JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EFFECT OF DELAYED CASTING OF CONCRETE-ON-CONCRETE STRENGH DUE TO FORMATION OF COLD JOINT

A thesis submitted to School of graduate studies of Jimma University Institute of Technology in partial fulfillment for the requirement for the master of the degree of science in structural engineering

BY:

BIRUK FEKADU HAILE

JANUARY, 2022

JIMMA, ETHIOPIA

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By:

Baruch Fekadu Haile

Advisor:

Dr. Kabtamu Getachew

Co advisor:

Eng. Abinet Alemseged

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DECLARATION

I, declare that this study entitled **— Effect of delayed casting of Concrete-on-Concrete Strength due to formation of Cold joint** is my original work and has not been presented for a degree or diploma in any other University, and that all sources of materials used for the study have been duly acknowledged.

Students Name: Biruk Fekadu Haile Signature…................. Date…………….

Student ID: RM 7680/11

Student Email: abiyefekadu1618@gmail.com

Thesis Advisor:

Dr. Kabtamu Getachew …..07/07/22

Co-Advisor

Eng. Abinet Alemseged Signature…................. Date…………….

APPROVAL SHEET

This thesis has been submitted for examination as university supervisor. The thesis titled "**Effect of delayed casting of Concrete-on-Concrete Strength due to formation of Cold joint**" by Biruk Fekadu is approved for the Degree of Masters of Science in Structural Engineering.

Approved by board of examiners:

We, the undersigned, approve the master's Thesis of Biruk Fikadu

Name	Signature	date
Dr. Kabtamu Getachew (PhD) (Advisor)		07/07/22
Engr. Abinet Alemseged (Msc.) (Co-advisor)	_________	_________
Engr. Goshu Kenea (Msc.) (Internal Examiner)	_________	_________
Dr. Biniya Patnalk (PhD) (External Examiner)		07/07/2022
Engr. Besukal Befekadu (Msc.) (Chairperson)	_________	_________
Engr. Abinet Alemseged(Msc.) (Structural Engineering Chair)	_________	_________

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ABSTACT

*Delayed casting of concrete forms a joint between hardened and newly placed fresh concrete which is commonly called construction or cold joints and affects strength of concrete. An experimental investigation was performed to evaluate the effect of different delayed casting of concrete on strength of concrete due to cold joint formation and configuration. A total of 44 number of concrete specimens were produced, out of those 12 numbers of (150*150*150mm^3) cubes were used to determine the compressive strength, 12 number of (Φ=150mm and h=300mm) cylinders were used to determine the split tensile strength and 20 number of (100*100*500mm^3) beam specimens were used to determine flexural strength of concrete with different cold joint formation time and configuration at the end of curing period of 28 days. For all samples firstly fresh concrete specimen was produced by placing fresh concrete for half cylinder, cube, or beam mold and for the remaining half filling of the cylinder, cube or beam mold freshly mix concrete was casted with the times laps of 0, 7, 14, and 21 days and metallic molds was used to produce vertical, horizontal, and inclined cold joint configuration in each separation; therefore, the resulting plane was flat. Finally, the ultimate strength tests were recorded and analyzed on each of these samples at the ages of 28 days of curing time to study the behavior for the joints under compressive, split tensile and flexural strength of concrete. From laboratory test result it was observed that percentage reduction of compressive strength of concrete when casting the second layer of cube specimens after 7, 14 and 21days where 5.92%, 14.07%, and 28.54% respectively with respect to reference specimens. The reduction of tensile strength of concrete when casting the second layer of cylinder specimen after 7, 14 and 21 days where 10.75%, 12.9%, 32.25% respectively compared to control specimen. Flexural strength was decreased with increasing times delay of casting the second layer of concrete with inclined, horizontal, and vertical failure plane of beam specimens where 32.38%, 22.86% and 52.85% respectively. From laboratory test result it was observed reduction of concrete strength was increased when delay period of casting increases.*

***Keywords**: - Delayed casting, cold joint, concrete strength, concrete specimens.*

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASTM	American society for testing and materials
BS	British Standard
CSA	Central Statistical Agency
EBCS	Ethiopian Building Code of Standard
Ec	Modulus of elasticity of concrete
ES	Ethiopian Standard
f_c	Concrete compressive strength
f_{ck}	Characteristic cylinder compressive strength
f_{ctk}	Characteristic tensile strength of concrete
f_{ctm}	Mean value of axial tensile strength of concrete
FST	Final setting time
f_{st}	Splitting tensile strength
IST	Initial setting time
IS	Indian Standard
KN	Kilonewton
KM	Kilometers
Kcf	Kilo (Thousand) cubic feet
Ksi	Kilo pounds per square inch
Kg/cm^2	Kilogram per centimeter square
Lb/ft3	Pound per feet cube
Mm	Millimeter
Ml/L	Milligram per liter
Mpa	Mega Pascal
MR	Modulus of rapture
Ppm	Parts per million
Psi	Pound per square inch
Pvc	Polyvinyl chloride
R/C	Rainfall condition
SABS	South African Bureau of standards
SNNPR	South Nation Nationally People Regions
SSD	Saturated surface dry
W/c	Water to cement ratio

CHAPTER ONE: INTRODUCTION

1.1. Background of the Study

Now a day world construction continues to move towards increasing because of advances in civilization of modern technology in construction industries, growth in developing countries and need for infrastructures. Concrete is the most constructive material throughout the world industry and it is produced from three basic ingredients; namely, cement, aggregate and water. It develops strength in the presence of water when added to the dry mixture of the ingredients. The development of concrete strength in the said mass starts instant of the time when the water is just added to it up to a certain time preferably the initial setting time and the prepared mass remains plastic and can be molded easily, after which the hardening process proceeds faster towards the final setting time and the mass becomes hard and solid which cannot be molded at all. Delays in concreting are leading to partial setting of concrete which has suffered a long period of exposure in the open before actual casting in the mold. This concrete should not be utilized for strength purpose in practice, and is to be discarded, but still, it contains a good portion of the active part of the reactive cement in that mass. These situations may affect the strength of final product. The strength also depends on the plane at the concrete joint made while casting. In addition, admixture is sometimes used to improve some properties of concretes like workability and setting times. The ingredients of concrete and procedures should be of good quality that satisfies the requirements set in standards [9].

Most of construction projects are concrete structures particularly in developing countries, In our country Ethiopia improper casting of concrete or jumped casting or delayed casting of concrete is common in many construction sites because of lack of knowledge, poor construction procedure, poor project management, poor workman ship and extreme delay of construction materials specially cement, fine aggregate and coarse aggregate and project termination; however this trend of casting of concrete varies with time and delivery of the new mix of concrete and the older or hardened concrete. When new mix of concrete is casted together with older or hardened concrete, discontinuity layer formed due to variable moisture and temperature difference as result, weak bond layer called cold joint formed and it affects concrete strength. This is one of the serious problems of improper casting sequence or extreme delay of concrete casting [6].

Improper placing of concrete may segregate the concrete and undermine its quality. Delay in placing of concrete forms a joint between hardened and newly placed fresh concrete which is commonly called construction or cold joints. These joints are weak planes, hence, must be avoided during concrete constructions. However; it may not be practical to avoid cold joint formation completely, but it is possible to minimize and reduce its effect by properly implementing the right construction techniques [11]. However; it is very difficult to cast the whole structure monolithically and the construction joints are very important in the structure for the expansion and contraction of the concrete. Also, the amount of the concrete to be placed is depends on the mixing capacity of plant crew sizes. The correctly designed, located, and constructed joints do not affect the strength of the concrete. For many structures, it is impractical to place concrete in a continuous operation. Construction joints are needed to accommodate the construction sequence for placing the concrete. The amount of concrete that can be placed at one time is governed by batching and mixing capacity, crew size, and the amount of time available. Correctly located and properly executed construction joints provide limits for successive concrete placements, without adversely affecting the strength of structure [6].

A plane of weakness or discontinuity formed when a batch of concrete hardens before the next batch is placed against it is called cold joint. A cold joint is usually characterized by poor bond unless remedial measures are taken before placing concrete against a previously hardened batch. To avoid cold joints, placing should be resumed substantially before the time of initial set. For unusually long delays during concreting, the concrete should be kept alive by periodically re vibrating it. However, concrete should not be over-vibrated to the point of causing segregation. Furthermore, should the concrete approach time of initial setting, vibration should be discontinued and the concrete should be allowed to harden.

A cold joint will result, and suitable surface preparation measures should be applied. When, in practice, either casting cannot be completed in one go or there is a time lapse between mixing and placing, the strength of the final product is affected. The strength could also depend on the plane where casting at two different points in time meets [6].

Delay in concreting, resulting the cold joints and it affect concrete strength minor to very major reduction. Following are some cause results of improper casting sequence: -

1. Delay in casting or jumped casting or mixing due to time gaps
2. Due to delay in transportation of cement, sand, and aggregate from production to site
3. Extension of the incomplete construction on next day
4. Due to termination of projects

In order to prevent or to control the above problem the sequence of concrete casting, batching, mixing, transporting, compaction, curing and selecting of appropriate formwork material should be planned properly. In addition to this, reinforcement bar requires proper handling during stocking and proper care during fabrication process such as cutting, bending, tying, and fixing. According to EBCS 2, 1995, quality control comprises a combination of action and decision taken incompliance with specification and checks to ensure that these are satisfied. Therefore; this research carried out to study the effect of improper casting sequence on concrete strength due to formation of cold joint problem.

1.2 Statement of the problem

Generally cold joint is common occurrence in concrete structures; however, this affects the strength of concrete structures, appearance of structures and rise public concern and attention regarding safety issues. The main cause of cold joint wase extreme delay of concrete placement forms a joint between hardened and newly placed fresh concrete. Such joints may trigger on early start of corrosion of rebar or penetration of harmful liquids or gases in to the concrete body. Such situation can result in poor shear transfer and flexural continuity due to poor bond at the interface results, significantly increased maintenance cost and loss of durability. Therefore, it is important to prevent or control these joints [5].

Delayed construction material delivery, high cost of fine and coarse aggregate is the main reason for the creation of delayed or jumped casting so that many projects are exposed to cold joint, loss of durability, bad appearance, leakage of concrete roof slabs and long-term maintenance cost.

1.3 Objectives of the study

1.3.1 General objective of the study

The main objective of the study is to assess the effect of delayed casting on concrete strength due to formation of cold joint.

1.3.2 Specific objectives of the study

The main objective of the research is achieved through the following specific objectives

1. Studying effect of different delay period of cold joint formation when casting the second layer of concrete after 7, 14, and 21 days on concrete compressive strength.

2. Studying effect of different delay period of cold joint formation when casting the second layer of concrete after 7, 14, and 21 days on concrete tensile strength.
3. Determining the effect of configuration of cold joint with inclined (45^0), horizontal (0^0) and vertical (90^0) formation angle on flexural strength of concrete.

1.4 Justification/ Rationale/ Motivation

This research may be useful to meet the requirements of good quality of concrete to the construction industry, using proper concrete casting and spreading uniformly without delaying or jumping sequences. And this paper helps the consultant in regulating and specifying the effectiveness of proper casting of concrete to produce good quality of concrete and to prevent or minimize formation of cold joint.

All actors of construction stakeholders within an insight into the benefits of using different factors studied in this research to predict the factors that affecting quality of concrete additionally, the contractors can use the findings of this study to build quality and durable structures. Furthermore, selecting appropriate placement of concrete helps to ensure the strength of concrete structures, speed up construction performance, keep aesthetic value, keep the safety of occupants, and reduces long term maintenance cost. And helps other researcher as source material for further study.

1.5 Scope of the study

The research focuses on the effects of delayed casting of concrete on the strength of concretes due to formation of cold joint made with Portland cement in Ethiopia. Fine and coarse aggregates selected for the researches are from; Dimma and Aggaro respectively because they are available in the south west parts of Ethiopia. The scope of this study delimited to study effect of delayed casting of plain concrete only in reduction of ultimate strength of concrete at laboratory

Conceptually: Concrete strength, formation of cold joint, delayed casting of concrete and effect of cold joint are constraints are the center of the study.

Experimentally: Laboratory investigation at normal laboratory temperature of 27^0C. The tests carried out in order to achieve the objectives of this research includes; workability test, density test, compressive strength test, split tensile test and flexural test and the cold joint formation time were 7, 14 and 21 days.

This research is to understand the effect delayed casting of concrete placement resulting cold joint on concrete strength and meet the requirements of good quality of concrete to the construction industry.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

2.2 Basic features of concrete

Concrete is the most common building material used in today's construction industry. It can be cast in any desired shape and fashion and is therefore applicable for most building purposes. Its long life and relatively low maintenance requirements add to its popularity. Concrete does not rot, rust, or decay and is resistant to wind, water, rodents, and insects. It is a non-combustible material, making it fire resistant and able to withstand high temperatures. In the road sector, concrete is used for several purposes, including pavements, bridges, culverts, retaining walls and other structures. Concrete is a mixture of cement, water, and aggregate. The aggregate consists of a mixture of various sizes of gravel and sand. When water is added to cement, a chemical reaction takes place causing the mix to harden. Concrete is a strong durable building material that can be formed into many varied shapes and sizes. It is achieved by combining the best features of concrete and steel because concrete is a brittle, composite material that is strong in compression and weak in tension. Cracking occurs when the concrete tensile stress in a member reaches the tensile strength due to externally applied loads, temperature changes, or shrinkage. Concrete members that do not have any type of reinforcement in them will typically fail very suddenly once the first tension crack is formed as there is nothing to prevent the cracks from propagating completely through the member. So, it becomes desirable to reinforce the concrete with reinforcement bar which provide greater resistance to tensile and shear forces [1].

2.3 Composition of concrete

Concrete is basically a mixture of two components: aggregates and paste. the pastes bind the aggregate into rocklike mass because of the chemical reaction between cement and water, sometimes mineral and chemical admixtures may also be included in the paste. The quality of the concrete depends upon the quality of the paste and aggregate, and the bond between them. In properly made concrete, each particle of aggregate is completely coated with paste and all the spaces between aggregates are filled with paste [3].

2.3.1 Portland cement

Cement in general can be described as a material with adhesive and cohesive prosperities which make it capable of bonding mineral fragments into a hard continuous compact mass. Though there are various types of cements used for concrete production, Portland cement is the one which is commonly used in Ethiopia. Portland cement is one of the Hydraulic cements which are capable of setting and hardening under water. The principal raw materials used in the manufacture of cement are: -

1. Argillaceous or silicates of alumina in the form of clays and shales.
2. Calcareous, or calcium carbonate, in the form of limestone, chalk and marl which is a mixture of clay and calcium carbonate [3].

The major constituents of raw materials used in Portland cement production; mainly, lime, silica, alumina, and iron oxide compounds interact with one another in the kiln to form a series of more complex products. These are the tricalcium silicate (C3S), Dicalcium silicate (C2S), tricalcium aluminates (C3A) and tetra calcium alumina ferrite or iron compound (C4AF).

Table 2.1 Approximate limits of oxide composition in cement [3]

Oxide	Function	Content in percent (%)
Cao	Control strength and soundness. Its deficiency reduces setting time and strength	60-67
SiO_2	Gives strength. Excess of it causes slow setting	17-25
Fe_2O_3	Gives color and helps in fusion of different ingredients	0.5-6
Mao	Impart color and hardness, if excess it causes cracks in mortar and concrete and unsoundness	0.1-4.0
Alkalis	Those are residues, and if excess causes efflorescence and cracking	0.2-1.3
SO_3	Makes cement sound	1-3
Al_2O_3	Responsible for quick setting, if excess, it lowers the strength	0.2-1.3

2.3.2 Aggregates

Aggregates are the materials basically used as filler with binding material in the production of concrete and provide concrete with better dimensional stability and wear resistance. They are derived naturally from igneous, sedimentary, and metamorphic rocks or manufactured from blast furnace slag, etc. [2]. It is therefore significantly important to obtain right type and quality of aggregates (fine and coarse) because aggregates occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. So that to proportion suitable concrete mixes, certain properties of aggregate which influence the paste requirement of fresh concrete such as shape and texture, size graduation, moisture content, specific gravity and bulk unit weight must be known. In addition to these, aggregates should be hard, strong, dense, durable, clear, and free from veins and adherent coating; and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances. As far as possible, flaky, and elongated pieces should be avoided [2].

