical architectural typologies, sizes, constructions, and installations, at different states of deterioration. The data was collected based on a standardized methodology for building audits. Follow up analysis revealed the most important influencing factors on the deterioration of existing residential buildings throughout Europe and estimated service lives of various building architectural elements and electromechanical installation.

B.H Chafekar et. Al (2018), before going in detail about the structural audit is necessary to know about the structure. A structure is a system of inter connected elements to carry loads safely to underground earth. The health examination of concrete building called as structural audit. The author shows different methods in paper.

A.B. Mahadik et.al. (2019), This paper deals to create awareness amongst the civil engineers, residents, and owners of building towards the health examination of existing concrete buildings called as Structural Audit. The need of structural audit is for maintenance and repairs of existing structures whose life has exceeded the age of 30 years to avoid any mishaps and save valuable human life. The concrete is widely used as construction material being inexpensive, easy for construction, applications and because of it high strength-cost ratio. More than ever, the construction industry is concerned with improving the social, economic and environmental parameters of sustainability. In India, from 1980 onwards the infrastructure industry witnessed stepping up of public investment and growth in infrastructure industry which results in construction of new multistoried concrete apartments which are now in the age of thirty plus years. There are many buildings during this period and earlier have reduced strength in due course of time because of structural deficiency, material deterioration, unexpected over loadings or physical damage. If, further use of such deteriorated structure is continued it may endanger the lives of occupants and surrounding habitation. There is demand of appropriate actions and measures for all such building structures to improve its performance and restore the desired functions of structures which may leads to increase its functional life.

Francesca Ceronia (2020), synergic approach for the investigations of the historical building performances - with reference to both the structural behavior and the energy performances for the space heating and cooling - is presented. The historical masonry building “Palazzo Bosco Lucarelli”, located in Benevento, has been chosen as case study. The structural and energy analyses are carried out in parallel, especially during the identification of the building characteristics through tests and surveys in- situ. For the structural analysis - beyond examinations on materials – some dynamic tests have been used for better assessing a numerical Finite Element model necessary for the verification of the structure safety. Moreover, being necessary a structural refurbishment, also an energy retrofit could be realized. A rigorous evaluation procedure - aimed to guarantee the necessary reliability of numerical predictions - is performed to verify the technical and economical convenience of various energy retrofit solutions.

Mohammad Ismail, the paper presents research findings on the deteriorating conditions of abandoned residential projects due to environmental factors of degradations. Sampling was made from two hundred and sixty-one abandoned housing projects. Structural degradations associated with the uncompleted buildings were studied. In a similar manner, a small-scale reinforced concrete structure was erected in an open and critically monitored for defects caused by environmental factors of degradations. The selected uncompleted buildings were assessed for surface salt deposits, crack formations and reinforcement corrosion. However, the small-scale structure was evaluated for performance degradations through destructive and non- destructive strength tests, steel tensile strength test and corrosion test. Results show that there is an alarming decrease in structural integrity and durability functions in abandoned reinforced concrete buildings with time. Eventually, performance- depreciation versus age graph was developed for assessing life-span limit beyond which unacceptable mechanical properties are eminent. Based on the surrounding exposure conditions, an abandoned reinforced concrete building could fail to perform acceptable designed strength functions within a period of twelve (12) years.**J. Bhattacharjee**, the construction material mainly reinforced concrete is being used extensively for various types of construction projects. However, the deterioration of Reinforced Concrete structures is recognized as a major problem worldwide. Apart from requiring regular maintenance, many structures require extensive Repair, Rehabilitation &Retrofitting. Over a period, as these structures become older, we find in them certain degradation or deterioration with resultant distress manifested in the form of cracking, splitting, delaminating, corrosion etc. Such deteriorated structures can be rehabilitated and retrofitted by using various types of admixtures & modern repair materials. The paper brings out the present state of concrete structures & the major areas where improvement is needed during its service life stage for sustainable development & also the method of carrying out Repair, Rehabilitation &Retrofitting. This has been brought in details in the paper along with Case studies, where the Authorof the paper was directly involved in planning and execution of the jobs.

Monteria. J., Pathak, N.J. They have estimated the soundness of existing structures whose life has crossed the age of thirty years. Concrete constructions are generally expected to give trouble free service throughout its intended design life. The deterioration of buildings can be a result of various factors including fire damage, frost action, chemical attack, corrosion of steel etc. during the life span of the structure.

Kishor Kunal, et. al. (2021), This paper talks about how visual inspection of cracks can be helpful to identify and categorize them with respect to various parameters by taking case study of an institutional building. He has concluded that some prevention could be taken care of during the construction process itself. Any lack of attentiveness can lead to a cause for damage in the building in its future, which can also lead to the failure of structure. Cracks may occur due to various reasons, as discussed earlier. The occurrence of cracks cannot be stopped but measures can be taken to restrict them to reduce the level and degree of consequences. For causes and prevention of cracks in any case it is necessary to make careful observations and to collect detailed information in the form of a checklist

Sanket.S.Suryavanshi.et al, the paper gives a complete study on structural repair report carried by author. As per the author, Building was inspected as per each flat internally as well as externally. Defects were observed in columns, slabs, beams, walls, and conditions of structural components were return in the sheet. At the same time photographs were taken by the author to collaborate with defects visually. By the investigations surveys they came to know that health condition of building is fair. With the NDT‟s conducted it was concluded that structural members are suffering from class 3 damage. According to CPWD (Central public works department) class 3 damage stands for observation like spalling of concrete cover, structural cracks etc., in which principal repairs are required. So as per observations, Principal repairs were needed to be started as early as possible to avoid further deterioration of the structure.

Quality of RCC found was poor as per the result of rebound test and UPV test performed at various locations, so the recommendation was to start repair work which included strengthening of column, plastering works of defected areas and water proofing, etc. Also, of leakage should be in various location of top floors Delay in works could increase the quantity of work due to continuous deterioration the structure.

B.H Chafekar, O.S Kadam, K.B Kale.et al (2022) Gives us the methods to inspect a building. Also, they have focused mainly on Visual inspection of a building. The points to be taken into consideration for visual inspection of a building. The various points have been listed to check the building. The paper also talks about the purpose of carrying out the audit of a building for various reasons like to save lives and property, to know the future life of the building and for municipal bylaws consideration.