All standards specify their own requirements for aggregate used for concrete production, for instance ES 81:2001, SABS 1083 specify aggregate requirements by limiting on their grading, soundness, fineness, and amount of deleterious matter in addition to these requirements, Indian standard [IS: 383- 1970] included aggregate crushing value, aggregate impact value. On other hand British standard [882:1992] consider flakiness index, shell content and acid soluble sulfate as requirement.

Aggregates can be classify based on their origin, based on their size, based on their shape, and based on their unit weight but most specifications such as Ethiopian, Indian, and South African standards classified aggregates based on their sizes as fine and coarse aggregate depends on their most particles retained or passed on 4.75 mm sieve. But British standard uses 5 mm sieve size for classification. In addition to this, aggregates can be classified as light weight, normal weight and heavy weight depending on their unit weight [2].

2.3.3 Water

The purpose of using water with cement is to cause hydration of the cement. Water in excess of that required for hydration acts as a lubricant between coarse and fine aggregates and produces a workable and economical concrete. In addition to this water is also used for washing aggregates and curing.

2.3.3.1 Quality of mixing water

Potable water is acceptable for the concrete mix such water needs no testing but water that is unsuitable for drinking must be tested by taking a sample of minimum 5 liter within two weeks of sampling for its suitability for concrete production because excessive impurities may affect setting time, strength, durability and may cause efflorescence, surface discoloration, and corrosion of steel. The effects of impurities in water are mainly expressed in terms of setting time of Portland cement [2]. In addition to this British standard BS 3148 recommends surface water for concrete works by infiltration or impounding to allow suspended matter to settle if it is free from undesirable organic contents or an acceptable content of inorganic salts. According to Ethiopian Standard ES 2310:2005 water used for concrete shall fulfill chemical requirement listed on the Table 2.2 below for chlorides, sulfates and alkali and other harmful contamination (sugar, phosphates, nitrates, lead and zinc) or the requirement for setting time mean compressive strength requirements by specify initial setting time obtained in the specimens made with water shall be not less than one hour and not differ by 25 % from initial setting time obtained from specimens made with distilled water and final setting time shall not exceed 12 hours and not differ more than 25% from final setting time obtained from specimens made with distilled water is supposed to be acceptable in addition to this the mean compressive strength at 7 days of the concrete specimens prepared with water shall be at least 90% of the mean compressive strength of concrete specimens prepared with distilled water.

Table 2.2 Chemical requirements of water used for concrete [7]

Chemicals	**mg/l**
Maximum Chloride content - used for prestressed concrete or grout - concrete with reinforcement or embedded metal - concrete without reinforcement or embedded metal	 500 1000 4500
Maximum Sulphates content	2000
Maximum Alkalis (sodium oxide content)	1500
Harmful contamination (maximum) - sugar - phosphates expressed as P_2O_5 - nitrates expressed as NO_3^- - lead expressed as Pb^{2+} - zinc expressed as Zn^{2+}	 100 100 500 100 100

2.3.3.2 Effect of mixing water from different sources

Natural ground water seldom contains more than 20 to 30 ppm of iron. However, acid mine waters may carry rather large quantities of iron salts in concentrations up to 40,000 ppm do not usually affect mortar strengths adversely. Sea water may be used if suitable fresh water is not available [2].

The sea water generally contains 3.5 per cent of salts with about 75 per cent of sodium chloride, about 15 per cent of chloride and sulphate of magnesium. It has been found to reduce the strength of concrete by 10-20 per cent and slightly accelerate the setting time [2]. Sea water may lead to corrosion. Therefore, British standard BS 3148 does not recommend sea water for reinforced or prestressed concrete and its chloride content must be restricted to use for plain Portland cement concrete and to make mortar for plastering to prevent plastered surface from efflorescence.

2.3.4 Admixtures

These are substances or chemicals used in concrete for the purpose of improving or imparting properties. The use of admixture should offer an improvement not economically attainable by adjusting the proportions of cement and concrete, and should not adversely affect any property of the concrete. Admixtures are not substitute for good concreting practice. An admixture should be employed only after an appropriate evaluation of its effects on the concrete that is intended to be used is made. It is often necessary to conduct tests on the representative samples of the materials for a particular job under simulated job conditions in order to obtain reliable information on the properties of concrete containing admixtures [3].

The properties of concrete commonly modified are workability, rate of hydration or setting time i.e., either accelerating or retarding the setting time, and air entertainment. Admixture is generally added in a relatively small quantity. A degree of control must be exercised to ensure proper quantity of admixture, as an excess quantity may be detrimental to the properties of concrete. In using any admixture, careful attention should be given to the instructions provided by the manufacturer of the product [3].

2.4 Properties of fresh and hardened concrete

2.4.1 Properties of fresh concrete

The choice of the constituents and of their mix proportions shall be such as to satisfy requirements concerning the properties of fresh concrete are;

- Workability
- Consistency

- Segregation
- Bleeding
- Placement of concrete
- Uniformity of concrete
- Curing of concrete

Workability: It is desirable that freshly mixed concrete be relatively easy to transport, place, compact and finish without harmful segregation. A concrete mix satisfying these conditions is said to be workable.

Consistency: Is the fluidity or degree of wetness of concrete. It is generally dependent on the shear resistance of the mass. It is a major factor in indicating the workability of freshly mixed concrete.

Segregation: Refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. The primary causes of segregation are differences in specific gravity and size of constituents of concrete.

Bleeding: Is the tendency of water to rise to the surface of freshly placed concrete. It is caused by the inability of solid constituents of the mix to hold all the mixing water as they settle down.

Placement of concrete: If concrete temperatures as placed are expected to be abnormally. High, preparation shall be made to place, consolidate, and finish the concrete at the fastest possible rate For best assurance of good results with concrete placing in hot weather, the initial concrete placement should be limited between 25°C and 40°C. Every effort shall be made to keep the concrete temperature uniform. Under extreme conditions of high ambient temperature, exposure to direct rays of the sun, low relative humidity, and wind, it is suggested to restrict concrete placement to late afternoon or evening [2].

Uniformity of concrete: Concrete uniformity is checked by conducting tests on fresh and hardened concretes such as, slump, unit weight, air content and strength test. Due to heterogeneous nature of concrete, there will always be some variations. These variations are grouped as:

Within-Batch Variations: inadequate mixing, non-homogeneous nature

Batch-to-Batch Variations: type of materials used, changes in gradation of aggregates, changes in moisture content of aggregates [3].

Curing of concrete: In hot weather there is great need for continuous curing of concrete by water. The need is greatest during the first few hours, and throughout the first day after the concrete is placed. In hot weather, forms shall be covered and kept moist. The forms shall be loosened, as soon as this can be done without damage to concrete, and provisions made for the curing water to run down inside them. During form removal, care shall be taken to provide wet cover to newly exposed surfaces to avoid exposure to hot sun and wind. At the end of the prescribed curing period (10 days is recommended), the covering shall be left in place without wetting for at least four days, so that the concrete surface will dry slowly and be less subject to surface shrinkage cracking [2].

2.4.2 Properties of hardened concrete

According to the ES EN 1992-1-1:2015, Structural use of concrete in building the principal properties of hardened concrete which are of practical importance can be listed:

1. Compressive Strength, Tensile strength, and Modulus of elasticity
2. Permeability & durability
3. Drying Shrinkage & creep deformation

2.4.2.1 Compressive strength

According to the ES EN 1992-1-1:2015, Structural use of concrete in building the compressive strength of concrete is denoted by concrete strength classes which relate to the characteristic (5%) cylinder strength f_{ck}, or the cube strength f_{ck}, cube, in accordance with EN 206-1 [10].

The compressive strength of concrete at an age t depends on the type of cement, temperature and curing conditions. For a mean temperature of 20°C and curing in accordance with EN 12390 the compressive strength of concrete at various ages f_{cm} (t) maybe estimated from expressions (2.1) and (2.2)

$$f_{cm}(t) = \beta_{cc}(t)\, f_{cm} \qquad \text{Eq 2.1}$$

$$\beta_{cc}(t) = \exp\left\{s\left[1-\left(\frac{28}{t}\right)^{1/2}\right]\right\} \qquad \text{Eq 2.2}$$

Where:

$f_{cm}(t)$ is the mean concrete compressive strength at an age of t days

f_{cm} is the mean compressive strength at 28 days

$\beta_{cc}(t)$ is a coefficient which depends on the age of the concrete t

t is the age of the concrete in days

s is a coefficient which depends on the type of cement

= 0.20 for cement of strength classes CEM 42.5 R, CEM 52.5 N and CEM 52.5R (Class R)

= 0.25 for cement of strength classes CEM 32.5 R, CEM 42.5 N (Class N)

= 0.38 for cement of strength classes CEM 32.5 N (Class S)

2.4.2.2 Tensile strength

According to the ES EN 1992-1-1:2015, Structural use of concrete in building the tensile strength refers to the highest stress reached under concentric tensile loading.

Where the tensile strength is determined as the splitting tensile strength, fct sp, an approximate value of the axial tensile strength, fct, may be taken as:

$fct = 0.9\ fct,sp$ Eq 2.3

The development of tensile strength with time is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members [10]. As a first approximation it may be assumed that the tensile strength fctm *(t)* is equal to:

$fctm\ (t) = (\beta cc(t))^{\alpha}.fctm$ Eq 2.4

Where:

βcc *(t)* follows from Equation (2.2) and

$\alpha = 1$ for $t < 28$

$\alpha = 2/3$ for $t \geq 28$

Note: Where the development of the tensile strength with time is important it is recommended that tests are carried out considering the exposure conditions and the dimensions of the structural member [10].

2.4.2.3 Modulus of Elasticity

ES EN 1992-1-1:2015 provided the modulus of elasticity of a concrete is controlled by the moduli of elasticity of its component ts. Approximate values for the modulus of elasticity Ecm, secant value between $\sigma c = 0$ and $0.4f cm$ for concretes with quartzite aggregates, for limestone and sandstone aggregates the value should be reduced by 10% and 30% respectively. For basalt aggregates the value should be increased by 20% [10].

2.4.2.4 Permeability & durability

Permeability is important because: The penetration of some aggressive solution may result in leaching out of $Ca\ (OH)_2$ which adversely affects the durability of concrete.

In R/C ingress of moisture of air into concrete causes corrosion of reinforcement and results in the volume expansion of steel bars, consequently causing cracks & spalling of concrete cover.

The moisture penetration depends on permeability & if concrete becomes saturated it is more liable to frost action. In some structural members permeability itself is of importance, such as, dams, water retaining tanks. The permeability of concrete is controlled by capillary pores. The permeability depends mostly on w/c, age, degree of hydration. A durable concrete is the one which will withstand in a satisfactory degree, the effects of service conditions to which it will be subjected.

2.4.2.5 Creep and shrinkage

According, ES EN 1992-1-1:2015 creep and shrinkage of the concrete depend on the ambient humidity, the dimensions of the element and the composition of the concrete. Creep is also influenced by the maturity of the concrete when the load is first applied and depends on the duration and magnitude of the loading. The creep coefficient, $\varphi(t, t_0)$ is related to Eke, the tangent modulus, which may be taken as 1.05 Ecm. Where great accuracy is not required, the value found from Figure 1 may be considered as the creep coefficient, provided that the concrete is not subjected to a compressive stress greater than 0.45 fck (t_0) at an age t_0, the age of concrete at the time of loading.

Note: For further information, including the development of creep with time, Annex B may be used. The creep deformation of concrete $\varepsilon cc\ (\infty, t_0)$ at time $t = \infty$ for a constant compressive stress σc applied at the concrete age t_0, is given by:

$$\varepsilon cc(\infty, t_0) = \varphi(\infty, t_0)\cdot(\sigma\ c\ Ec) \qquad \text{Eq 2.5}$$

When the compressive stress of concrete at an age t_0 exceeds the value 0.45 fcm (t_0) then creep non-linearity should be considered. Such a high stress can occur as a result of pre tensioning, e.g., in precast concrete members at tendon level. In such cases the nonlinear notional creep coefficient should be obtained as follows:

$$\varphi nl\ (\infty,t_0) = \varphi(\infty,t_0)\exp(1.5(k\sigma - 0.45)) \qquad \text{Eq 2.6}$$

Where:

$\varphi nl\ (\infty,t_0)$ is the non-linear notional creep coefficient, which replaces $\varphi\ (\infty,t_0)$

$k\sigma$ is the stress-strength ratio σc/fck (t_0), where σc is the compressive stress and fck (t_0) is the characteristic concrete compressive strength at the time of loading.

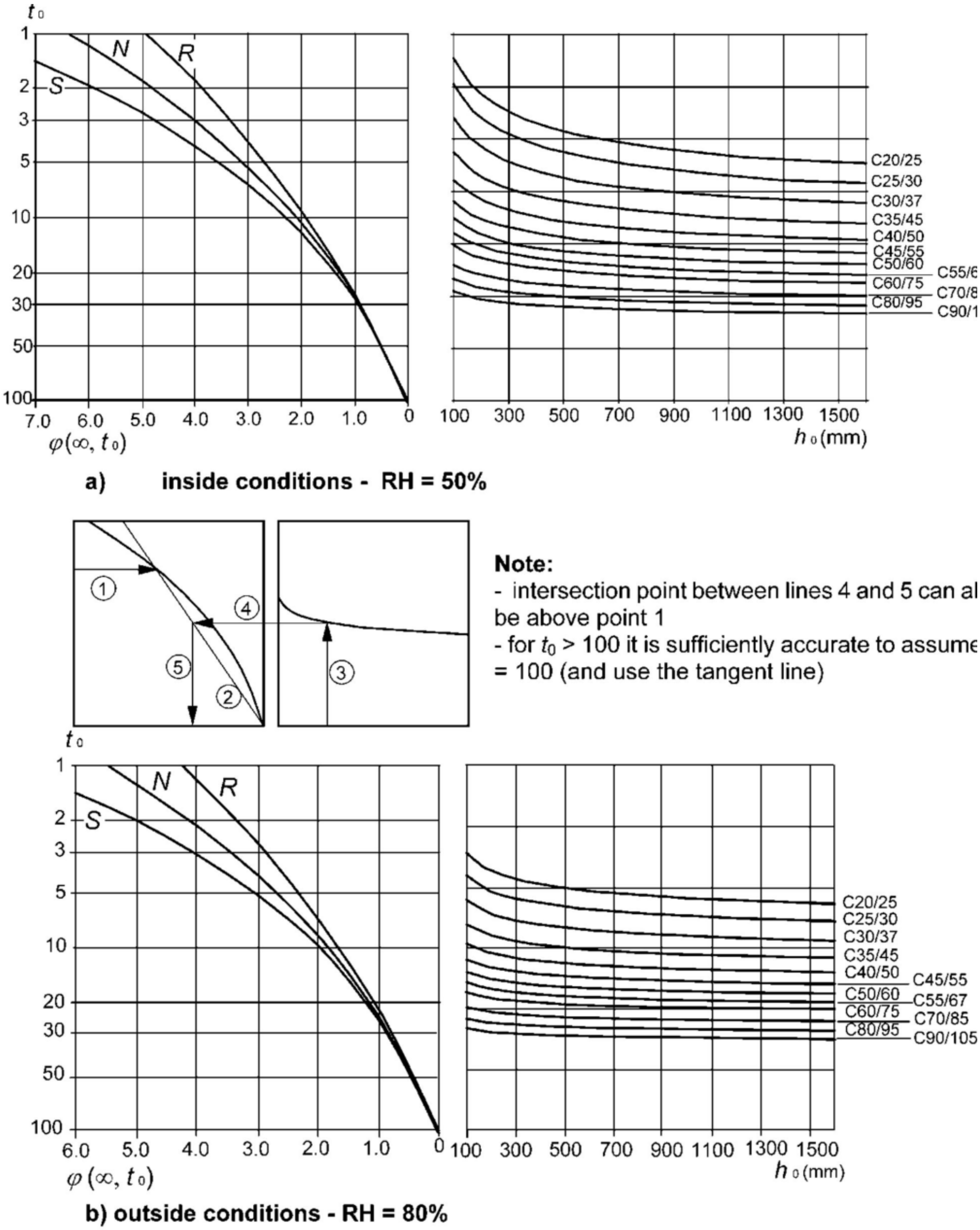


Figure 1: Method for determining the creep coefficient φ (∞, t_0) for concrete under normal environmental conditions [10].

The values given in Figure 1 are valid for ambient temperatures between -40°C and +40°C and a mean relative humidity between RH = 40% and RH = 100%. The following symbols are used:

$\varphi(\infty, t_0)$ is the final creep coefficient

t_0 is the age of the concrete at time of loading in days

h_0 is the notional size = 2Ac/u, where, Ac is the concrete cross-sectional area and u is the perimeter of that part which is exposed to drying

S is Class S, according to 3.1.2

N is Class N, according to 3.1.2

R is Class R, according to 3.1.2

2.5 Factors affecting strength of concrete

2.5.1 Effect of cold joint and improper, delayed or jumped concrete placement

The effect of delay in placement of concrete varies with the richness of the mix and initial slump different delay times for various temperatures, a maximum of half hour for placing at 20^0, three-fourth of an hour for temperature that ranges 15^0 to 20^0 and 1hr if the temperature is about 15^0 [4]. When concrete in a lift hardens before the next lift can be placed, a weak layer called cold joint or construction joint is formed. This is one of the serious problems of extreme delay of concrete placement. In case when such a joint is formed either because of delay in concrete placement or for another reasons, the following measures are recommended to be taken during construction time. The surface of the last lift should be left in a roughened state to provide a good mechanical bond. Before placement of the next lift, the surface should be scarified to remove any laitance. Air-water jets, wire booming, or even sand blasting are useful techniques. The concrete should be dampened and a layer of mortar worked well into the surface [4].

Delay in concreting can result in cold joints. To avoid the cold joint, placing should be resumed substantially before the time of initial set. A cold joint will result and suitable preparation measure should be applied. when in practices either casting cannot be completed in one go or the time lapse between mixing and placing the strength of final product is affected. If for any reason the concrete placement is stopped for longer than the setting time, the joint should be treated as cold joints. Cold joint need additional surface preparation, dowel action & bonding agents. The study was carried out to evaluated bond strength of old and fresh concrete. To try out the various dowel action along with the bonding agents. the surface preparation was done by chipping the main objective of work is to determine the bond strength of old and fresh concrete by using the slant shear strength and flexural test to evaluate the flexural strength The study was carried out to evaluated which dowel action and bonding agents give better results. However, the chipping of surface when combined with the dowel action generated by insertion of the corrugated PVC pipes gives more bond strength. The slant shear strength test values for all the combinations were found to be on par with the combination of corrugated PVC pipes with cement slurry, which proves the latter to be an economical option for achieving the required bond strength [5].

Proper location and construction of construction joints has a great influence on deflection of beam member and their cracks. If there is a need to use construction joint in concrete work, select a location that is the least likely develop high stresses. One must ensure that the contact surface of the two concrete batches is prepared correctly. The use proper construction joint has a significant impact on beam properties [8].

If there is an improper casting sequence which form cold joints, for these we use cement slurry which improve the compressive flexural and split tensile strength as compared to stained and fresh concrete. By experimental results author proves that delay in concrete joint also affect strength of concrete the type of joint also affects strength of concrete. From observation we conclude that, use of retarding agent in concrete joint to improve the strength of concrete in the joint portion [9].

Processes of casting concrete in flat slabs; raft foundation and massive concrete may be faced delay in time period due to many reasons, such as glitch in casting machine that causes the stopping of the casting process for a period that can produce a forced layer separation. Therefore, knowledge of the setting characteristics of concrete is rather important in the field of concrete construction operations such as transporting, placing, compacting, and finishing of concrete, these will help in scheduling the various stages involved in concrete construction the mechanical properties of concrete contain cold joint treated with grout (4, 9, and 16 hours). By increasing the time of casting the second layer of concrete, the compressive, splitting tensile strength, and flexural strength will decrease the use of grout may increase the mechanical properties the mechanical properties of concrete grade 300 Kg/cm^2 are more influence than concrete grade 250 Kg/cm^2. The effect of grout on mechanical properties of concrete appears at 16 hours and has low effect at 4 to 9 hours [11].

Delay in concreting due to various conditions as well as improper casting sequence can result in cold joints. For unusually long delays during concreting, the concrete should be kept alive by periodically re-vibrating it to keep concrete workable. However, concrete should not be over-vibrated to the point of causing loss in homogeneity. This study gives strength data simulating such improper casting sequences. The strength of concrete increases till initial setting time of Cement (75minutes) and later for a time lag exceeding the initial setting time it decreases. Among the different failure planes the decrease in compression, flexure and split tensile strength was least in case of horizontal plane as compared to vertical and diagonal planes from experimental study, it is observed that after initial setting time also slump value is satisfactory after addition of retarding agent it will be helpful if there is delay in concreting [6].

Although it is desirable to place fresh concrete as soon as the mixing operation is completed, the placing of concrete in its final position might be delayed due to many reasons. Improper methods of handling of concrete, site organization, work scheduling, adverse environmental condition a breakdown of equipment is some of the causes for the unexpectedly long delay. In the construction sites where ready-mixed concrete is used, the delay time is mainly determined by the site location from the central batching plant and by the traffic conditions on road. As the workability of fresh concrete greatly diminishes with time, too long of a delay may cause the concrete to be unfit for placing. This problem is especially serious in hot weather and when chemical admixtures are used. It is a bad practice of construction to regain the workability of fresh concrete by adding some water. This may result in a variation of water-cement ratio, thus can reduce the strength of concrete, since the water-cement ratio is inversely related to concrete strength: the higher W/c the lower the strength [6].

Delay in casting can result in the cold joint and it can affect concrete strength as well. A study was undertaken on a delay time-lapse of “45, 75, 120 and 180 min”, focusing on the cold joint where two batches of different delayed mixes are placed. It was found that without a retarding agent, a delayed placed second part in the sample causes an increase in strength. Compressive strength increased initially up to the initial setting time and then decreased as the time lag between mixing and casting increased. Then the IST and FST of the cement were increased by adding 0.1% of sugar as a retarding agent. As a result, the strength of concrete increased even after 180 min delay in casting [6].

The behavior of concrete-to-concrete interfaces under cyclic loading was investigated. The main goal of the researcher was to determine how the design expressions, developed for monotonic loading, should be modified in order to be used also for cyclic loading [26]. Two design expressions developed by this researcher for both normal and lightweight concrete, were adopted to assess the ultimate longitudinal shear stress at the interface of composite specimens under cyclic loading. Shear strength of the concrete-to-concrete interface under cyclic loading, should be taken equal to 0.8 of the shear strengths under monotonic loading, for monolithic specimens made of normal and lightweight concrete and rough interfaces between concrete parts cast a different age. If the bond between concrete parts is destroyed, the shear strength under cyclic loading should be taken as 0.6 of the shear strengths under monotonic loading. It was observed that the shear transfer mechanism of composite specimens after cracking, for both monotonic and cyclic loading, is identical to that of monolithic specimens [26].

2.5.2 Effect of mixing time on concrete strength

On a site, there is often a tendency to mix concrete as rapidly as possible, and it is, therefore, important to know what the minimum mixing time necessary to produce a concrete uniform in composition and of satisfactory strength. The mixing time varies with the type of mixer and on its size. On some researches made previously, it appears that it is not the mixing time but the number of revolutions of the mixer that is the criterion of adequate mixing. Generally, about 20 revolutions are sufficient. Since, however, there is optimum speed of rotation recommended by the manufacturer of the mixer; the numbers of revolutions and the time of mixing are interdependent [2]. The average strength of concrete increase with an increase in mixing time up to about 5 minutes, the rate of increase in strength falls rapidly beyond about one minute and is not significant beyond two minutes. Within the first minute, however, the influence of mixing time on strength is of considerable importance. A mixing time of not less than one minute after all the materials have been added in the mixer drum is generally recognized as a satisfactory period for mixers up to capacity of 750 liters [2].

If mixing is done over a long period, evaporation of water from the mix takes place, with a consequent decrease in workability. A secondary effect is that of grinding of the aggregate, particularly if soft, the grading of the aggregate thus becomes finer, and the workability lower. The friction effect also produces an increase in the temperature of the mix.

No general rules on the order of feeding the ingredients into the mixer can be given as they depend on the properties of the mix and of the mixer. Generally, a small amount of water should be fed first, followed by all the solid materials, preferably fed uniformly and simultaneously in to the mixer. If possible, the greater part of the water should also be fed during the same time, the remainder of water being added after the solids. The choice of mixer depends on the size, extent, and the nature of work. The choice between central and site mixing will be governed by factors such as accessibility, water supply, transport routes, availability of working space, etc. [3].

2.5.3 Effect delayed transport of concrete

Concrete from mixer should be transported to the point where it must be placed as rapidly as possible by a method, which prevents segregation or loss of ingredients. The concrete must be placed before setting has commenced. A maximum of two hours between mixing and discharge of concrete is permitted, if the concrete is transported in a truck mixer or agitator. In the absence of agitator, the time is reduced to one hour only.

Delayed concrete transportation may result in the formation of pour planes, cold joints, or construction joints between the interfaces of previously placed and newly placed concrete. Such joints are susceptible to water leakage and leave weak structural parts [8].

2.6 Effect of cold joint in stress transformation and bond strength between old and new concrete

Cold joint is one in which the two concrete surfaces or relative movement of old and new concrete from one another as a result of shrinkage or temperature change is prevented. As the concrete starts to hydrate and volume change starts to occur due to temperature and shrinkage effects, the concrete deformations are restrained by this joint which causes stress to develop. For this reason, stress concentrations occur in these regions and the strength, shear transfer, flexural continuity, and load transfer capacity decrease. The bond strength at the interface between concrete layers cast at different ages is important ensure the monolithic behavior of reinforced concrete members. The bond between concrete parts cast at different ages is affected by several parameters such as the surface preparation method adopted to remove the damaged concrete and to increase the roughness of the substrate. Differential shrinkage and differential stiffness between concrete parts can also have a significant influence on the behavior of the interface [13]. The increase of the difference of ages implies an increase of the differential shrinkage between concrete layers and, therefore, an increase of stresses at the interface. For this reason, a decrease of the bond strength of the interface was expected. The increase of differential stiffness between concrete layers changes the stress distribution at the interface and stress concentrations are observed at both ends. The assessment of the bond strength in tension proved to be inconclusive. The evolution of the bond strength, with the increase of the surface roughness and with the increase of the difference of ages between concrete layers, is not clear. Two distinctive failure modes were observed: adhesive (interface debonding) and cohesive (monolithic). Adhesive failure occurs at the interface whenever the bonding strength is reached; cohesive failure occurs in the bulk by concrete crushing [13].

2.7 Modeling of cold joint

Structural design must respect several conditions. Safety is essential but economy cannot be left out. In the case of composite concrete members, with parts cast at different times, it is fundamental to ensure that stresses are adequately transferred between both parts. Otherwise, either safety or economy is not achieved. The influence of several parameters, such as: a) material constitutive law; b) existence of cracking; c) material time-dependent properties (creep, shrinkage, and relaxation); and d) existence of different materials; makes the previous expression unusable, for the assessment of the shear stresses at the concrete-to-concrete interface, leading to the development of more accurate design expressions.

The first linear expression to evaluate the ultimate longitudinal shear stress of concrete interfaces was proposed [15]. The proposed expression is as follows:

$Vu=\rho fy \tan\varphi=\rho fy \mu$…………………………………………………………… Eq 2.6

Where, Vu is the ultimate longitudinal shear stress at the interface; ρ is the reinforcement ratio; fy is the yield strength of the reinforcement; and φ is the internal friction angle. The tangent of the internal friction angle is also designated as coefficient of friction, being represented by the Greek letter μ, and the term ρfy is designated as clamping stresses [15].

This expression was proposed for smooth concrete surfaces, artificially roughened concrete surfaces, and concrete-to-steel interfaces. The coefficient of friction was empirically determined, varying with the surface preparation, and it was defined for several situations, namely: a) μ = 1.7, for monolithic concrete (59.5º); b) μ = 1.4, for artificially roughened construction joints (54.5º); and c) μ = 0.8 to 1.0, for ordinary construction joints and for concrete to steel interfaces (38.7º to 45.0º). This expression was limited to the following conditions:

$\rho \leq 1.5\%$

$vu \leq 5.52$Mpa

The adopted design philosophy stated that: the tensile strength of concrete should be neglected; all tensile forces are absorbed by the steel reinforcement; and shear forces are transmitted by friction. As the unbounded concrete parts slide one over another, the crack will open and the reinforcement steel will be tensioned. Therefore, it is assumed that the longitudinal shear reinforcement will compress the interface, resulting in frictional resistance along the interface [15].

Hofbeck et al. (1969) performed an experimental study to quantify the influence of the following parameters on the shear strength of concrete-to-concrete interfaces: a) pre cracked shear plane; b) strength, size, and arrangement of shear reinforcement; c) concrete strength; and d) dowel action.

He has stated that pre-existing cracks along the shear plane results in a decrease of the shear strength and increase of the relative slip between both concrete parts. Changes in the strength, geometry and arrangement of shear reinforcement crossing the interface also affects the clamping stresses ρ fy [16].

The concrete strength showed to have influence in the shear strength of the interface. For values of the clamping stresses below 4.14MPa (600psi), the concrete strength does not affect the shear strength. Above this limit, the shear transfer is affected and the shear strength increases with the increase of the concrete strength. The shear-friction theory gives a conservative estimate of the shear strength of the concrete-to-concrete interface for specimens with a pre-existing crack along the shear plane. [16].

The dowel action due to the shear reinforcement was significant only for concrete specimens with a pre-existing crack along the shear plane. For initially un-cracked specimens, the influence of the dowel action was insignificant since the relative slip between concrete parts was too small.

The shear strength of initially cracked specimens was computed using the design expression proposed by Birkeland and Birkeland (1966) a coefficient of friction of 1.4 was adopted [15].

Euro code 2 (2004) indicates that, in the absence of more detailed information, surfaces may be classified as very smooth, smooth, rough, or indented. The first three types of surfaces are obtained by preparing the concrete surface in order to achieve the desired roughness.

The very smooth surface is considered as a surface cast against steel, plastic, or specially prepared wooden molds. The smooth surface is a slipform or extruded surface, or a free surface left without further treatment after vibration. The rough surface is a surface that has at least 3mm roughness at about 40mm spacing, achieved by raking, exposing of aggregate or other methods giving an equivalent behavior. For each type of surface, two coefficients are defined and used in the prediction of the shear at the interface between concretes cast as different times [17].

Due to the good results obtained in previous research studies, conducted by Júlio (2001) and Santos (2005), the slant shear test was adopted in the experimental study developed in the scope of this PhD thesis to assess the bond strength of the concrete-to-concrete interface in shear.

A specially conceived formwork was built to produce the slant shear specimens. In order to optimize the adopted formwork and due to physical restrictions of the equipment, the following dimensions for the slant shear specimen were adopted: a cross section of $150 \times 150 mm^2$ and a maximum height of 600mm [18].

The slant shear specimen defined in standards from different countries, such as France, Italy, Great Britain, and United States of America, presents different sizes and different shear plane angles. It is possible to find specimens with $100 \times 100 \times 300 mm^3$ or $70 \times 70 \times 200 mm^3$ and shear plane angles between 17 and 30 degrees with the vertical [20].

For all the reasons previously referred to, it was decided to conduct a numerical modeling to evaluate the influence of several parameters on the stress distribution along the concrete-to-concrete interface of the slant shear specimen. A commercial finite element package, LUSAS 14.1(2008), was adopted. The assessed parameters were: a) the specimen geometry; b) the confinement provided by the plates of the testing machine, due to friction; c) the difference between the young modulus of the substrate concrete and of the added concrete layer; and d) the differential shrinkage between the substrate concrete and the added concrete layer. A 3D model of the slant shear specimen was built using a mesh of 1000 finite elements with twenty nodes hexahedrons, and a linear behavior of the material were assumed. Several strength classes were considered depending on the modeling objectives: a) C20/25; b) C25/30; c) C40/50; and d) C90/105. The Young modulus was determined according to Euro code 2 (2004): 30GPa, 31GPa, 35GPa and 44GPa, respectively. The coefficient of Poisson was considered equal to 0.2 [20].