K.R. Sonawane, Dr. A.W. Dhawale had stated the general health and performance of building depends on its quality of maintenance. As a building grows old ageing, use (misuse) an exposure to the environment can affect the health of building significantly. Therefore, it is advisable to monitor it periodically by taking professional opinion Structural Audit is preliminary technical survey of building to assess its general health as a civil engineering structure. It is usually initiated as the first step for repair this is like periodic health checkup recommended for older people.

CHAPTER 3 MATERIALS & METHODLOGY

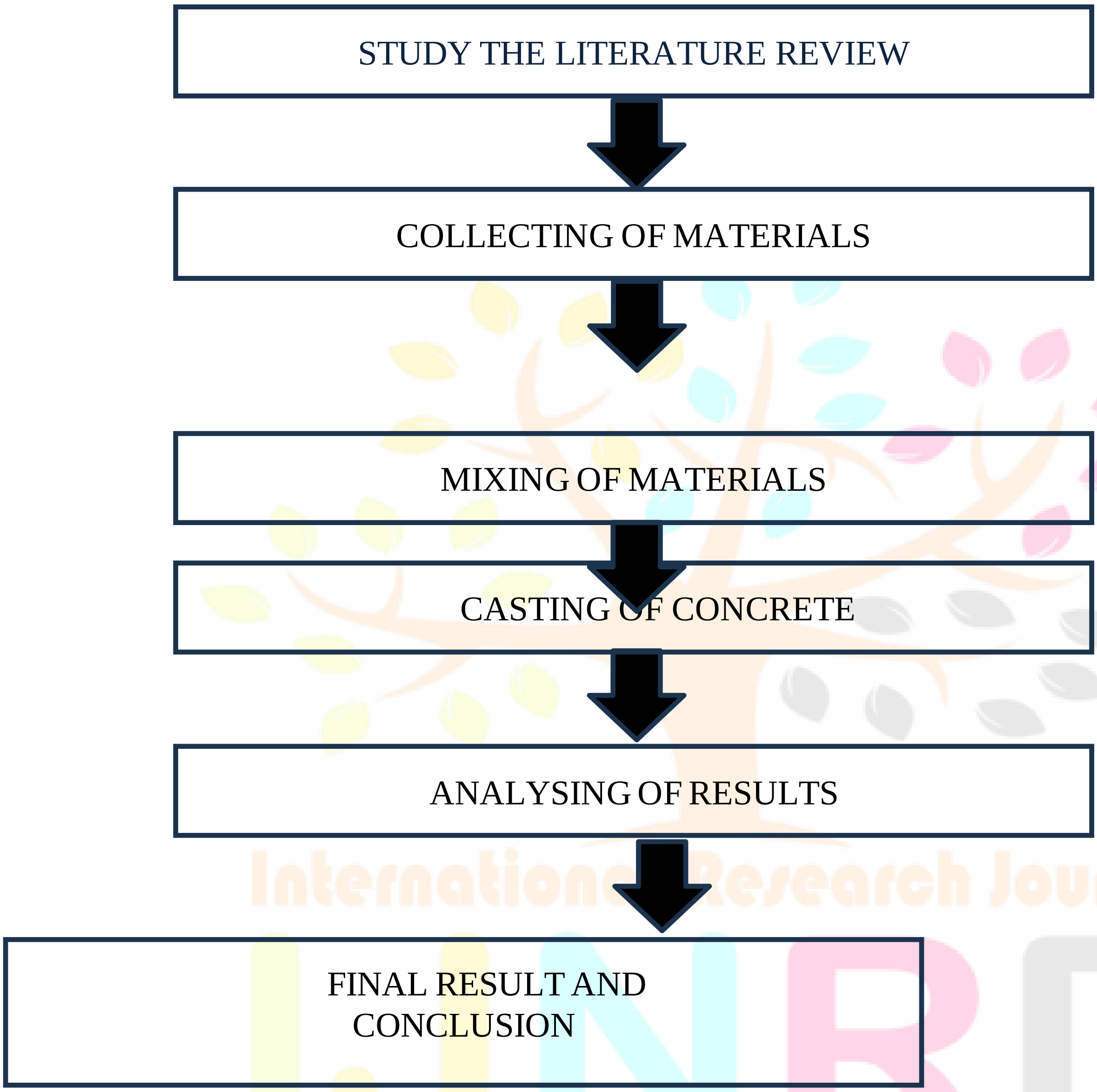


Figure 3.1 – Methodology

3.1 CEMENT

Cement has different properties and characteristics which depend upon their chemical compositions. By changing in fineness of grinding, oxide compositions cement has exhibit different properties and different kind of cement. The use of additives, changing chemical composition, and use of different raw materials have resulted the availability of many types of cements. Cement used in the experimental work is Ordinary Portland Cement of 43 grades conforming to IS: 8112/1989.

Table 3.1 Properties of Cement

S.No	PARAMETERS	RESULTS
1	Specific gravity of Cement	3.15
2	Standard Consistency of Cement	35%

3.2 AGGREGATES

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. The fact that the aggregates occupy 70-80 present of volume of concrete, it has some impact on various characteristics and properties of concrete. Earlier, aggregates were considered as chemically inert material but now it has been recognized that some of the aggregates are chemical active and certain aggregates ere exhibit chemical bond at the interface of aggregate and paste.

3.2.1 Coarse Aggregates

Crushed granite of 10mm & 20mm size are used as coarse aggregate.

Table 3.2 Sieve analysis of Coarse Aggregate

S.No	IS Sieve Size (mm)	Weight Retained(Kg)	%Weight Retained	Cumulative %Weight Retained	Cumulative %Weight Passing
1	4.75	0.265	2.65	2.65	97.35

2	2.36	0.0305	3.05	5.70	94.30
3	1.18	0.121	12.1	17.80	82.20
4	0.6	0.238	23.8	41.60	58.40
5	0.3	0.367	36.7	78.35	21.65
6	0.15	0.153	15.3	93.65	6.35
7	Pan	0.0165	1.65	-	-
8	Fineness Modulus			2.39	

WATER ABSORPTION OF COARSE AGGREGATES

S.No.	Determination No.	I	II	III
1	Weight of saturated surface-dried sample in g (A)	2409	2380	2491
2	Weight of oven-dried sample in g (B)	2404	2375	2486
3	Water absorption $= \frac{A - B}{B} \times 100\%$	$\frac{5}{2404} \times 100 = 0.208\%$	$\frac{5}{2375} \times 100 = 0.210\%$	$\frac{5}{2486} \times 100 = 0.201\%$
	Average value		0.206%	

3.2.2 Fine Aggregates

Fine aggregate which satisfied the required properties for experimental workand conforms to zone as per the specification of IS: 383-1970.