Time-dependent viscoelastic model using a Maxwell material parallel to the so-called “reactive” model. This model allows varying the concrete’s properties over time and phenomena can be simulated where there is loss or gain of stiffness due to the existence of a chemical reaction inside the material causing physical changes. Several phenomena can make concrete to lose or gain mechanical properties as time goes by, such as the chemical attack of harmful substances and the cement’s hydration process, which derives in the stiffening of concrete. Whatever the reaction causing physical changes in the concrete has a variable speed over time, which is ruled by an equation α that determines the percentage of the completed reaction, also called volume function [14].

CHAPTER THRE: METHODOLOGY AND EXPERIMENTAL PROGRAMME

This chapter contains a detailed description of all the materials used in the experimental program, as well as the methods followed in conducting the various tests.

This investigation aims studying the effect of improper casting sequence on the strength of concrete due to formation of cold joint which includes compressive, tensile, and flexural strengths.

3.1 Research methodology

Experimental tests were performed at laboratory to investigate the effect of delayed casting on the concrete strength due to formation of cold joint. Experimental Cold joint is formed at casting the second layer of concrete paste after 7, 14, and 21 days of each of the samples on 28-day of curing time of compressive, tensile, and flexural strength of concrete. According to EBCS or Ethiopian standard Class-I concrete grade of C-25 standard mix design was prepared. Portland-Pozzolana cement was used during whole casting of specimens to observe the variation in change of concrete strength for concrete cast at different time of delay. Before casting the specimens, oiling to the surface of the molds was carried out; this was used to avoid the bonding between concrete and the inner surface of the molds. Class-I concrete grade of C-25 mix design was produced for this experiment with crushed granite rock, with maximum size of 19 mm for coarse aggregate is used. The aggregates were thoroughly washed (to remove unwanted materials, silts, and dust) and dried, graded in accordance with the construction industry of Ethiopia the manuals used for the sieve analysis and other laboratory manuals [27]. Natural River sand for fine aggregate was obtained from a quarry site at Dimma river located in the SNNPR Gambela State; Dimma woreda. The Pozzolana Portland cement (PPC) of Debra cement factory was used. The physical properties of natural sand and coarse aggregate were conducted. samples are divided in two groups the first group was divided in to four parts (1-4) of different delay period of cold joint formation when casting the second layer of concrete after 0 (monolithic) ,7, 14 and 21 days in such a way that from each part, three cubes of (150 * 150 * 150 mm^3) for each 28 days of curing time for compressive strength, and three cylinders (of Φ=150mm and h=300mm) for each 28 days of curing time for tensile strength and from each part, two beam of (100*100*500mm^3) for each 28 days of curing time for flexural strength of concrete. The second group was divided in to four parts (A-D) of cold joint configuration with inclined (45^0), horizontal (0^0) and vertical (90^0) formation angle and reference specimen; from each part, two beams of ($100*100*500mm^3$) for each 28 days of curing time for flexural strength of concrete. For all samples firstly fresh concrete specimen was produced by placing fresh concrete for half cylinder, cube, or beam mold and for the remaining half filling of the cylinder, cube, or beam mold of freshly mix concrete was casted with the times laps of 0, 7, 14, and 21 days and metallic molds was used to produce vertical, horizontal, and inclined cold joint in each separation; therefore, the resulting plane was flat. Finally, the ultimate strength tests were recorded and analyzed on each of these samples at the ages of 28 day of curing time to study the behavior for the joints under compressive, split tensile and flexural strength of concrete.

3.1.2 Physical properties of the materials

3.1.2.1 Sieve analysis and grading

This is the process of screening a sample of aggregate into size fractions each consisting of particles of the same range size i.e., particle size distribution. Sieve analysis is done by passing the dried aggregate through a series of standard test sieves beginning with the one sufficiently coarse to pass all the material. Having completed the sieving, the weights of aggregate retained in each sieve in turn are recorded. The weights and percentages of aggregate passing each test sieve are then computed. The results of sieve analysis are represented graphically in charts known as grading curves/charts. By using these charts, it is possible to see briefly if the grading of a given sample conforms to that specified or it is too fine or coarse or deficient on a particular size. In the curves, the ordinates represent cumulative percentages passing. Grading is of importance as it affects the workability of concrete. The development of strength corresponding to a given water/cement ratio requires full compaction and this can only be achieved with a sufficiently workable mix. The sieve analysis test was conducted in accordance with [27]. The sample of 6kg of fine aggregate was weighed and then poured on different AASHTO sieve sizes of 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600μm, 300μm, 150μm, 75μm and pan. After shaking the sieves vigorously, the sample retained on each sieve was recorded as weight of sample retained. The fineness modulus was then determined as summation of cumulative percentage retained divided by 100.

Sand

River sand is used and sieve analysis was carried out to whether it meets the [27] standards and the result is given in table 3.1 below.

Table 3.1: Particle size distribution of natural sand AASHTO M 6-93

Weight in gm.	**Sample 1**					
	6000gm					
AASHTO Sieve Size mm	Weight Retained (gm.)	Cumulative Weight Retained (gm.)	% Weight Retained	% Weight pass	AASHTO M 6-93	
					Lower	Upper
9.5	55	55	0.9	99.1	100	100
4.75	192.4	247.4	3.2	95.9	95	100
2.36	483	730.4	8.1	87.8	80	100
1.18	1150	1880.4	19.2	68.7	50	85
0.600	1320	3200.4	22	46.7	25	60
0.300	1620	4850.4	27.5	19.2	10	30
0.150	811	5661.4	13.5	5.6	2	10
0.075	288.6	5950	4.8	0.8		
Passing pan	50	6000	1	0		
Total sum	6000		100			

Table 3.2 Fineness modulus of fine aggregate

AASHTO Sieve Size mm	Weight Retained (gm.)	Cumulative Weight Retained (gm.)	Cumulative Weight Retained %
9.5	55	55	0.92
4.75	192.4	247.4	4.15
2.36	483	730.4	12.27
1.18	1150	1880.4	31.60
0.600	1320	3200.4	53.78
0.300	1620	4850.4	81.52
0.150	811	5661.4	95.14
0.075	288.6	5950	0.0168
Passing pan	50	1	0
Total	6000	6000	279.42 Hence F.M=279.42/100=2.794

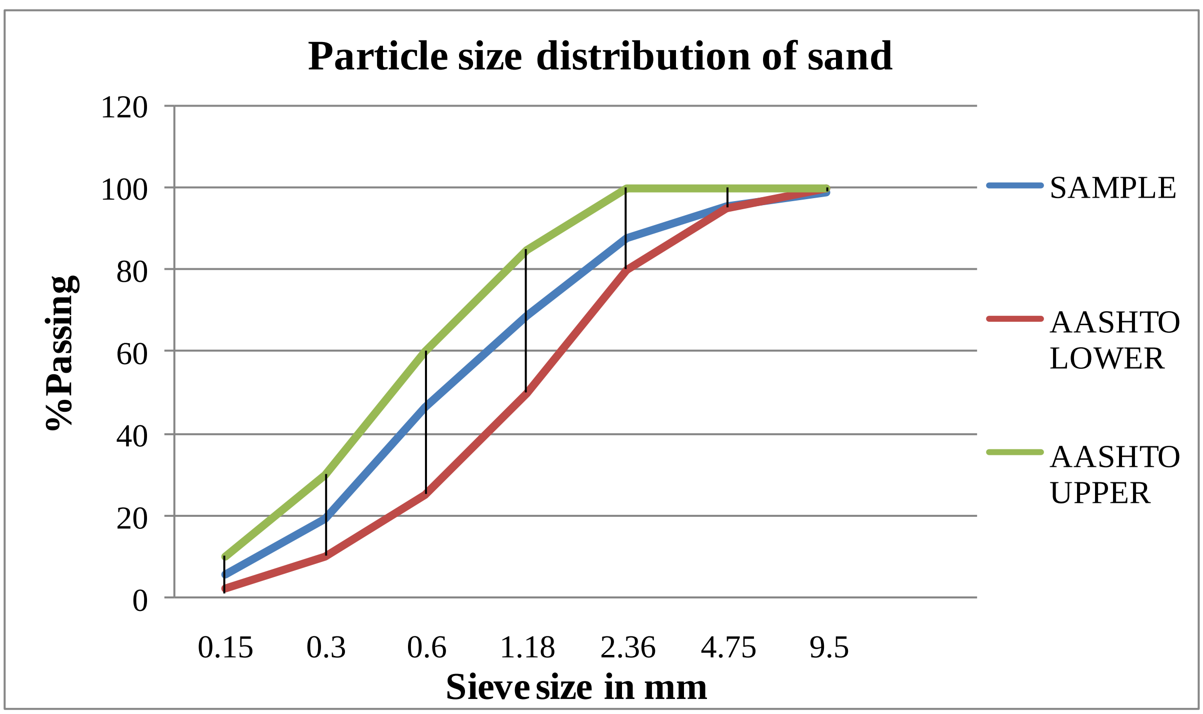


Figure 2: Particle size distribution of natural sand

As can be is seen from the above figure the gradation of sample of sand used is within the upper and lower limit of the standards. Therefore, it is satisfactory to be used for the concrete production.

Coarse aggregate

Grading is important for attaining an economical mixture because poor grading requires more water and more cementations material. Coarse aggregates should be graded up to the largest nominal maximum size practical under job conditions. The use of large aggregates reduces the demand for paste, decreases shrinkage, and provides better aggregate interlock at pavement joints and cracks. The nominal maximum size that can be used depends on the size and shape of the concrete member to be cast, as well as on the amount and distribution of reinforcing steel in the concrete member [19].

The maximum size of coarse aggregate should not exceed one-fifth the minimum distance between sides of forms or three-fourths the clear space between individual reinforcing bars or wire, bundles of bars, or prestressing tendons or ducts. For unreinforced slab son ground, the maximum size should not exceed one-third the slab thickness. The maximum aggregate size is limited to prevent bridging of aggregates leading to poor consolidation. Smaller sizes can be used when availability or economic considerations require them. The amount of mixing water required to produce a cubic meter of concrete of a given slump is dependent on the nominal maximum size and shape and the amount of coarse aggregate [19].

[28] Provides guidance on the volume of coarse aggregate, provides guidance on the requirements for coarse aggregates.

Table 3.3 Volume of coarse Aggregate per Unit of Volume of Concrete

Nominal maximum size of Aggregate, mm	**Volume of Dry-Rodded Coarse Aggregate per Unit Volume of Concrete for different Fineness modulus of Fine Aggregate**			
	2.4	2.6	2.8	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76

Bulk volumes are based on aggregates in dry-rodded condition as described in [27]. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction.

A crushed aggregate of maximum size 19mm is used. Sizes of aggregates (5-19mm) were blended and sieve analysis was carried out and proportioned to meet the [27] standards and the result is given in table 3.4 below.

Table 3.4: Particle size distribution of crushed aggregate (5-19mm) specified by [27].

Weight in gm.	**Sample 2**				
	6000gm				
AASHTO Sieve Size mm	Weight Retained	% Retained	% Pass	AASHTO M43-88	
				Lower	Upper
25	0	0	100	100	100
19	453	7.6	92.5	90	100
10	3454.5	57.6	34.9	20	55
4.75	1760	29.3	5.6	0	10
2.36	330.5	5.5	0.044	0	5
Passing pan	2.7	0.1	0		
Total sum	6000.1	100			

Table 3.5 Fineness modulus of coarse aggregate

Excel sheet for sieve analysis of coarse aggregate and to calculate fineness modulus			
AASHTO Sieve Size mm mm	Weight Retained (gm.)	Cumulative Weight Retained (gm.)	Cumulative Weight Retained %
25	0	0	0
19	453	453	7.55
10	3454.5	3907.5	65.12
4.75	1760.4	5667.9	94.45
2.36	330.5	5998.4	99.96
1.18			100
0.600			100
Passing pan	2.7	6000.1	100
Total sum	6000.1		
		Fineness Modulus (F.M)	5.67

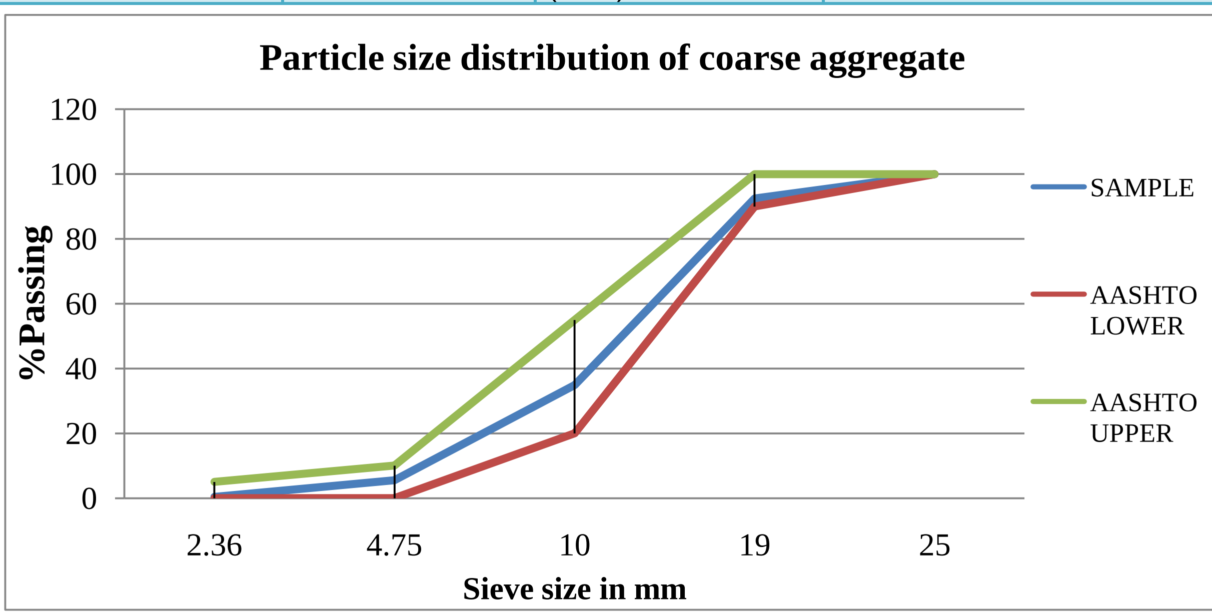


Figure 3: Particle size distribution of Coarse aggregate

As can be is seen from the above figure the gradation of sample of Coarse aggregate used is within the upper and lower limit of the standards. It is therefore satisfactory to be used for the concrete preparation.

3.1.3 Specific gravity

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable; whose structure (size, number, and continuity pattern) affects water absorption, permeability, and specific gravity of the aggregates [19].

3.1.3.1 Specific gravity of fine aggregates

The specific gravity of the fine aggregate was determined using pycnometer methods. So 500gm of oven dried fine aggregate was used. The result is presented in table 3.6.

The specific gravity was calculated using the formula in equation 3.1.

$$Gs = \frac{A}{(A+B-C)} \quad \text{--Eq 3.1}$$

Were,

Gs = Specific gravity

A= Mass of dry sand sample in gm.

B = Mass of pycnometer + water in gm.

C = Mass of pycnometer +water + sand in gm.

Table 3.6: Specific gravity of fine aggregate (Source from laboratory)

Sample	**A = Mass of dry sand sample in gm.**	**B=Mass of pycnometer + water in gm.**	**C=Mass of pycnometer + water + sand in gram**	**Specific gravity Gs $\frac{A}{(A+B-C)}$**
1	500	1262	1571	2.62
Specific gravity of fine aggregate				2.62

3.1.3.2 Specific gravity of coarse aggregate

The specific gravity of the coarse aggregates was determined using displacement method. First, approximately 1.5kg of coarse aggregate sample was taken and submerged in water for 24 hours. The aggregates were then taken out and their surface was dried using a towel to remove the excess moisture. After determining their masses, the aggregates were carefully immersed into a beaker filled with water, after which volume of the displaced water was measured [19]. The results obtained for aggregates (5-10mm) and (10-19) are shown in table 3.7 below.

Table 3.7: Specific gravity of coarse aggregate (5-10mm) and (10-19mm) (source from laboratory)

Crushed coarse aggregate	SSD mass in gm.	Volume of displaced water	Specific gravity
Aggregate sample (5-10) mm	1500	540	2.77
Aggregate sample (10-19) mm	1821	639	2.85

3.1.3.3 Bulk density and specific gravity of materials

Table 3.8 presents the results of bulk density and specific gravity of the materials used for this research work. It can be observed that the results of bulk density and specific gravity of aggregates falls within the range of 1280 to 1920 and 2.30 to 2.90 respectively specifies by [27].

Table 3.8: Specific gravity and bulk density of materials (source from laboratory)

Ingredients of concrete	Bulk Density (kg/m^3)	Specific gravity
Cement	1400	3.15
Natural sand	1365	2.62
Crushed aggregate(5-10mm)	1390	2.77
Crushed aggregate(10-19mm)	1540	2.85

3.1.4 Water content

Select the water to cement ratio such that it is the value not to be exceeded that is required to meet the exposure considerations. For corrosion protection of reinforcing steel, the ratio should not exceed 0.40 (with a minimum strength of 35 MPa) and, for frost resistance, 0.45 (with a minimum strength of 31 MPa). Some state specifications require lower ratios for durability when high-performance concrete is specified.

When durability is not a controlling factor, the water to cement ratio should be selected based on concrete compressive strength. In such cases the water to cement ratio and mixture proportions for the required strength should be based on adequate field data or trial mixtures made with actual job materials to determine the relationship between the water to cement ratio and strength. Table 3.9 can be used to select water to cement ratio with respect to the required average strength, fcr, for trial mixtures when no other data are available [28].

Table 3.9: Typical Relationship between water to cement ratio and Compressive Strength of Concrete

Compressive strength at 28 days, MPa	**Water to cement ratio by mass**	
	Non-Air-entrained concrete	Air-entrained concrete
45	0.38	0.30
40	0.42	0.34
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60

This relationship assumes nominal maximum size of aggregate of about 19.0 or 25.0 mm (0.75 or 1.0 in.) [28].

3.1.5 Air content or entrained air

Entrained air must be used in all concrete that will be exposed to freezing and thawing and deicing chemicals. It can also be used to improve workability even where not required for durability. Air entrainment is accomplished by using an air-entraining Portland cement or by adding an air-entraining admixture at the mixer. The amount of admixture should be adjusted to meet variations in concrete ingredients and job conditions. The amount recommended by the Admixture manufacturer will, in most cases, produce the desired air content. Whiting and Nagi provide guidance on controlling air in concrete, including tips on adjustments to mixture Proportions [22].

Recommended target air contents by ACI for air-entrained concrete are shown in Table 3.10. Note that the amount of air required for adequate resistance to freezing and thawing is dependent upon the nominal maximum size of aggregate and the level of exposure. The levels of exposure are defined by [28], as follows:

- Mild exposure. This exposure includes indoor or outdoor service in a climate where concrete will not be exposed to freezing or deicing agents. When air entrainment is desired for a beneficial effect other than durability, such as to improve workability or cohesion or in remedying the effects of low cement-content concrete, air contents lower than those needed for durability can be used.
- Moderate exposure. This exposure includes service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing or other aggressive chemicals. Examples include exterior beams, columns, walls, girders, or slabs that are not in contact with wet soil and are so located that they will not receive direct applications of deicing chemicals.
- Severe exposure. Concrete that is exposed to deicing or other aggressive chemicals or where the concrete may become highly saturated by continual contact with moisture or free water prior to freezing. Examples include pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps.

Specific air content cannot be readily or repeatedly achieved because of the many variables affecting air content; therefore, a permissible range of air contents around a target value must be provided. Although a range of 2% around the target value is often used in project specifications, it is sometimes an impractical limit. A more practical range is 3% (i.e., ±1.5% around the target value) [28].

Table 3.10 Approximate Air Content Requirements for Different and Nominal Maximum Sizes of Aggregate Source: [28].

Max. size (mm)	**Air Content (percentage)**							
	9.5	12.5	19	25	37.5	50	75	150
Mild	4.5	4	3.5	3	2.5	2	1.5	1
Moderate	6	5.5	5	4.5	4.5	4	3.5	3
Severe	7.5	7	6	6	5.5	5	4.5	4

3.2 Production of Concrete Specimens with cold joint

3.2.1 Batching of materials

Following the mix design process, concrete materials (Cement, Fine and Coarse Aggregates) should be prepared early enough before the concrete works begins. This allows the smooth running of the experimental study. Batching of materials was done by weight basis. The advantage of weight method is that bulking of aggregates (especially fine aggregates) does not affect the proportioning of materials by weight unlike batching by volume method [31]. Batching of concrete materials by weight may be expressed as follows;

Wt (C) + Wt (CA) + Wt (FA) + Wt (Air) = Wt (CC)

Where;

Wt (C) = Weight of cement

Wt (CA) = Weight of coarse aggregate

Wt (FA) = Weight of fine aggregate

Wt (Air) = Weight of entrained air

Wt (CC) = Weight of compacted concrete

3.2.2 Proportioning by Trial Mixtures

When field test records are not available or are insufficient for proportioning by field experience methods, the concrete proportions selected should be based on trial mixtures. The trial mixtures should use the materials proposed for the work. At least three mixtures with three different w/cm and cementations material contents should be made to produce a range of strengths that encompass f'cr. Prepare trial mixtures with a slump and air content within ±20 mm and ± 0.5%, respectively, of the maximum permitted. At 28 days or the designated test age, the compressive strength of the concrete is determined by testing of the cylinders in compression.

The test results are plotted to produce strength versus w/cm curve that is used to select the mixture proportions. Several different methods of proportioning concrete ingredients have been used at one time or another.

The best approach is to select proportions based on experience and reliable test data with an established relationship between strength and w/cm for the materials to be used in the concrete. The mixtures can be relatively small batches made with laboratory precision or job-size batches made during normal concrete production. Use of both is often necessary to reach a satisfactory job mixture.

The following parameters must be selected first: required strength, cementations material content or maximum w/cm, nominal maximum size of aggregate, air content, and desired slump. Trial batches are then made, varying the relative amounts of fine and coarse aggregates, as well as other ingredients. Based on considerations of workability and economy, the mixture proportions are selected.

When the quality of the concrete mixture is specified by w/cm, the trial batch procedure consists essentially of combining a paste (water, cementations material, and, generally, an air entraining admixture) with the necessary amounts of fine and coarse aggregates to produce the required slump and workability. Quantities per cubic meter are then calculated.

Representative samples of the cementation's materials, water, aggregates, and admixtures must be used. To simplify calculations and eliminate error caused by variations in aggregate moisture content, the aggregates should be rewetted then dried to a saturated surface dry (SSD) condition and placed in covered containers to keep them in this condition until they are used. The moisture content of the aggregates should be determined and the batched quantities corrected.

The size of the trial batch is dependent on the equipment available and on the number and size of test specimens to be made. AASHTO T126 (ASTM C192) provide guidance on mixing procedures

3.2.3 Absolute Volume

The absolute volume of granular materials such as cementations materials or aggregates is the volume of the solid matter in the particles; it does not include the volume of the spaces between particles. The volume of freshly mixed concrete is equal to the sum of the absolute volumes of the cementation's materials, water (exclusive of that absorbed in the aggregate particles), aggregates, admixtures when applicable, and air. The absolute volume is equal to the mass (kg) of the ingredient divided by the product of its relative density (specific gravity) times the density of water (1,000 kg/m^3).

$$\text{Absolute volume } (m^3) = \text{kg of loose material} / (\text{relative density} \times 1{,}000 \text{ kg}/m^3)$$

A value of 3.15 can be used for the relative density of Portland cement, and a value of 2.5to 3.1 for blended cement. Fly ash has a relative density in the range of 1.9 to 2.8. Silica fume and slag typically have values of 2.2 and 2.9, respectively. The relative density (specific gravity) of water is 1 and the mass density (unit weight) of water is 1,000 kg/m^3. The relative density of normal weight aggregate usually is between 2.4 and 2.9. The relative density (specific gravity) of aggregate as used in mixture calculations is the bulk relative density (specific gravity) of either saturated surface-dry material or oven-dry material. Relative densities of admixtures, such as water reducers, must also be considered [27].

The absolute volume of air in concrete is equal to the air-content percentage divided by 100 (e.g., 7% ÷ 100) and then multiplied by the volume of the concrete batch.

The volume of concrete in the batch can be determined by either of two methods: (*a*) if the relative densities (specific gravities) of the aggregates and cementations materials are known, these can be used to calculate concrete volume; and (*b*) if relative densities (specific gravities) are unknown or varying, the volume can be computed by dividing the total mass of materials in the mixer by the density of concrete. In some cases, both determinations are made, one serving a check on the other.

The method of mix design in this work was the absolute-volume method and the following equation was used for proportioning of concrete ingredients.

$$\frac{C}{\gamma_c} + \frac{S}{\gamma_s} + \frac{G}{\gamma_g} + \frac{W}{\gamma_w} = 1000 \text{ --------------------- Eq 3.2}$$

Were,

C, S, G, W, is Cement, Sand, Gravel, and Water respectability in kg/m^3 and Ɣ is the specific gravity.

Table 3.11: Adjusted mass of materials considering one cube meter of concrete the ingredients are calculated on absolute volume basis– on SSD basis

Ingredients of concrete	Volume(m^3)	Specific gravity (kg/m^3)	Batch mass Kg/m^3
Cement	0.114	3.15	360
Sand	0.240	2.62	628.8
Crushed fine aggregate (5-10mm)	0.137	2.77	379.5
Crushed coarse aggregate (10-19mm)	0.309	2.85	880.65
Water	0.180	1.00	180
Entrapped Air 2% (considered)	0.02		
Estimated concrete volume and density	1.00		2428.95

3.3 Testing of fresh concretes

Fresh concrete was assessed to test its level of workability prior to the casting of concrete samples using the following test.

3.3.1Slump test

The slump test is a measure of concrete consistency. For given proportions of cement and aggregate without admixtures, the higher the slump, the more fluid the mixture. The aggregate size, grading, and shape affect the workability. Slump is indicative of workability when similar mixtures are assessed. However, slump should not be used to compare significantly different mixtures. When used with different batches of the same mixture, a change in slump indicates a change in consistency and in the characteristics of materials, mixture proportions, or water content. The test was carried out for each batch of fresh concrete produced to assess the workability of the fresh concretes. In the slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete.

Table 3.12. Consistency of the concrete as measured by the ASTM C143 "Slump of Portland Cement Concrete”.

Portion of structures	Slump in mm	Recommended range
Pavement and slabs on ground	50	25-75
Plain footings, gravity walls, slabs, and beams	50	25-75
Heavily reinforced foundations, walls, Footings and cast in situ piles (Concreting in dry condition)	75	50-100
Thin reinforced walls and columns	75	50-100
Concreting under water	150	125-180

Concrete shall be of such consistency and mix composition that it can be readily worked into the corners and angles of the forms and around the reinforcement, inserts, embedded items, and wall castings without permitting materials to segregate or free water to collect on the surfaces and due consideration shall be given to the methods of placing and compacting.

The apparatus used to carry out this test consist of mold, scoop, sampling tray, trowel, tamping rod and measuring ruler. The internal surface of the mold was cleaned lubricated with engine oil and then placed on the sampling tray and hold firmly against the surface. The fresh concrete was poured into the mold in three layers, approximately one third of the height of the mold where each layer was tamped 25 strokes and the mold was removed vertically upward. The different between height of the mold and slump concrete was measured as a slump value.

There are three kinds of slumps [23].

- True slump: - where the concrete just subsides, keeping its shape approximately
- Shear slump: - where the top half of the cone shears off and slips sideways down an inclined plane
- Collapse slump: - where the concrete collapses completely

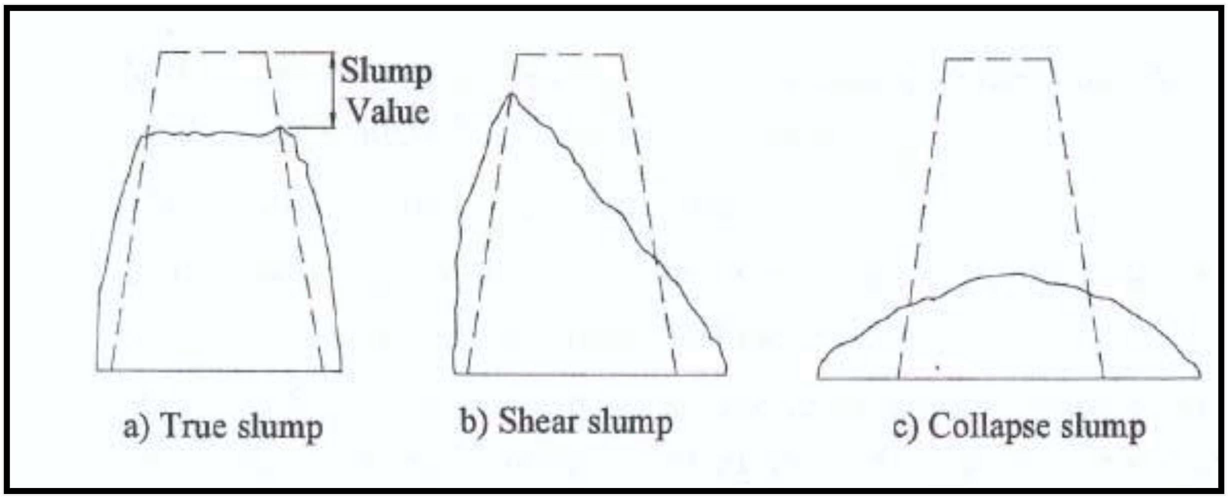


Figure 4: Three kinds of slumps [23]

Apparatus used

- Standard slump cone – 300mm high with a bottom diameter of 200mm and top diameter of 100mm
- A steel tamping rod, 600 mm long with a diameter of 16 mm that has at least one end rounded
- Sampling tray
- Measuring tape or ruler
- Scoop
- Steel float

Procedures

a) Make sure the cone is clean, free from hardened concrete and dry inside. Stand it on the base plate, which must also be clean.
b) Stand with your feet on the foot rests.

c) Using the scoop fill the cone to about one-third of its height and rod this layer of concrete exactly 25 times using the tamping rod.

d) Add two further layers of equal height (each about 100mm deep), Roding each one in turn exactly 25 times, allowing the rod to penetrate through in to the layer below. After Roding the top layer make sure that there is a slight surcharge of the concrete, i.e., that some concrete sticks out of the top.

e) Strike off the surplus concrete using steel float.

f) Wipe the cone and the base plate clean keeping your feet still on the foot rests.

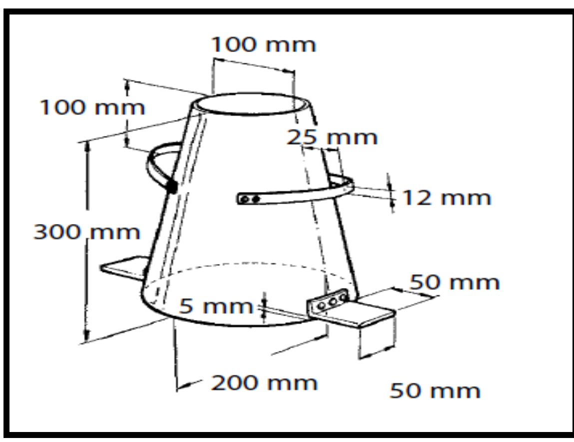
g) Take hold of the handles and pushing downwards remove your feet from the foot rests.

h) Very carefully lift the cone straight up, turn it over and put it down on the base plate next to the mound of concrete. As soon as the cone is lifted the concrete will slump to some extent.

i) Rest the tamping rod across the top of the empty inverted cone so that it reaches over the slumped concrete.

j) Using the ruler measure from the underside of the rod to the highest point of the concrete, to the nearest 5mm.That will be the slump. (See figure 4, C)

k) If you do not get a true slump, repeat the test. If the slump is still not normal, ask for advice. (See figure 4, D) [23].