Table 3.3 Fineness modulus limits for various zones of fine aggregate accordingto IS 383-1970

S.No	Seive Size	Zone I	Zone II	Zone III	Zone IV
1	10mm	100	100	100	100
2	4.75mm	90-100	90-100	90-100	95-100
3	2.36mm	60-95	75-100	85-100	95-100

4	1.18mm	30-70	55-90	75-100	90-100
5	0.6mm	15-34	35-59	60-79	80-100
6	0.3mm	5-20	8-30	12-40	15-50
7	0.15mm	0-10	0-10	0-10	0-15
8	Fineness Modulus	4.0-2.71	3.37-2.1	2.78-1.71	2.25-1.5-35

3.3 WATER

Clean potable water was used for mixing and curing of concrete.

Table 3.4 Properties of Water

S.No	PARAMETER	RESULT
1	pH	6.7
2	Total Dissolved Solids (ppm)	-
3	Conductivity at 25 °C (μs/cm)	515.5
4	Chlorides as Cl^{-1}(ppm)	24.5
5	Sulphate (ppm)	59.9
6	Magnesium(mg/L)	14

Value of A = 500 gms Value of B = 1824 gms Value of C = 1513 gms Value of D = 496 gms

Calculation of water absorption capacity of fine aggregate

Absorption =(A-D)/D ×100% Absorption = (500-496)/496 ×100% Absorption = 4/496 ×100%

Water absorption = 0.8 %

3.4 FIBRE OPTIC SENSOR

Fiber optic sensors are devices that use optical fibers to measure physical properties such as temperature, strain, or pressure. In the context of reinforced concrete, fibre optic sensors can be embedded within the concrete matrix during casting or retrofitting. These sensors work by detecting changes in light transmission caused by strain or deformation in the surrounding material. The fibre optic sensors embedded in the concrete can detect the formation and propagation of internal cracks by monitoring changes in strain or stress within the concrete matrix. When a crack forms, it causes a disruption in the surrounding material, altering the strain profile sensed by the fibre optic sensors. This change instrain can be correlated with crack formation and growth.

CHAPTER 4 EXPERIMENTAL INVESTIGATION

4.1 INVESTIGATION ON EXPERIMENT

This chapter presents the details of experimental investigations carried out on the test specimens to study the strength characteristics of Concrete in different proposition of SILICA FUME. The experiment is conducted on test specimens to ascertain the strength related properties such as cube compressive strength, cylinder split tensile strength, prism flexural strength and Concrete Specimen flexural strength. Three specimens are tested, and the average is reported for each mix for each test. All the tests are conducted as per Indian standards. Based on the strength test results of cube and cylinders the optimum percentage is arrived. After 7,14&28 days curing, the specimens are tested for compressive, Tensile, and flexural strength.

4.2 SIZE OF TEST SPECIMEN USED

The Concrete mix, after having checked for the satisfaction of the fresh properties cast into cube mould of size 150 mm x 150 mm, beam moulds of size 100mm x 100mm x 500 mm and cylindrical moulds of 300 mm height x 150mm diameter & Concrete Sizes is 1200x1200x150mm. The moulds were fabricated with steel sheets. It is easy for assembling and removing the mould specimen without damage. Moulds were provided with base plates, having smooth surface to support. The mould is filled without leakage. Care was taken to ensure that there were no leakages.

4.3 CURING OF TEST SPECIMENS

After 24 hours of casting, the specimens were removed from the moulds and immediately dipped in clean fresh water. The specimens were cured for 7 days, 14 days and 28 days respectively depending on the requirement of age of curing. The freshwater tanks used for the curing of the specimens were emptied and cleaned once in every fifteen days and were filled once again. All the specimens under immersion were always kept well under water and it was seen that at least about 15 cm of water was above the top of the specimens. Specimen casting as shown in Fig.6.1

,

fig.4.1 Specimen Casting

4.4 TESTS ON HARDENED CONCRETE

Testing of hardened concrete plays an important role in controlling and confirming the quality of silica fume concrete.

4.4.1 CUBE COMPRESSIVE STRENGTH

The cube compressive strength test is carried out on cube specimens of size 150mm x 150mm x 150mm. All specimens are tested in saturated surface dry condition, after wiping out the surface moisture. For each mix combination, three identical specimens are tested at the age of 28 days using compression testing machine. Loading was continued till the specimen had failed. The reading at that instant of reversal gives the ultimate load. The test setup is shown in fig. 6.2

Fig.4.2 Compressive strength test (Cube)

In the present investigation, the compressive strength test has been conducted on silica fume concretes with varies proposition of SILICA FUME. M25 grade of concrete at 7, 14 and 28 days were tested.

4.4.2 CYLINDER SPLIT TENSILE STRENGTH TEST

This is an indirect test to determine the tensile strength of cylindrical specimens. Splitting tensile strength test is carried out at the age of 28 days for the concrete cylinder specimen of size 150mm diameter and 300mm length using universal testing machine.

The load is applied gradually till the specimen split and the readings are noted. The test setup is show in fig.6.3. The splitting tensile strength has been estimated using the relationship

$f = 2P/\pi dl$

Where, f = Splitting tensile strength of concrete in MPa.

P = Load at failure in Newton

d = Diameter of cylinder = 150mml = Length of cylinder = 300mm

Fig. 4.3 Split tensile strength test (Cylinder)

4.4.3 PRSIM FLEXURAL STRENGTH

Standard beam test (Modulus of rupture) was carried out on the beams of size 100 mm x 100 mm x 500 mm as per IS: 516 [Method of test for strength of concrete], by considering that material is homogeneous. The beams were tested on a span of 400 mm for 100 mm specimen by applying two equal loads placed at third points. To get these loads, a central point load has applied on a beam supported on steel rollers placed at third point as shown in Fig.6.5.

The rate of loading is 1.8 kN/minute for 100 mm specimens and the load was increased until the beam failed.

Depending on the type of failure, appearance of fracture and fracture load, the flexural tensile strength of the sample was estimated.