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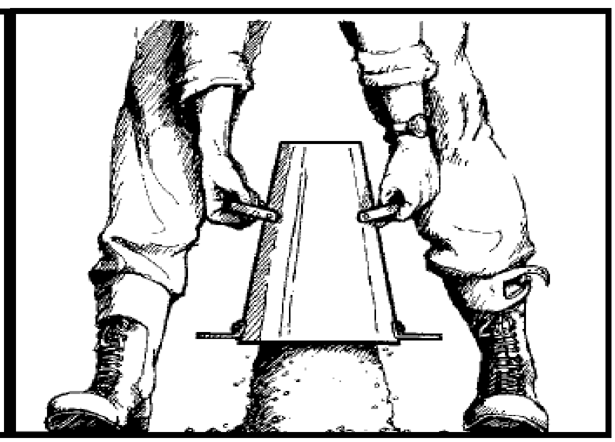

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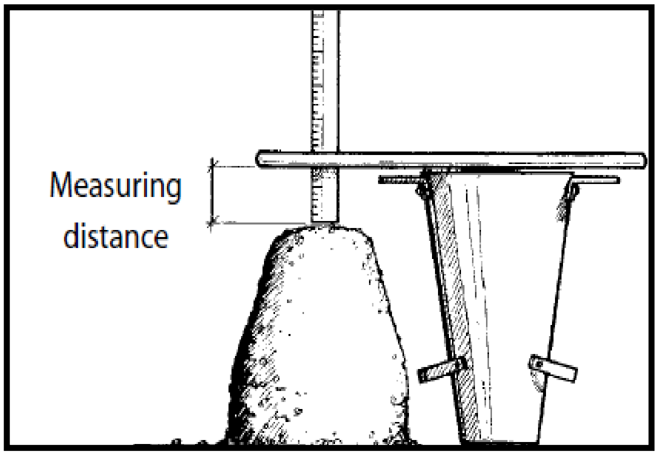
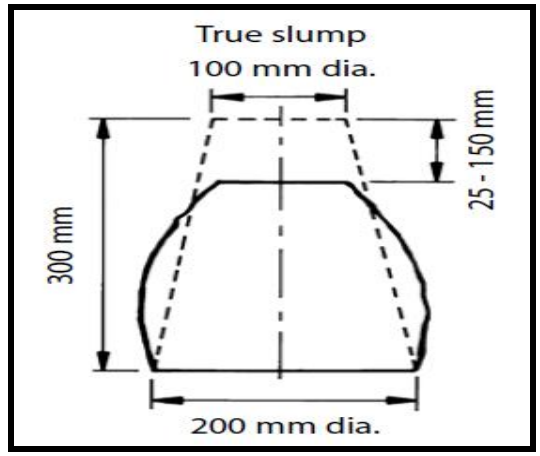




C D

Figure 5: Slump test procedure [23]

3.4 Casting of concrete specimens

The specimens were cast in iron molds generally 150mm cubes. This conforms to the specifications of [29]. The molds surfaces were first cleaned and oiled on their inside surfaces in order to prevent development of bond between the mold and the concrete.

Each specimen was cast by filling each cube, cylinder, and beam mold in two layers each layer been compacted manually before the next layer was poured. The size of cube mold used to produce concrete specimens was 150 mm * 150 mm * 150 mm^3 for each 28 days of curing period for compressive strength. Cylinders (of Φ=150mm and h=300mm) for each 28 days of curing period for split tensile strength of concrete and beam of (100*100*500mm^3) for each 28 days of curing time for flexural strength of concrete.

A total of 44 number of concrete specimens were produced out of which 12 number (cubes) were used to determine the compressive strength at the end of curing period of 28 days and 12 number (cylinder) were used to determine the split tensile strength and 20 number (beams) specimens were used to determine flexural strength of concrete with different cold joint configuration at the end of curing period of 28 days.

3.5 Consolidation of concrete

Concrete that has not been adequately consolidated will have excessive entrapped-void content. The presence of such voids results in lower strengths, both compressive and flexural; poor bond to reinforcement or dowels, adversely affecting load transfer; and an increase in the transport rate of fluid through the concrete [24]. The effort needed to adequately consolidate the concrete is dependent on its workability at the time of placement

Concrete workability is affected by the grading and proportioning of the constituent materials. To assure good concrete characteristics, these factors should be considered during the materials selection phase of the work, along with the anticipated placement and consolidation techniques. Excessive vibration of concrete should be avoided, because this may result in segregation of poorly proportioned (over sanded) mixtures and may have an adverse effect by reducing the air content of concrete intended for resistance to freezing and thawing. However, laboratory research indicates that proper consolidation by internal vibration does not adversely affect the spacing factor of air-entrained concrete [25]. According to guidance on the proper use of different consolidation techniques found in ACI 309, specimens were consolidated according to laboratory procedures.

3.6 Curing of concrete specimens

To develop design strength, the concrete must be cured for up to 28 days with the normal curing techniques that is with direct supply of water. As the rate of hydration, and hence the rate of development of strength, reduces with time, it is not worthwhile to cure for the full period of 28 days [2]. The concrete specimens cast were cured by complete immersion in water for the required period of hydration of 28 days in the laboratory.

3.7 Testing of hardened concrete specimens

3.7.1 Compressive strength test

Compressive test is the most common test for hardened concrete involves taking a sample of fresh concrete and putting it into a special cube mold so that when hardened, the cubes can be tested to failure in a special machine in order to measure the strength of concrete. The strength of concrete specimen is affected by many factors such as; water-cement ratio, degree of compaction and curing temperature. Care should be taken, in preparing samples for testing. Water-cement ratio goes up above a certain level, the strength will decrease correspondingly. Compaction reduces the amount of entrapped air and therefore increases the strength of concrete (for each 1% air entrapped there will be about 5% to 6% loss of strength). Curing temperature affects the hydration of cement and hence, the duration of the strength gain (cubes kept at about 10^0c will have their 7-day strength reduced by 30%and their 28-day strength reduced by 15%). This shows for proper cure of test cubes at a recommended temperature 20^0c [23].

Cube test was undertaken at age of curing period of 28 days. The concrete specimens (cubes) with different cold joint formation time were removed from the curing tank and placed outside to surface dried, then weighed and positioned at the center of manual hydraulic compression machine for crushing. The force was applied at the specimen by swinging the handle of the crushing machine till the specimen was crushed. The maximum load at failure was then recorded.

Apparatus used

- ➢ Separator (form work)
- ➢ Cubical mold (150*150*150) mm^3
- ➢ Spatula
- ➢ Compressive strength testing machine

Procedures

- ✓ Three concrete cubes with (150*150*150) mm^3 for each sample of concrete with different cold joint formation time were casted in the vertical direction of separator in order to make flat plane with smooth cold joint and the second layers of freshly mix concrete was casted in the remaining half cubical mold without roughened the old concrete layer (the first half layer) with the times laps of 0, 7, 14, and 21 days of time period were tested for compressive strength at 28 days after curing.
- ✓ The same concrete mix is used for each sample of concrete cubes for added and substrate concrete in order to produce uniform consistency for each sample.
- ✓ All the casted specimens are covered by plastic sheets and left in the laboratory for 24 hours then transferred to a saturated water curing tank at 25^0C until the age of testing.
- ✓ The concrete specimens were loaded to failure at 28 days of curing time by using testing machine and the failure loads were recorded.
- ✓ The stresses at failure (compressive strength) were calculated by dividing the failure load by the respective contact area of the specimen with the load [23].

The compressive strength was calculated using the formula in equation 3.2.

$$\text{Compressive strength} = \frac{\text{Maximum load (KN)} \times 1000}{\text{Cross- sectional Area (mm}^2\text{)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq 3.3}$$

Figure 6: Pictures of samples with different cold joint formation time at JU laboratory

Figure 7: Pictures of cube samples with cold joint at JU laboratory

Figure 8: Pictures of cube samples in compressive test machine at JU laboratory

3.7.2 Split tensile strength test

This test was carried out at age of curing period of 28 days. The concrete specimens (cylinders) were removed from the curing tank and placed outside to surface dried. The specimens were then weighed and placed at the center of hydraulic manual compression machine for splitting. In this test, a concrete cylinder, of the type used for compression tests, is placed with its axis horizontal between a plate of the testing machine, and the load is increased until failure by indirect tension in the form of splitting along the vertical diameter takes place. However, immediately under the load a high compressive stress would be induced and, in practice, narrow strips of packing material, such as plywood are interposed between the cylinder and the plate.

Apparatus

- Testing machine
- Bearing strips- two bearing strips of nominal 3mm thick plywood, free of imperfections, approximately 25mm wide and of length equal to or slightly longer than that of the specimen shall be placed between the specimen and both the upper and lower bearing blocks of the testing machine.
- The cylindrical mold with diameter 150mm and height 300mm.

Procedure

1. Three-cylinder molds with (Φ=150mm and h=300mm) for each sample of concrete with different cold joint formation time were casted in the vertical direction of separator on order to make flat plane with cold joint and the second layers of freshly mix concrete was casted in the cylinder mold with the times laps of 0, 7, 14, and 21 days of time period were tested for split tensile strength at 28 days after curing.
2. The same concrete mix is used for each sample of cylinder for added and substrate concrete mix in order to produce uniform consistency for each sample.
3. All the casted specimens are covered by plastic sheets and left in the laboratory for 24 hours then transferred to a saturated water curing tank at 25^0C until the age of testing.
4. Diameter lines were drawn on each end of the using suitable device that insured that they were in the same axis plane.
5. The length of the specimen was determined by averaging the two lengths measurements taken in the plane containing the lines marked on the two ends.
6. One of the plywood strips was centered along the center of the lower bearing block. The specimen was placed on the plywood strip and aligned so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip.
7. The second plywood was placed on the cylinder lengthwise centered on the lines marked on the ends of the cylinder.
8. A load was applied continuously and without shock at a constant range until failure of the specimen. The maximum applied load was recorded and the type of failure and the appearance of the concrete were noted [21].

Calculation

$$\sigma = \frac{2*\rho}{\pi l d} \quad \text{--Eq3.4}$$

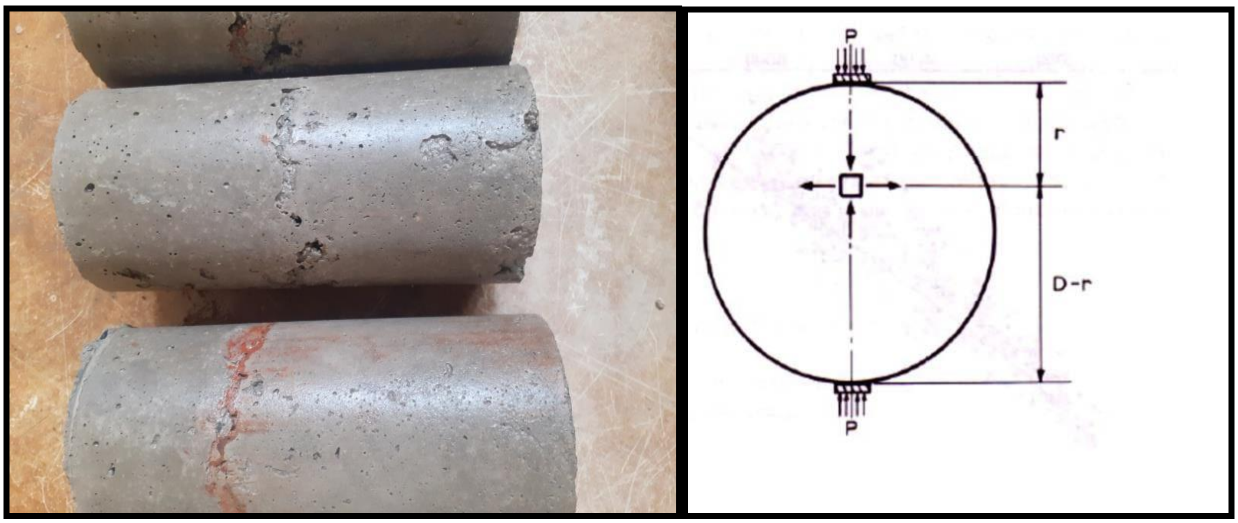
Were,

σ =Splitting tensile strength (kN/m^2)

ρ=Maximum applied load (KN)

l=Length (m)

d=Diameter (m)



A B

Figure 9: Pictures of cylinders with cold joint at JU laboratory [21]

Figure 10: Pictures of cylinder samples in split tensile strength test machine at JU Laboratory

3.7.3 Flexural strength

Flexural strength is one measure of the tensile strength of concrete. It is measure of an unreinforced concrete (plain concrete) beam or slab to resist failure in bending. It is measured by loading (150*150*500mm^3) concrete beams used in this research. The flexural strength is expressed as modulus of rupture (MR) in (MPa) and is determined by standard test methods [30]. Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. MR determined by third-point loading is lower than MR determined by center point loading, sometimes by as much as 15%.

Designers of pavement use a theory based on flexural strength. Therefore, laboratory mix design based on flexural strength tests may be required material content may be selected from experience to obtain the needed design MR. some also use MR for field control and acceptance of pavements. Very few uses flexural testing for structural concrete. Agencies not using flexural strength for field control generally find the use of compressive strength convenient and reliable to judge the quality of the concrete [7].

During pure bending, the member resisting the action is subjected to internal actions or stresses (shear, tensile and compressive). For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are, generally, subjected to compressive stresses and those below the neutral axis to tensile stresses. For this load and support system, portion of the member near the supports are subjected to relatively higher shear stresses than tensile stresses.

In this test the concrete member to be tested is supported at its ends and loaded at its interior location(s) by a gradually increasing load to failure. The failure load (loading value at which the concrete cracks heavily) is then recorded and used to determine the tensile stress at which the member failed, i.e., its tensile strength [23].

Third-point loading

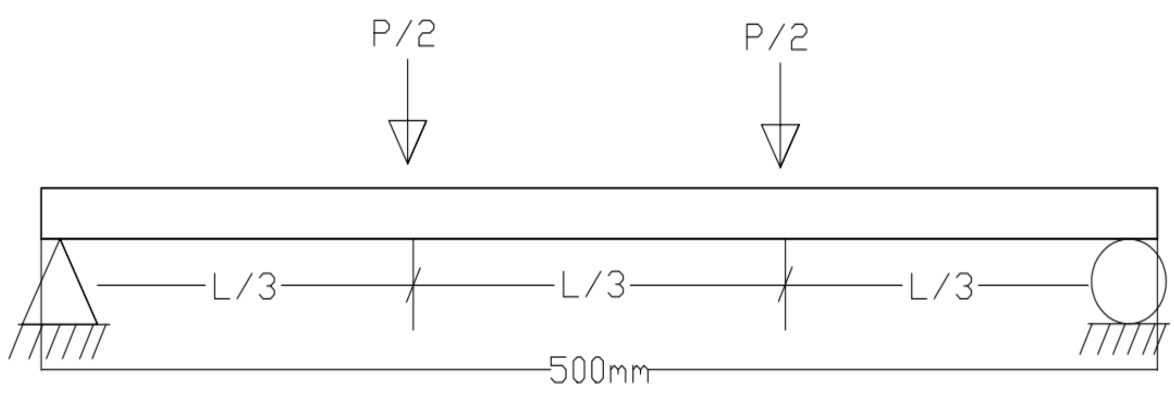


Figure 11: Flexural strength testing by third point loading

Apparatus

- Measuring tape
- Testing machine

Procedure

1. Two beams (150*150*500) mm^3 molds in each sample were casted in different delay period and configuration at casting the second layer with cold joint were tested for determination of flexural strength at 28 days of curing period.
2. The same mix of concrete is used for each added and substrate concrete mix in order to produce uniform consistency for each sample.
3. All the casted specimens are covered by plastic sheets and left in the laboratory for 24 hours then transferred to a saturated water curing tank at 25^0C until the age of testing.
4. The specimen in bending was loaded at its center using bending test machine gradually increasing the bending load to failure.
5. The failure load was recorded and it was used to calculate the flexural stress [23].

Calculation

$$C = \frac{d}{2} mm$$ -- Eq3.5

$$M = \frac{PL}{4} Nm$$ --Eq3.6

$$I = \frac{bd3}{12} m4$$ --Eq3.7

$$\sigma = \frac{Mc}{I} MPa = 1.5 \frac{pL}{bd^2}$$ --Eq3.8

P= Failure load

σ =Bending strength

M= Maximum moment

L=span of specimen

I= Moment of inertia

d=depth of specimen

C= Centroidal depth

b=width of specimen

Figure 12: Pictures of beam samples in flexural strength test machine at JU Laboratory

CHAPTER FOUR: RESULT, DATA PRESENTATION AND DISCUTION

4.1 Results of fresh and hardened concrete specimens

The results of the compressive, tensile, and flexural and workability or slump test result are presented and discussed.

4.1.2 Results of fresh concrete specimens

4.1.2.1 Slump or workability tests result of fresh concrete

Table: 4.1 presents the results of workability tests for each group of the substrate (old) and added (new) concrete mix.