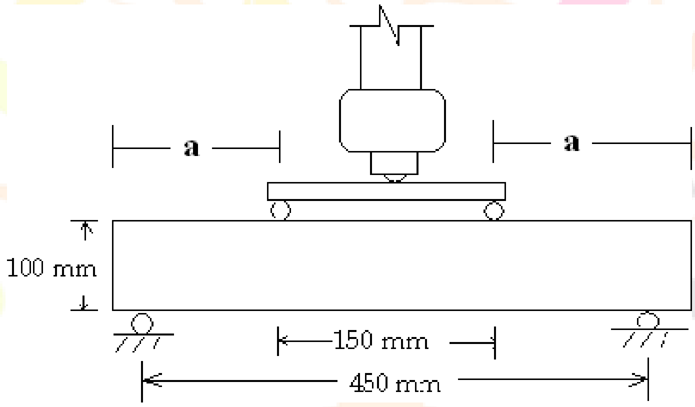


Fig.4.4 Schematic diagram for flexure test

Fig.4.5 Flexural strength test

As explained earlier, in the present investigation, the flexural strength test has been conducted on concretes with different type of coarse aggregate M25 grade of silica fume concrete silica fume concrete.at 7,14 and 28 days.

If 'a' be the distance between the line of fracture and the nearer support, then for finding the modulus of rupture, these cases should be considered.

i) When a > 133 mm for 100 mm specimen

fcr = PL/bd^2, where P = total load applied on the beam

ii. When 110 mm < a < 133 mm, $f_{cr} = 3Pa/bd^2$

iii. When a < 110 mm, the result should be discarded.

4.4.4 RC BEAM TEST

According to the IS (10262-2019) minimum size of specimen for beam mold is 700X150X150 mm. Hence select the beam size as 1200X100X200 mm. six wooden moulds of the same dimensions were fabricated for casting the deep beam specimens to be tested. The moulds were properly cleaned and greased for easy de-molding after casting. The concrete required for casting was prepared using a concrete hand mix. Before pouring concrete, the reinforcement cages were placed inside the mould with suitable sized cover. The concrete was properly compacted. All the beams were cast to the same dimension of 200 mm depth, 100 mm width and 1200 mm overall length. Prior to pouring in concrete into form, fibre optic sensor was pasted at mid span on one of the bottomreinforcing bars.

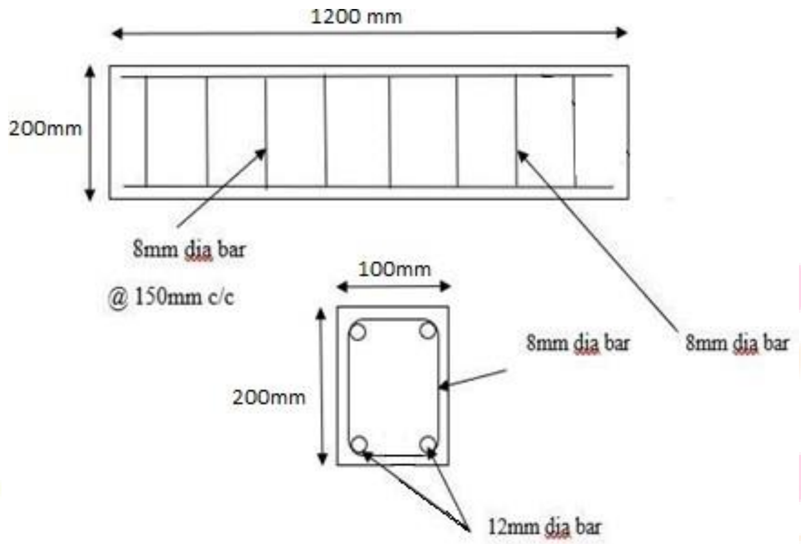
A beam with an effective span of 1200 mm was tested under two-point loading using a hydraulic jack, with the distance between the loading points set at 570 mm. The beam had been subjected to 28 days of curing using wet gunny bags at ambient temperature. An LVDT was fixed to measure mid-span deflection. The test beam was positioned for testing under incrementally applied flexural load.

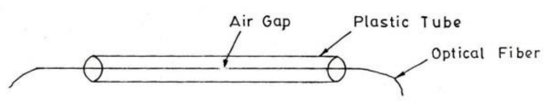
Prior to loading, a dial gauge was affixed to measure the deflection at mid- span. Fibre ends emerging from the beam were connected to the circuit, and connections were thoroughly checked. Load was applied at mid-span via a UTM (Universal Testing Machine). Observations were made regarding deflection on the dial gauge and intensity losses (attenuation) on the oscilloscope.

Specimen details:

Bars Stirrups = 8 mm dia bars @ 150mm c/c Specimen dimension: 200mmx100mmx1200mm

Fig. 4.6 Reinforcement Details





Fiber Optic Sensor

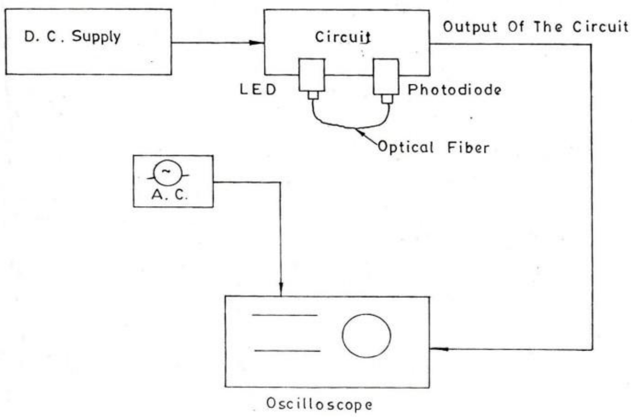


Fig. 4.7 Flow Chart Depicting Sensing Devices

In the present experimental study multimode step index plastic fibre of 1mm diameter has been used. Although fibre optic glass fibres are more precise than plastic fibres for receiving and transmitting light signal, but these are highly brittle and cannot be embedded inside the concrete.

Sensing Technique Employed: The sensing technique utilized in this study involves cleaving the ends of optical fibres and placing them into a capillary tube. A very small air-gap is intentionally created between the two cleaved ends of the optical fibre within the capillary tube (refer to fig.6.8). Extended disturbances may cause the air-gap in the tube to either shorten or widen, resulting in corresponding variations in the intensity of light passing through the optical fibre. The fibre optic sensing devices consist of a light source for injecting a signal into the sensor fibre, a light detector for receiving the modulated signal from the optical fibre sensor, and an electronic system for processing the detected light intouseful electrical quantities.

Fig. 4.8 RC Beam Test

4.5 MIX DETAILS

The mix proportion chosen for this study is 1:1.89:3.0 with water/cementratio of 0.4 shown in table 4.1. M25 concrete is used.

Table 4.1 Mix proportion of concrete

S.No	Water	Cement	Fine aggregate	Coarse aggregate
1	192	413 kg/m^3	859.3 kg/m^3	964.2 kg/m^3
2	0.4	1	2.0	2.5

Table 4.2 Mix proportion of concrete replacing with Silica fume

S.No	**Mix**	**Cementkg/m^3**	**Fine aggregate kg/m^3**	**Coarse aggregate kg/m^3**	**Water**	**Silica fume Kg/m**
1	M_0	413	859.3	964.2	192	0
2	M_1	408.87	859.3	964.2	192	4.13
3	M_2	404.74	859.3	964.2	192	8.26
4	M_3	400.61	859.3	964.2	192	12.39
5	M_4	396.48	859.3	964.2	192	16.52
6	M_5	392.35	859.3	964.2	192	20.65

CHAPTER 5 RESULTS AND DISCUSSIONS

5.1 RESULTS

The experimental investigation analysis is carried by considering various mix property of silica fume concrete on the Concrete Specimen has been carried out to find its structural performance. The results from the study are discussed in this chapter.

5.1.1 Compressive strength

The results of the mechanical properties obtained based on the specimens tested as per Indian standard test procedures (as per IS: 516) are discussed. M25 grade of concrete with various percentage of silica fume with their three different ages of curing are the variables of investigation. The details of the compressive strengths of M25 grade are shown in Table 7.1.

Table: 5.1 7, 14 & 28Day Cube Compressive strength

S.No	Mix	7 Days N/mm^2	14 Days N/mm^2	28 Days N/mm^2
1	M_0	20.91	26.05	32.1
2	M_1	22.61	26.25	32.2
3	M_2	23.12	26.80	33.4
4	M_3	23.28	28.35	35.54
5	M_4	22.16	27.71	34.78
6	M_5	21.16	27.53	33.89

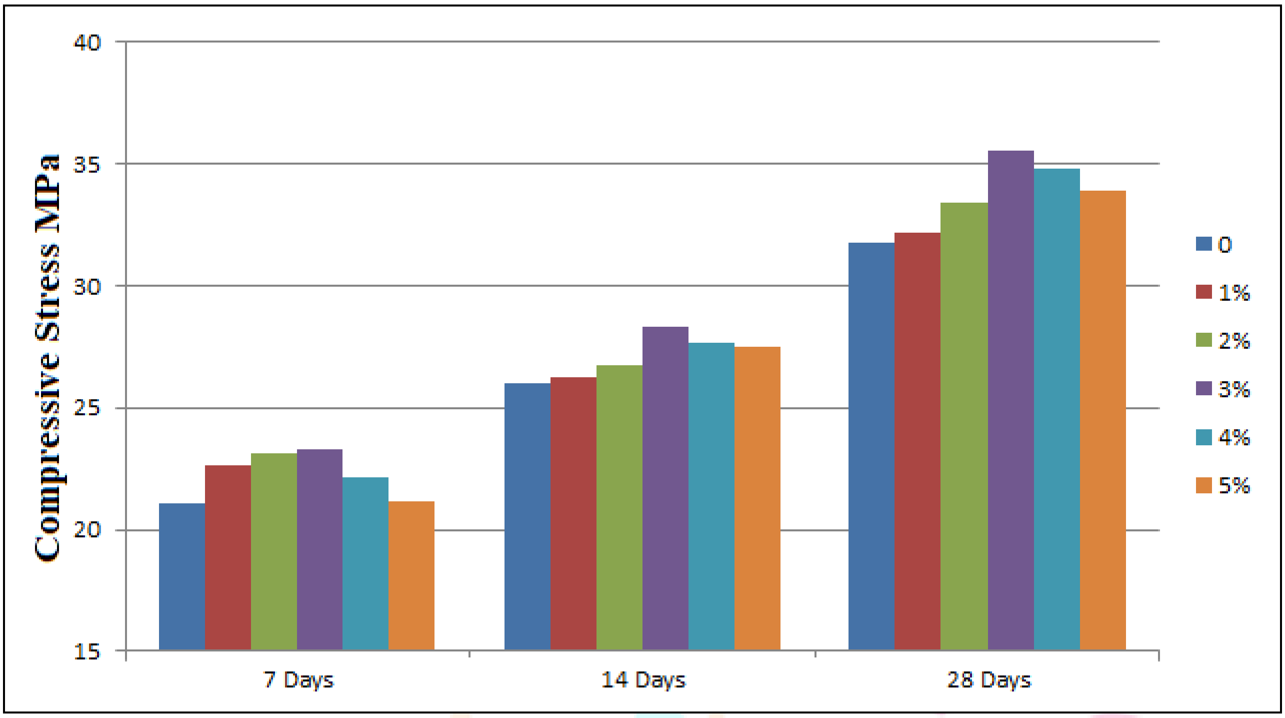


Figure: 5.1 7, 14 & 28Day Cube Compressive strength

From the table it is observed that rate of gain in Cube & ConcreteCompressive strength is more at 28 days compared to 14 days.

5.1.2 Split tensile strength

The splitting tensile strength are presented. For a mix three cylinders were tested for split tensile strength. The results from the tensile test are presented in Table 7.3.