Table: 4.1 Slump test of fresh concrete

Cold joint formation period (days) or difference of age between added and substrate concrete layers	**Slump (mm)**		**Slump (mm) average**
	Substrate (Old concrete layer)	Added (Fresh new concrete layer)	
0	44	44	44
7	42	42	42
14	42	42	42
21	44	42	43

4.1.3 Results of hardened concrete specimens

4.1.3.1 Compressive strength test result of concrete specimens

The results of the laboratory experiments on the compressive strength of concrete specimens with the different cold joint formation time or difference of age between both halves of the specimens, 0, 7, 14 and 21 days of are shown in tables 4.2, and graphs of their respective values in figures 13.

Table 4.2: Compressive strength test result of concrete specimens with different cold joint formation time

Cold joint formation period (days) or difference of age between added and substrate concrete layers	Cube Samples	Max.load (KN)	Compressive strength at curing time of 28 days in (MPa)
Monolithic concrete Reference **0 Day**	1	598.05	26.58
	2	590.4	26.24
	3	557.1	24.76
	Average		25.86
Substrate | Added **7 Days**	1	556.4	24.73
	2	527.17	23.43
	3	558.9	24.84
	Average		24.33
Substrate | Added **14 Days**	1	497.25	22.10
	2	482.85	21.46
	3	520.20	23.12
	Average		22.22
Substrate | Added **21 Days**	1	411.1	18.27
	2	433.8	19.28
	3	402.97	17.91
	Average		18.48

Table 4.3: Summary of average compressive strength concrete samples with different cold joint formation period

Cold joint formation period (days) or difference of age between added and substrate concrete layers	Compressive strength at curing time of 28 days in MPa
0 days at casting the second layer of concrete	25.86
7 days at casting the second layer of concrete	24.33
14 days at casting the second layer of concrete	22.22
21 days at casting the second layer of concrete	18.48

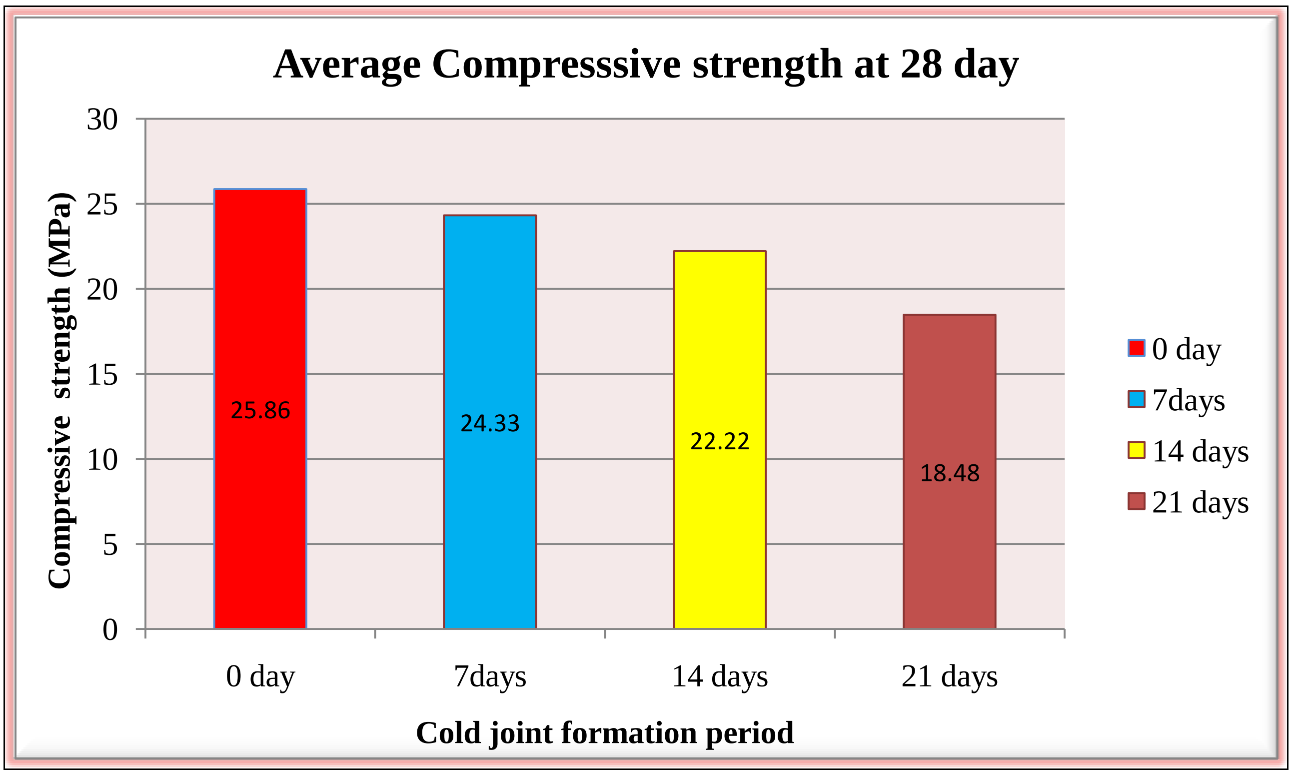


Figure 13: Comparison of Compressive strength versus casting delay or cold joint formation time

4.1.3.2 Split tensile strength test result of concrete specimens

Table 4.4: Shows the split tensile strength test result of concrete with the different cold joint formation time or difference of age between both halves of the cylinder specimens, 0, 7, 14 and 21 days and graphs of their respective values in figures 15.

Table 4.4: Tensile strength of concrete samples with different cold joint formation period

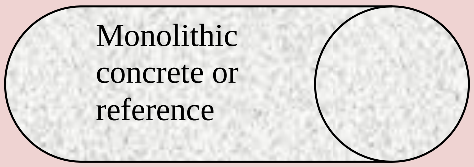
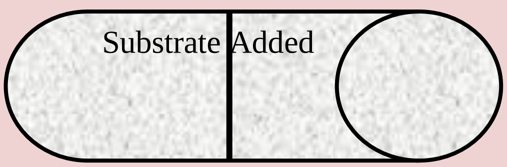
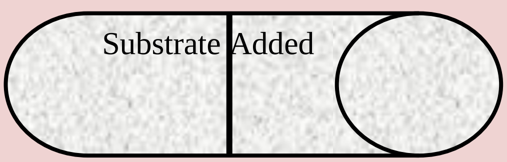
Cold joint formation period (days) or difference of age between added and substrate concrete layers	**Cylinder Samples**	**Max. load (KN)**	**Tensile strength at curing time of 28 days in (MPa)**
 **0day**	1	142.7	2.02
	2	131.4	1.86
	3	119.4	1.69
	Average		1.86
 **7 days**	1	116.5	1.65
	2	-	-
	3	118.7	1.68
	Average		1.66
 **14 days**	1	113.7	1.61
	2	115.8	1.64
	3	-	
	Average		1.62
 **21 days**	1	91.1	1.29
	2	81.9	1.16
	3	95.3	1.35
	Average		1.26

Table 4.5: Summary of average Tensile strength concrete samples with different cold joint formation period

Cold joint formation period (days) or difference of age between added and substrate concrete layers	**Tensile strength at curing time of 28 days in MPa**
0 days at casting the second layer of concrete	1.86
7 days at casting the second layer of concrete	1.66
14 days at casting the second layer of concrete	1.62
21 days at casting the second layer of concrete	1.26

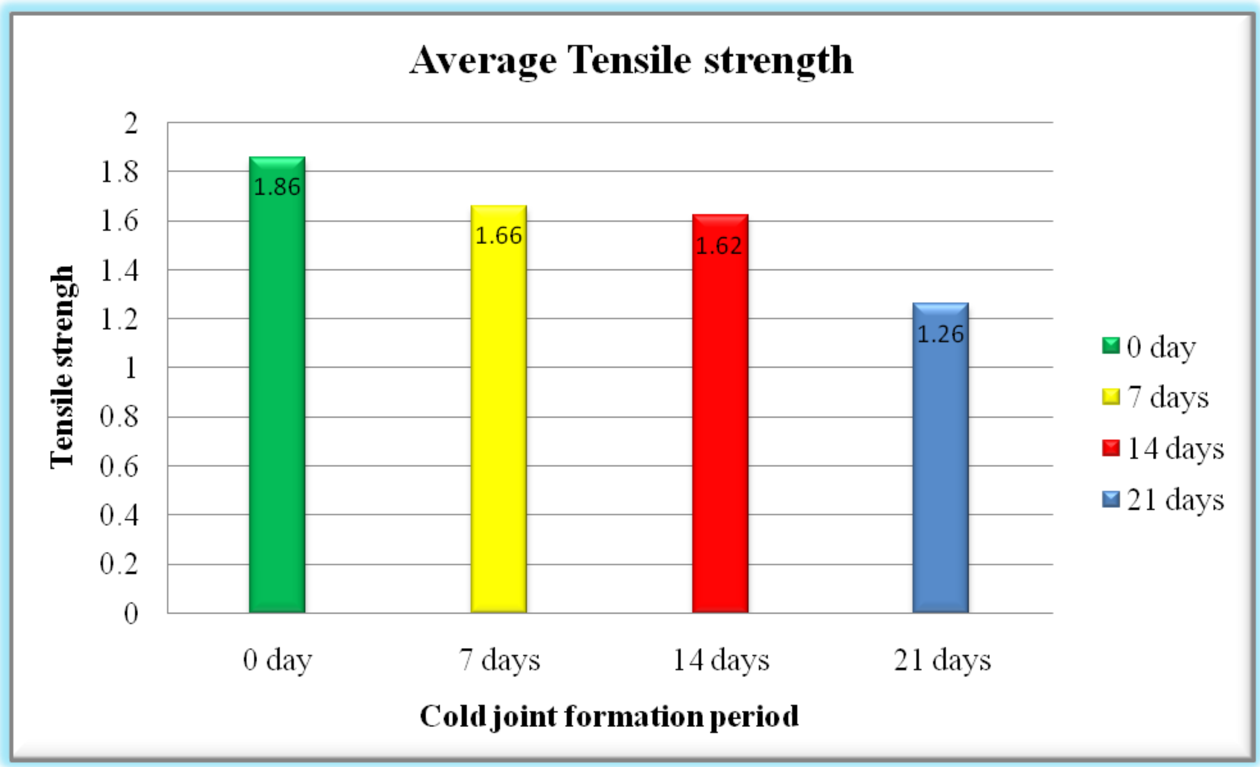
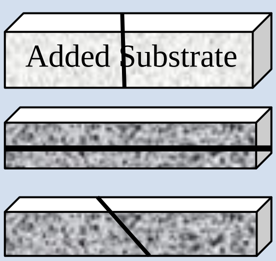


Figure 15: Comparison of Tensile strength versus casting delay or cold joint formation time

4.1.3.3 Flexural strength test result of concrete specimens

Table 4.6 Shows Flexural strength test result of concrete beam specimens with different cold joint formation and configuration (Horizontal, Vertical, and inclined formation angles)

Table 4.6: Shows Flexural strength test result of concrete beam specimens with different cold joint formation and configuration

Cold joint formation time and configuration	**Beam Sample**	**Max load**	**Flexural strength at curing time of 28 days Mpa**			
			Full beam	Inclined plane (90^0)	Horizontal plane (0^0)	Vertical plane (45^0)
 **0 day**	1	19.1	4.24			
	2	18.7	4.16			
	Average		4.2			
 **7days**	1	18.6		3.51	4.12	3.05
	2	17.3		3.87	4.05	2.29
	Average			3.69	4.08	2.67

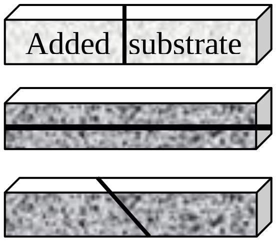
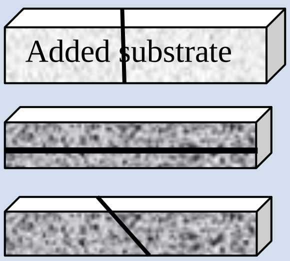
 **14 days**	1	17.6		3.02	3.76	2.24
	2	17.5		-	3.62	2.12
	Average			3.02	3.69	2.18
 **21 days**	1	16.4		2.95	3.31	2.02
	2	16.2		2.72	3.17	1.94
	Average			2.84	3.24	1.98

Table 4.7: Summary of average Flexural strength concrete samples with different cold joint formation period and configuration

Cold joint formation period (days) and configuration	Flexural strength at curing time of 28 days in MPa			
	Full beam Reference	Inclined plane	Horizontal plane	Vertical plane
0 days at casting the second layer of concrete	4.2			
7 days at casting the second layer of concrete		3.69	4.08	2.67
14 days at casting the second layer of concrete		3.02	3.69	2.18
21 days at casting the second layer of concrete		2.84	3.24	1.98

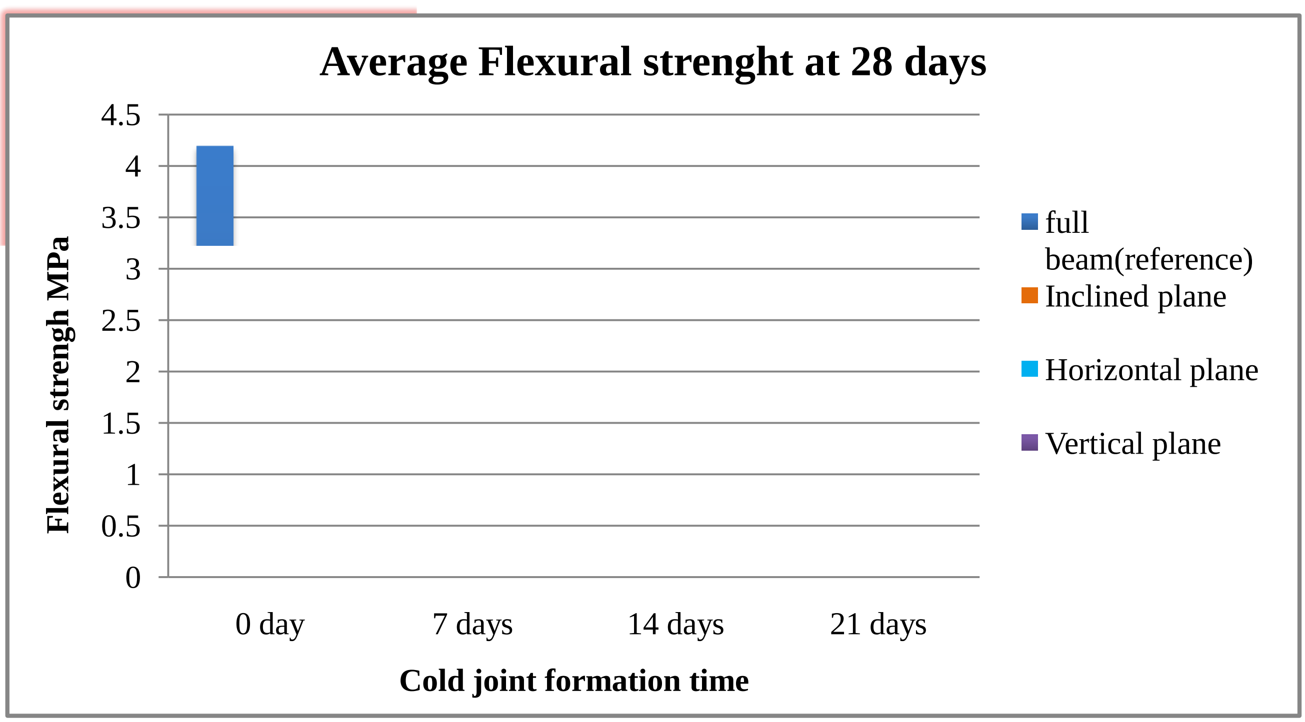
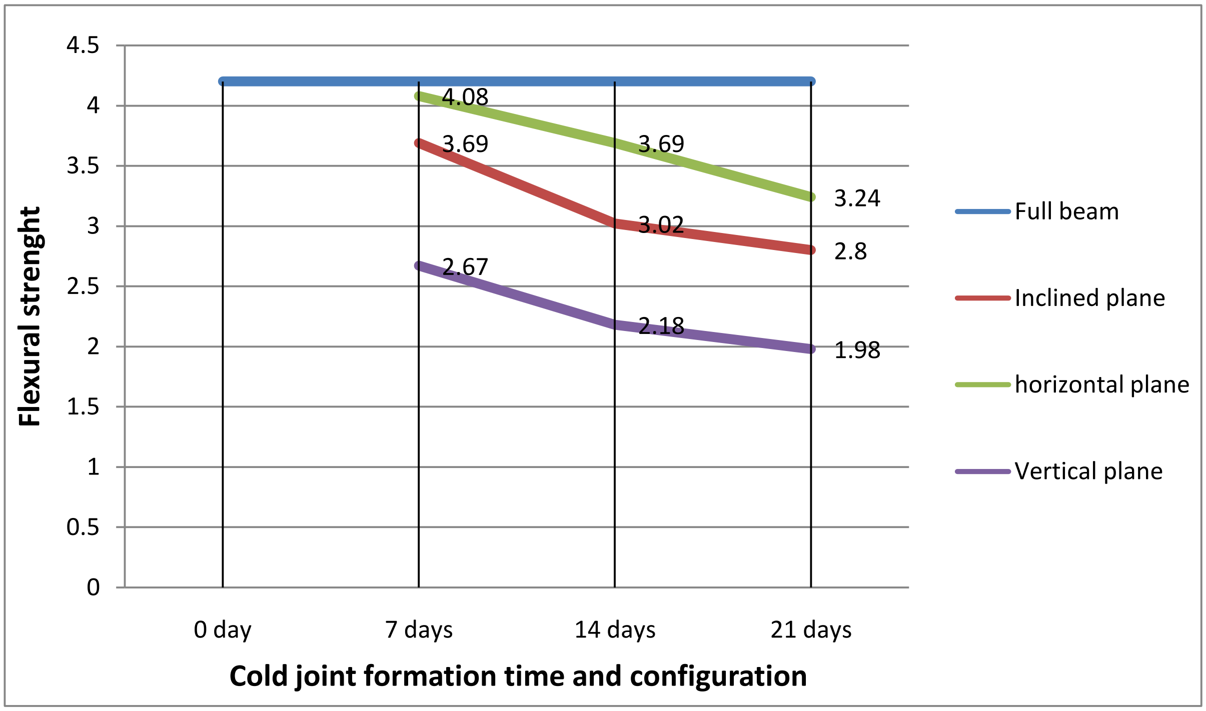