Table: 5.2 7, 14 & 28Day splitting tensile strength

S.No	Mix	7 Days N/mm^2	14 Days N/mm^2	28 Days N/mm^2
1	M_0	3.26	3.42	4.1
2	M_1	3.31	3.57	4.46
3	M_2	3.42	3.64	4.59
4	M_3	3.97	3.97	5.56
5	M_4	3.81	4.4	5.3
6	M_5	3.85	4.1	5.43

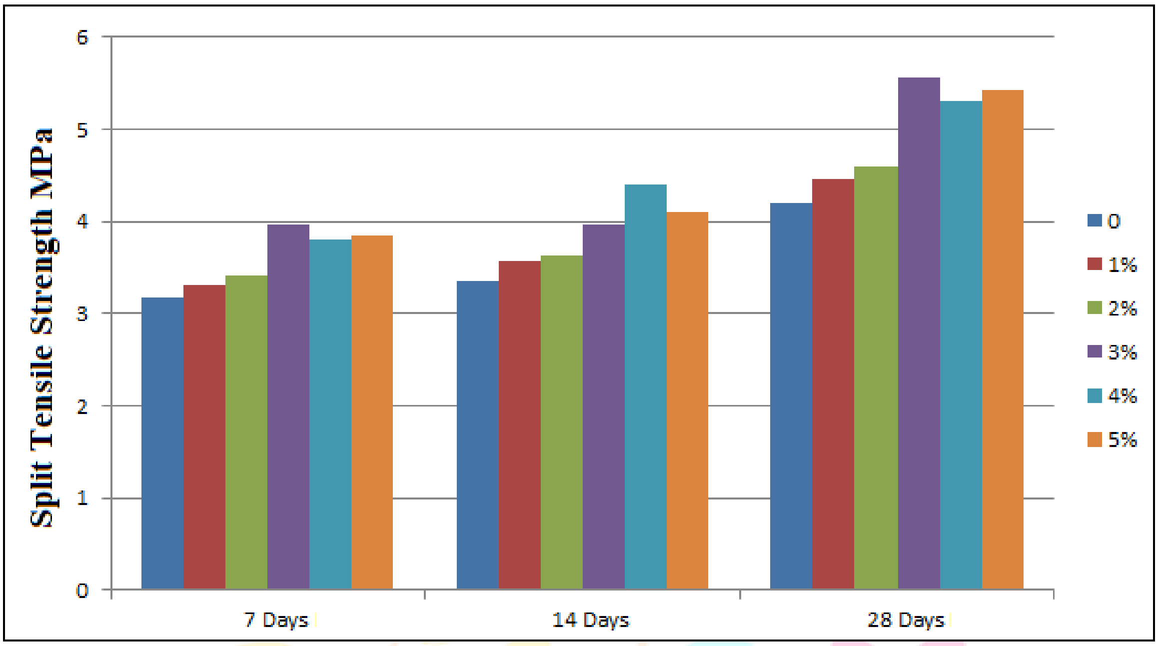


Figure 5.2.: 7, 14 & 28Day Split Tensile Strength

From the table it is observed that rate of gain in splitting tensile strength ismore at 28 days compared to 14 days.

5.1.3 Deflection test

Concrete specimens were tested in accordance with the relevant standard testing methods for the flexural strength of RC beams, utilizing a fixed supported beam setup. The flexural test, conducted under two-point loading, was performed on the RC beam. Three LVDTs were strategically positioned beneath the two- point loading supports and at the mid-point. During the testing, loads and their corresponding deflections were recorded and are presented herein in the form of tables and graphs. Deflections were measured using embedded optical fibre sensors provided in the test beams at the level of steel at mid-span, while deflection was also measured by a dial gauge at mid-span.

This clearly shows that the adding Silica Fume the concrete does not much contribute in the strength development. As the loading increased, hair cracks were appeared at the bottom of the Concrete and transverse towards the top of the Concrete. The 3% silica fume mix having the higher load carrying capacity. The comparison of first crack load and ultimate load for the Concrete was shown in figure 7.13.

During the experiment it is found that at a load of about 25.2 kN cracks appear on the beam surface but before that there is a considerable loss in the intensity of light, which may be due to crack formation (invisible) in the beam. This characteristic of embedded fibre sensor can be used as a crack detection tool.

Table 5.3 : RC Beam Results

S.No	MIX	First Crack Load kN	Ultimate LoadkN	Deflection mm
1	M_0	6.7	15.9	0.3
2	M_1	11.1	17.8	0.5
3	M_2	18.1	23.1	0.9
4	M_3	19.6	25.2	1.4
5	M_4	16.3	22.2	1.2
6	M_5	15.9	21.9	0.95

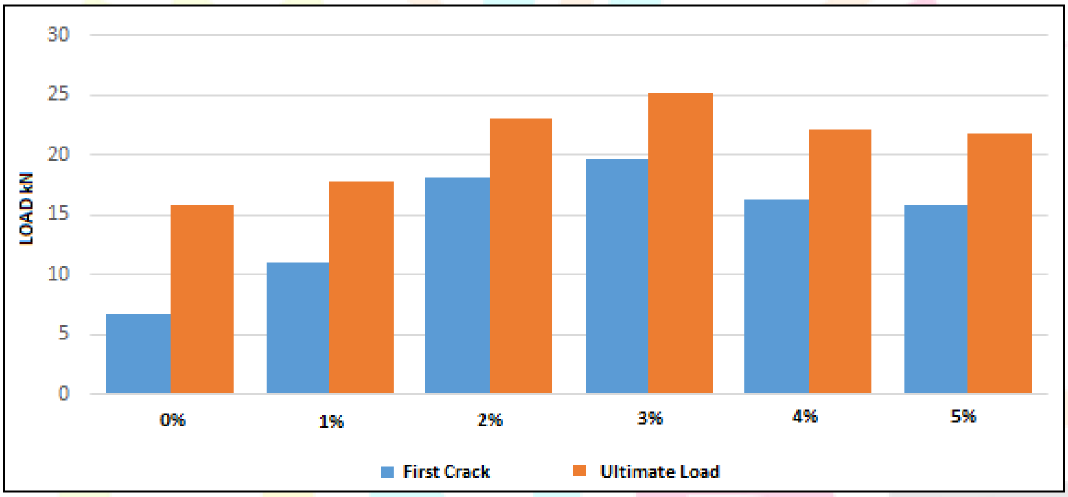


Figure 5.3 Comparisons of First Crack Load and Ultimate Load

The first crack load for the 3% Mix was 19.6 kN and for 1% mix 11.1 kN which was greater than the first crack load for the Conventional Concrete was observed to be 6.7 kN.