Figure 17: Comparison of Flexural strength versus casting delay or cold joint formation time and configuration



4.2 DISCUSION

4.2.1 Discussion on Compressive strength of concrete specimens

Table 4.3 and figure 13 shows that the compressive strength was decreased with increasing the time period (delay in concreting) between casting of the first and second layer of concrete. It is observed that the percentage reduction of compressive strength of concrete at casting the second layer of cube specimens after 7, 14 and 21days is 5.92%, 14.07%, and 28.54% respectively with respect to reference specimens. The magnitude of percentage reduction in compressive strength as the difference of age between the substrate and the added concrete layer increases from 14 to 21 days (16.8%) is almost twice than the magnitude of percentage reduction from 7 to 14 days (8.6%). The magnitude of percentage reduction in compressive strength as the difference of age between the substrate and the added concrete layer increases from 0 to 7 days is (5.9%) which is smaller effect when compared to control specimen (specimen without cold joint). It shows us that, casting the second layer concrete after 7 days significantly affect the compressive strength of the concrete when compared to control specimen.

4.2.2 Discussion on Tensile strength of concrete specimens

Table 4.5 and figure 15, 16 shows that the split tensile strength was decreased with increasing the time period (delay in concreting) between casting of the first and second layer of concrete. It is observed that the percentage reduction of tensile strength of concrete at casting the second half layer of cylinder specimens after 7, 14 and 21 days is 10.75%, 12.9%, 32.25% respectively compared to control specimen. It was observed that the reduction of tensile strength of concrete cylinders at casting the second layer of concrete after 7 and 14 days is 2.4% which is the same effect or reduction on splitting tensile strength but after 14 days of casting of the second layer has major effect or reduction on tensile strength of concrete specimens. The magnitude of percentage reduction in split tensile strength as the difference of age between the substrate and the added concrete layer increases from 14 to 21 days (22.2%) is significantly higher than the magnitude of percentage reduction from 7 to 14 days which is (2.4%).

4.2.3 Discussion on Flexural strength of concrete specimens

Table 4.7 and figure 17, 18 shows that the flexural strength was decreased with increasing times delay of casting the second layer of concrete with inclined, horizontal, and vertical plane of beam specimens from 0 to7 days is 12.14%, 2.85% and 36.42% from 0 to 14 day is, 28.09% 12.14% and 48.09% and from 0 to 21 days is 32.38%, 22.86% and 52.85% respectively.

The magnitude horizontal plane of flexural strength of concrete beam at casting the second layer after 7 days increased by 11% and 33% compared to inclined and vertical plane.

The magnitude horizontal plane of flexural strength of concrete beam at casting the second layer after 14 days increased by 16% and 38% compared to inclined and vertical plane.

The magnitude horizontal plane of flexural strength of concrete beam at casting the second layer after 21 days increased by 10% and 30% compared to inclined and vertical plane.

The magnitude inclined plane of flexural strength of concrete beam at casting the second layer after 7 days increased by 24.26% compared to vertical plane. The magnitude inclined plane of flexural strength of concrete beam at casting the second layer after 21 days increased by 21% compared to vertical plane.

General relationships between Compressive, Tensile, and flexural strength of concrete samples

The percentage reduction of tensile strength of concrete cylinder specimens at casting the second layer from 7 to 21 days is 32.25% is almost the same as that of reduction of flexural strength of concrete beam with inclined joint formation was 32.38%.

The percentage reduction of compressive strength is 28.54% which is smaller than reduction of both tensile and flexural concrete specimens at 28 days of curing time when compared to control specimen, so tensile and flexural strength of concrete significantly affected by cold joint.

The reduction of compressive and flexural strength of concrete specimens is linear up to delay period of 14 days while above 21 days is not linear while, the reduction of tensile strength is almost the same effect up to 14 days but there is significant effect after 21 days.

Among all plane or cold joint configuration vertical cold joint has greater reduction in flexure and horizontal plane performed better resistance than all other configuration compared to reference specimens.

Tensile and flexural strength of concrete is highly affected by cold joint because there is no reinforcement or dowel action.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the above discussion or findings the following conclusion were drawn

- The percentage reduction of compressive strength of concrete at casting the second layer up to 7 days have smaller effect on the compressive strength but after 14 days the loss of compressive strength was increased twice this shows us that, casting the second layer concrete after 7 days highly affect the compressive strength of the concrete when compared to control specimen.
- The percentage reduction of compressive strength is smaller than reduction of both tensile and flexural strength of concrete specimens at 28 days of curing time when compared to control specimen, so tensile and flexural strength of concrete significantly affected by cold joint because all samples are plain concrete which means no reinforcement or dowel bar are provided so both tensile and flexural stress resisted by reinforcement bar.
- It is observed that the percentage reduction of tensile strength of concrete at casting the second half layer of cylinder specimens after 7, 14 and 21 days is 10.75%, 12.9%, 32.25% respectively compared to control specimen. This shows us the tensile strength of concrete is highly affected by cold joint compared to compressive strength.
- It is observed that the percentage reduction of tensile strength of concrete at casting the second half layer of cylinder specimens up to 14 days have the same effect but significant loss of tensile strength of concrete was observed after 21 days.
- The magnitude horizontal cold joint plane of flexural strength of concrete beam at casting the second layer after 7 days increased by 11% and 33% compared to inclined and vertical cold joint plane.
- The magnitude horizontal cold joint plane of flexural strength of concrete beam at casting the second layer after 14 days increased by 16% and 38% compared to inclined and vertical cold joint plane.
- The magnitude horizontal cold joint plane of flexural strength of concrete beam at casting the second layer after 21 days increased by 10% and 30% compared to inclined and vertical cold joint plane.

- ♦ The percentage reduction of tensile strength of concrete cylinder specimens at casting the second layer from 7 to 21 days is 32.25% is almost the same as that of reduction of flexural strength of concrete beam with inclined joint formation was32.38%.
- ♦ Among all cold joint configuration vertical cold joint has greater reduction in flexure and horizontal cold joint plane performed better resistance than all other configuration compared to reference specimens. Therefore, from the above observations horizontal cold joint is best with respect to all cold joint planes.
- ♦ Tensile and flexural strength of concrete is highly affected by cold joint because there is no reinforcement or dowel action in all concrete specimens.
- ♦ Many researchers conducted with effect of cold joint on concrete strength with shorter time of cold joint formation time using different admixtures (accelerated) and reinforcement but this research is done with longer time of cold joint of formation time up to 21 days of delay at casting the second layer of plain concrete samples without using accelerated admixtures and reinforcement b/c limitation of budget and laboratory testing equipment's.

5.2 Recommendations

- ▶ If casting delays more than 7 days the remedial measures such as rejecting partially hardened concrete.
- ▶ Concrete casting sequence as detailed architectural and structural drawings shall be planned, designed, and located in the blue print.
- ▶ Minimizing cold joint by properly designing and planning construction sequence for continuous casting of concrete.
- ▶ Providing adequate reinforcement continuing through the joint or dowel action and surface preparation of the joint
- ▶ Locate construction joint at high points in the floor slab away from drains in order to prevent leakage of harmful wastes such as water and salt that may cause rusting of reinforcing bars or dowels in the joint.

5.3 Limitation and further studies

This research is done without reinforcing the concrete or doweling the joint, surface preparation (Texture) and without the usage of retarding admixtures so the result of the thesis restricted on the above parameters. Further studies should be conducted on how shear interlock and flexural continuity affected by cold joint using reinforcing bars or dowels, surface preparation and retarding admixture.

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APPENDIX A: Considering one cube meter of concrete the ingredients are calculated on absolute volume basis

CONCRETE MIX DESING CLASS OF CONCRETE C-25				
S1teps	Items	Calculation or reference		Value
1	1.1 Specified cubical strength			25
	1.2 Margin	ACI 318, Table 5.3.2.2		8
	1.3 Target Mean Strength	fcr (MPa) = fc'+8		33
	1.4 Cement Type	PPC (Derba)		
	1.5Aggregate Characteristics	Coarse Aggregate	Fine Aggregate	
	Specific Gravity	2.85	2.62	
	Fineness Modulus	5.67	2.79	
2	Required Slump	ASTM C143 "Slump of Portland Cement Concrete"		25-75mm
3	Maximum nominal Size of coarse Aggregate			19mm
4	Entrapped Air in non-air entrained concrete	ACI Table A1.5.3.3		2%
5	Maximum Water/Cement Ratio			0.5
6	Cement Content			360 kg/m^3
7	Required water	Wreq=0.5*360		180 kg/m^3
8	Quantity of Course Agg. Per unit vol. of concrete	ASTMC33 provides guidance on the requirements for coarse aggregates.		65%
9	Calculation of Aggregate			
10	The Sand Content can be Calculated by Absolute Volume Basis (ACI211.1-81)			
11	Volume of ingredients of the concrete per cubic meter is calculated as follows:	Volume of water (180/1000)		$0.18m^3$
		Volume of cement (360/ (3.15*1000))		$0.114m^3$
		Entrapped air (considering) 2%		$0.02m^3$
		Total volume of paste without fine and coarse aggregate		0.314 m^3
		Therefore, solid volume of fine and coarse aggregate (1.000-0.314)		$0.686m^3$
		Blending Portion of Course Agg 65% and 35% sand		

		20% Crushed aggregate(5-10mm) (0.2*0.686)	0.137m^3
		45% Crushed aggregate (10-19) mm (0.45*0.686)	0.309m^3
		35% Volume of sand	0.240m^3
12	Mix proportion – on SSD basis		

	Ingredients of concrete	Volume(m^3)	Specific gravity (kg/m^3)	Batch mass
1	Cement	0.114	3.15	360
2	Water	0.180	1.00	180
3	Crushed aggregate(5-10mm)	0.137	2.77	379.5
4	Crushed aggregate (10-19) mm	0.309	2.85	880.65
5	Sand	0.240	2.62	628.8
6	Entrapped Air2% (considered)	0.020		
	Total	1		2428.95

Proportion by volume of 50kg of cement
Factor for 50kg of cement = 50kg/360kg= 0.139

	Ingredients of concrete	Batch mass kg/m^3	Cement (50kg)	ratio	For 1 bag of cement (50kg)
1	Cement	360	50	1	1 Bag
2	Water	180	25	0.5	25 lit
3	Crushed aggregate (5-10mm)	379.5	52.7	1	1 box
4	Crushed aggregate (10-19) mm	880.65	122.4	2	2 boxes
5	Sand	628.8	87.4	1.75	2 boxes

APPENDIX B Cube result of compressive strength

Description of test specimens: cube test with cold joint					**Date specimens were cast: 6/08/2013 E.C**		
Cube Samples no	Cold joint formation time (Days)	Weight	Area mm^2	Max.load (KN)	Stress MPA	Cured Days	Date tested
1	0 day or control specimen	9.05	22,500	598.05	26.58	28	4/09/2013
2		9.14	22,500	590.4	26.24	28	4/09/2013
3		9.27	22,500	557.1	24.76	28	4/09/2013
Average		9.15	22,500	581,85	25.86		
1	7 days	9.02	22,500	556.4	24.73	28	4/09/2013
2		8.76	22,500	527.17	23.43	28	4/09/2013
3		8.83	22,500	558.9	24.84	28	4/09/2013
Average		8.87	22,500	547.49	24.33		
1	14 days	8.54	22,500	497.25	22.10	28	4/09/2013
2		8.16	22,500	482.85	21.46	28	4/09/2013
3		8.55	22,500	520.20	23.12	28	4/09/2013
Average		8.42	22.500	500	22.22		
1	21 days	8.34	22,500	411.1	18.27	28	4/09/2013
2		8.18	22,500	433.8	19.28	28	4/09/2013
3		8.25	22,500	402.97	17.91	28	4/09/2013
	Average	8.25	22,500	415.95	18.48		

APPENDIX C Cylinder test result of tensile strength of concrete

Description of test specimens: Cylinder test with cold joint					**Date specimens were cast: 6/08/2013 E.C**		
Cylinder Samples no	Cold joint formation time (Days)	Length mm	Diameter mm	Max.load (KN)	Stress MPA	Cured Days	Date tested
1	0 day or control specimen	300	150	142.7	2.02	28	4/09/2013
2		300	150	131.4	1.86	28	4/09/2013
3		300	150	119.4	1.69	28	4/09/2013
Average		300	150	131.16	1.86		
1	7 days	300	150	116.5	1.65	28	4/09/2013
2		300	150	-	Rejected	28	4/09/2013
3		300	150	118.7	1.68	28	4/09/2013
Average		300	150	117.6	1.66		
1	14 days	300	150	113.7	1.61	28	4/09/2013
2		300	150	115.8	1.64	28	4/09/2013
3		300	150	-	Rejected	28	4/09/2013
Average		300	150	114.7	1.62		
1	21 days	300	150	91.1	1.29	28	4/09/2013
2		300	150	81.9	1.16	28	4/09/2013
3		300	150	95.3	1.35	28	4/09/2013
	Average	300	150	89.4	1.26		

APPENDIX D Beam test result of flexural strength of concrete

	Description of test specimens: (150*150*500mm^3) beam test with cold					**Date specimens were cast: 12/08/2013 E.C**					
Beam Sample no	Cold joint formation time (Days)	Length mm	Width mm	Depth mm	Max. load (KN)	MR Configuration Mpa				Cured Days	Date tested
						full	IC	HC	VC		
1	0 day or control specimen	500	150	150	19.1	4.24				28	10/09/2013
2		500	150	150	18.7	4.16				28	10/09/2013
Average		500	150	150	18.9	4.2					
1	7 days	500	150	150	18.6		3.51	4.12	3.05	28	10/09/2013
2		500	150	150	17.3		3.87	4.05	2.29	28	10/09/2013
Average		500	150	150	17.9		3.69	4.08	2.67		
1	14 days	500	150	150	17.6		3.02	3.76	2.24	28	10/09/2013
2		500	150	150	17.5		-	3.62	2.12	28	10/09/2013
Average		500	150	150	17.5		3.02	3.69	2.18		
1	21 days	500	150	150	16.4		2.95	3.31	2.02	28	10/09/2013
2		500	150	150	16.2		2.72	3.17	1.94	28	10/09/2013
	Average	500	150	150	16.3	1.26	2.84	3.24	1.98		