5.1.4 LOAD-DEFLECTION BEHAVIOUR:

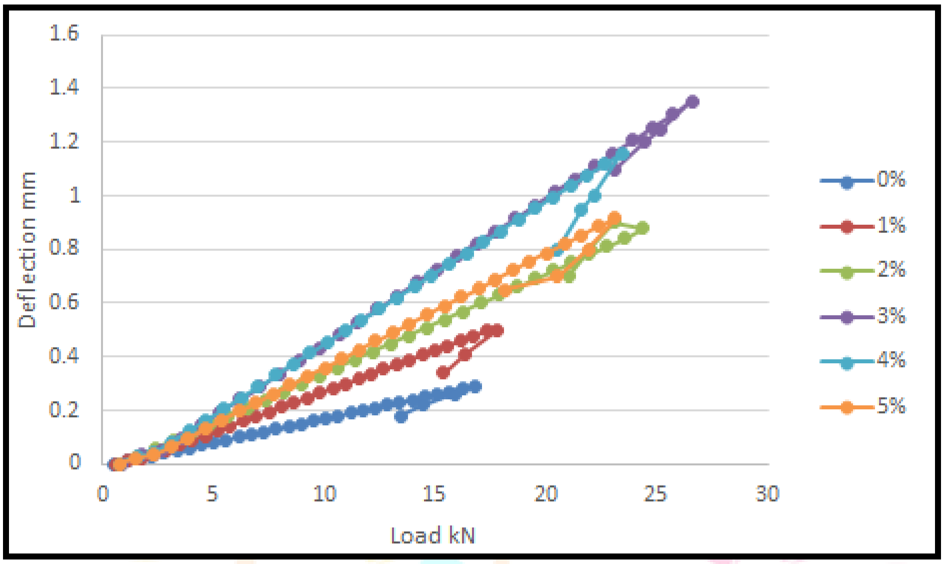


Fig. 5.4 Load Vs Deflection Curve for all Concretes(Experimental Result)

The load deflection curve for all the RC beams were plotted. The comparisons of load-deflection curve for the conventional, varies mix proposition of silica fume concrete was shown in figure 7.7 The load values of conventional Concrete were lower compared to other Concretes.

CHAPTER 8 CONCLUSION

The Concrete with silica fume has much greater advantageous than the normal reinforced concrete Concretes. In this project, various literatures were collected to get an idea about the crack in Concrete. Experimental analysis of various proposition of silica fume in Concrete was done and its results are obtained. From the above study silica fume in Concrete are used in many civil structures such as pedestrian decks, roof Concretes, railway sleepers, bridge beam etc.

Their properties like high stiffness to weight ratio, high thermal insulation property, and high impact and vibration absorption rates are very useful for civil structures. The structural behavior of Concrete using silica fume can change by making changes in the parameters accordingly. They are light weight and corrosion resistant compare to normal concrete and steel.

The addition of silica fume did not significantly enhance strength development in concrete, as evidenced by comparable first crack loads across different mix proportions.

The 3% silica fume mix exhibited superior load-carrying capacity, suggesting potential benefits for specific applications. Embedded fibre optic sensors proved effective in detecting crack formation, offering early warning signals before visible cracks appear. Interdisciplinary collaboration between concrete engineering, physics, and opto-electronics is crucial for advancing sensing technologies in the construction industry.

It shows that silica fume has good effectiveness for increasing the load carrying capacity, cracks, and stiffness for the concrete Concretes.

The utilization of silica fume in reinforced concrete, coupled with the implementation of fiber optic cable technology, has demonstrated remarkable efficacy in early detection of internal cracks. The first crack load values obtained for both the 3% mix (19.6 kN) and the 1% mix (11.1 kN) surpassed that of conventional concrete (6.7 kN), indicating enhanced structural integrity and resilience against crack initiation. This innovative approach not only offers a means to proactively identify potential weaknesses within reinforced concrete structures but also underscores the significant role of advanced materials and monitoring techniques in advancing the durability and safety of civil infrastructure

From the above discussion, it can be concluded that the Concrete with silica fume have high tensile strength, compression strength, flexure strengthand reduced self-weight.

APPENDIX MIX DESIGN

MIXING PROCEDURE:

In this project the mix shall be designed to produce the required grade of concrete having the designed workability and characteristic compressive strength, which will not be less than the appropriate values as per IS 10262:2009.

MIX DESIGN FOR M25 GRADE CONCRETE:SPECIFICATIONS FOR MIX DESIGN

Grade of cement	: OPC53
Type of exposure	: Medium
Size of coarse aggregate	: 12.5 mm
Specific gravity of cement	: 3.15
Specific gravity of Fine aggregate	: 2.54
Specific gravity of coarse aggregate	: 2.85

(i) Target strength for mix proportion

The target mean compressive strength at 28 days is given by

$f' = f_{ck} + 1.65S$ ck

From IS 10262:2000 S = 5 N/mm^2 (S – Standard Deviation)

$f' = 25 + (1.65 \times 4)$ ck

= 31.6 N/mm^2

(ii) Selection of water cement ratio From IS456:2000 table 5 Exposure condition: Moderate

W/C ratio = 0.4

Maximum water cement ratio = 0.5Adopt 0.45, 0.45 < 0.5(hence ok)

(iii) Selection of water content

From IS 10262:2009 table 2

Aggregate size = 20 mm = 186 liters (25 - 50mm slump)From IS456 - Page 17

Reinforced wall-medium (slump 50 - 100, 75 - 100)Adopt 75mm (slump)

Estimated water content for 100mm slump

= 186 + ((3/100) × 186)

= 191.58 litres

(iv) Cement content

W/C ratio = 0.45

Cement content = 186/0.45

= 413.4Kg/m^3

IS 456:2000 table 5

Minimum cement content = 360 Kg/m^3From IS 456:2000 cl.8.2.4.2

Cement content is limited to 450 Kg/m^3Cement content

= 360 Kg/m^3 < 413.4 Kg/m^3 < 450 Kg/m

(v) Proportion of volume of course and fine aggregate content

From IS 10262:2009 table 3

- Volume of coarse aggregate corresponding to 20 mm size and fine aggregate (zone II) for water cement ratio of 0.5 = 0.60.
- In the present work water cement ratio is 0.45. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water cement ratio is lower by 0.05 the proportion of volume of coarse aggregate is increased by 0.01(at the rate of $\pm$ 0.01 for every $\pm$ 0.05 change in water cement ratio).
- Therefore, correct proportion of volume of coarse aggregate for thewater cement ratio of 0.4 = 0.5.
- Volume of coarse aggregate for water cement ratio of 0.4 = 0.5
- Proportion of volume of FA = 1 - 0.5= 0.5

(vi) Mix calculation

a) Volume of concrete = 1 m^3

b) Volume of cement = $\frac{\text{Mass of cement}}{(\text{sp. gravity of cement}) \times (\text{density of cement})}$

= 413.4/ (3.15×1000)

= 0.1314 m^3

c) Volume of water = $\frac{\text{Mass of water}}{(\text{sp. gravity of water}) \times (\text{density of water})}$

=191.58 / (1×1000)

= 0.192 m^3

d) Volume of all in aggregate= a - (b + c)

= 1 - (0.1314 + 0.192)

= 0.6766 m^3

e) Mass of coarse aggregate = e × Volume of coarse aggregate × Specific gravity of coarse aggregate × 1000

= 0.6766 × 0.5 × 2.85 × 1000

= 964.2 kg.

a = e × volume of fine aggregate × Specific gravity of fine aggregate × 1000

= 0.6766 × 0.5 × 2.54 × 1000

= 859.3 kg.

REFERENCE

1. Allan, M.L. Guidlines for Mixing and Placing Thermally Conductive Cementitious Grout (Mix 111); Informal Report; Brookhaven National Laboratory: Upton, NY, USA, 1999.

2. Ansari, F.; Libo, Y(1998) Mechanics of bond and interface shear transfer in optical fiber sensors. J. Eng. Mech., 124, 385–394.

3. Bai, Q.; Wang, Q.; Wang, D.; Wang, Y.; Gao, Y.; Zhang, H.; Zhang, M.; Jin, B. (2019), "Recent advances in Brillouin optical time domain reflectometry", Vol. 19, pp.62.

4. Feng, X.; Zhou, J.; Sun, C.; Zhang, X.; Ansari, F. (2013) Theoretical and experimental investigations into crack detection with BOTDRdistributed fiber optic sensors. J. Eng. Mech., 139.

5. Gao, S.; Liu, Y.; Li, H.; Sun, L.; Liu, H.; Rao, Q.; Fan,(2020) X. Transformer winding deformation detection based on BOTDR and ROTDR. Sensors, 20, 2062.

6. Gholamzadeh, B.(2008); Nabovati, H. Fiber Optic Sensors. Int. J. Electron. Commun. Eng., 2, 1107–1117.

7. Guan, Z.; Jiang, X.Z.; Wu, Y.B.; Pang, Z.Y(2015). Study on Monitoring and Early Warning of Karst Collapse Based on BOTDR Technique; National Cave and Karst Research Institute: Carlsbad, NM, USA.

8. Han, T.; Wu, G.; Lu, Y(2021). Crack monitoring using short-gauged Brillouin fiber optic sensor. Measurement , 179.

9. Horiguchi, T.; Kurashima, T.; Tateda, M.(1989) Tensile strain dependence of Brillouin frequency shift in silica optical fibers. IEEE Photonics Technol. Lett. , 1, 107–108.

10. Hu, T.; Hou, G.; Li, Z.(2021) The field monitoring experiment of the roof strata movement in coal mining based on DFOS. Sensors , 20, 1318.

11. Iten, M.; Hauswirth, D.; Puzrin, A.M. Distributed fiber optic sensor development, testing, and evaluation for geotechnical monitoring applications. In Smart Sensor Phenomena, Technology, Networks, and Systems 2011; International Society for Optics and Photonics: Bellingham, WA, USA, 2011.

12. Liu, S.-P.; Gu, K.; Zhang, C.-C.; Shi, B. Experimental research on strain transfer behavior of fiber-optic cable embedded in soil using distributed strain sensing. Int. J. Geomech. 2021, 21, 04021190.

13. Madjdabadi, B. Experimental Evaluation of a Distributed Fiber Optic Sensor for Mining Application; University of Waterloo: Waterloo, ON, Canada, 2016;

14. Madjdabadi, B.; Valley, B.; Dusseault, M.B.; Kaiser, P.K. Experimental evaluation of a distributed Brillouin sensing system for measuring extensional and shear deformation in rock. Measurement 2016, 77, 54–66.

15. Madjdabadi, B.M.; Valley, B.; Dusseault, M.B.; Kaiser, P.K. Numerical Modeling of strain transfer from rock mass to a fiber optic sensor installed inside a grouted borehole. In Proceedings of the 46th US Rock Mechanics/Geomechanics Symposium, Chicago, IL, USA, 24–27 June 2012.

16. Maslo, A.; Hodzic, M.; Skaljo, E.; Mujcic, A. Aging and degradation of optical fiber parameters in a 16-year-long period of usage. Fiber Integr. Opt. 2020, 39, 39–52.

17. Mei, Y. Error Analysis for Distributed Fibre Optic Sensing Technology Based on Brillouin Scattering; University of Cambridge: Cambridge, UK, 2018.

18. Moffat, R.A.; Beltran, J.F.; Herrera, R. Applications of BOTDR fiber optics to the monitoring of underground structures. Geomech. Eng. 2015, 9, 397–414.

19. Nowak, S.; Sherizadeh, T.; Esmaeelpour, M. Optical Fiber Anchor for Distributed Sensing in Brittle Mediums; Missouri University of Science and Technology: Rolla, MO, USA, 2022.

20. Ohno, H.; Naruse, H.; Kihara, M.; Shimada, A. Industrial applications of the BOTDR optical fiber strain sensor. Opt. Fiber Technol. 2001, 7, 45–64.

21. Seabrook, B.C.; Ellmauthaler, A.; LeBlanc, M.; Jaaskelainen, M.; Maida, J.L.; Wilson, G.A. Comparison of Raman, Brillouin, and Rayleigh Distributed Temperature Measurements in High-Rate Wells. In Proceedings of the SPWLA 63rd Annual Logging Symposium, Stavanger, Norway, 11–15 June 2022; OnePetro: Richardson, TX, USA, 2022.

22. Tang, Y. Concrete structure monitoring with distributed long-gauge optical fiber sensor. In Proceedings of the 2015 4th International Conference on Sensors, Measurement and Intelligent Materials, Shenzhen, China, 27–28 December 2016; Atlantis Press: Paris, France, 2016.

23. Zhang, C.-C.; Shi, B.; Zhang, S.; Gu, K.; Liu, S.-P.; Gong, X.-L.; Wei, G.-Q. Microanchored borehole fiber optics allows strain profiling of the shallow subsurface. Sci. Rep. 2021, 11, 9173.

24. Zhang, H.; Wu, Z. Performance evaluation of BOTDR-based distributed fiber optic sensors for crack monitoring. Struct. Health Monit. 2008, 7, 143–156.

25. Zhang, X.; Broere, W. Sensing fiber selection for point displacement measuring with distributed optic fiber sensor. Measurement 2022, 197, 111275.