MIX DESIGN PROPOSAL FOR STRUCTURAL CONCRETE USING MESSOBO ORDINARY PORTLAND CEMENT

Abebe Dinku, Asnake Adamu and Girma Zerayohannes
Department of Civil Engineering
Addis Ababa University

ABSTRACT

Mix design is a process in which one determines the relative quantities of the ingredients prior to mixing to produce the desired quality of concrete. By varying the mix proportions of the ingredients, different strength grades of concrete can be obtained. Several factors, which include water cement ratio, workability, curing type and duration, sizes of coarse aggregate, and sand silt content are among the several factors attributing to the quality of concrete.

In this paper, attempts have been made to provide mix design proposals considering the most important factors contributing to the quality of concrete. Extensive concrete mix preparations were made to obtain concrete strength grades up to C-45 using Messebo Ordinary Portland Cement (OPC). Realizing the various factors contributing to the quality of concrete, 43 trial batches of different mix designs were investigated. Based on the test results, equations were derived to relate compressive strength to w/c and to predict the 28 days compressive strength from the 7 days compressive strength. In all cases, Messebo OPC was used and the results show that it can be used to produce concrete grades of higher quality (up to C-45) for the construction industry of normal practices.

Key words:
Aggregate, Compressive strength, Concrete, Curing, Mix proportion, Portland cement, Tensile strength, W/c ratio, Workability.

INTRODUCTION

Concrete is a heterogeneous construction material obtained artificially by mixing cement, sand, coarse aggregate and water in a certain proportion and thus different concrete strength can be obtained by altering the mix proportions of these ingredients. Structural Engineers usually specify the quality and grade of concrete for a given construction. If the desired quality of concrete cannot be obtained it may result in: material wastage, claims, production of substandard structural members and ultimately results in possible demolition of works after construction.

Among the several factors, the unavailability of explicit local mix proportion methods, poor aggregate quality, maximum aggregate size, cleanness of sand, cement type, curing type and duration and water cement ratio play the dominant role in the overall properties of fresh and hardened concrete. It is a normal practice in and around Addis Ababa to see concrete produced using 400-kg cement per cubic meter of concrete fail to achieve a C-25 grade. However, it can be shown how to obtain the same quality of concrete grade with 270-kg cement per cubic meter of concrete provided suitable mix proportions are used, good quality concrete making ingredients are selected, appropriate mix procedures and handling methods are followed.

This paper aims at providing mix proportions of the ingredients of concrete for various grades with emphasis being given to achieve higher strength concrete using Messebo ordinary Portland Cement. Messebo Cement Factory is a newly constructed factory in Mekelle town with a capacity of 600,000 tons per year. Although, it has started production only recently, it is already contributing its role in the construction industry, especially in the northern part of the country.

In this paper, theoretical backgrounds on concrete mix design and strength parameters are reviewed. The quality and properties of used materials and test programmes were discussed. The main test program includes preparation of standard mixes for structural use of concrete grades C-25, C-30 C-35, C-40 and C-45 using three maximum aggregate sizes and two degrees of workability. Analysis of the laboratory test results, followed by conclusions and sets of recommendations for various qualities of concrete mix proposals are provided at the end. With the exceptions of 4 mixes, all laboratory investigations were conducted in the Construction

Materials Laboratory of the Civil Engineering Department, Faculty of Technology of the Addis Ababa University.

LITERATURE REVIEW

Mix Design Procedure

The various components of a concrete mix are proportioned so that the resulting concrete has adequate strength, proper workability for placing, and low cost. The third calls for use of the minimum amount of cement (the most costly of the components) that will achieve adequate properties. The better the gradation of aggregates, i.e., the smaller the volume of voids, the less cement paste is needed for wetting the surface of the aggregate. As water is added, the plasticity and fluidity of the mix increases (i.e., its workability improves), but the strength decreases because of the larger volume of voids created by the free water. To reduce the free water while retaining the workability, cement must be added. Therefore, as for the cement paste, the water/cement ratio is the chief factor that controls the strength of the concrete.

Various methods of proportioning are used to obtain mixes of the desired properties from the cements and aggregates at hand. One commonly used procedure is the *Trial-batch method.* According to this method, by selecting a water-cement ratio from existing recommendations, one produces several trial batches with varying amounts of aggregate to obtain the required strength, consistency, and other properties with a minimum amount of paste.

The *ACI (American Concrete Institute) method* of proportioning makes use of the slump test together with a set of tables that, for a variety of conditions (e.g. types of structures, dimensions of members, degree of exposure to weathering, etc.), permits one to estimate proportions that will result in the desired properties [1]. These preliminary selected proportions are checked and adjusted by means of trial batches to result in concrete of the desired quality. Inevitably, strength properties of concrete of a given proportions vary from batch to batch. It is, therefore, necessary to select proportions that will furnish an average strength sufficiently greater than the specified design strength.

The mix-design procedure used for the present investigation is called the *DOE method* recommended by the Department of Environment in the United Kingdom [2]. This method is selected because it is widely used in world concrete construction practices and is found to be easier to be adopted to our situation. The design process involves five stages, each of which deals with a particular aspect of the design and ends with a required mix parameter. Accordingly, stages 1 and 2 deal with target strength and workability leading to the determination of free-water/cement ratio and free-water content respectively. Stage 3 combines the results of stages 1 and 2 to give the cement content. Stage 4 deals with the determination of the total aggregate content and stage 5 deals with the selection of the fine and coarse aggregate contents.

Strength of Concrete

Generally, the term concrete strength is taken to refer to the uniaxial compressive strength as measured by compression tests of a standard test cylinder and/or cubes. Other strength parameters, such as tensile test results are related to the compressive strength. It is an established fact that concrete compressive strength is influenced by w/c, types of cement, aggregate shape, size, moisture and temperature during curing.

Standard Compressive Strength Tests

The standard acceptance test for measuring the strength of concrete involves short time compression tests on 150-mm cubes or cylinders, cured, and tested in accordance with the local building codes. The standard acceptance test is carried out when the concrete is 28 days old. The standard strength test is the mean of the strengths of at least three cubes from the same sample tested at 28 days or an earlier age if specified. These are tested at an average loading rate of about 0.4 N/mm^2 per second, producing failure of the cubes in 1.5 to 3 minutes.

Statistical Variations in Concrete Strength

Concrete is a mixture of water, cement, aggregate, air and admixtures. Variations in the properties and proportions of these constituents, as well as variations in transporting, placing, compaction of the concrete, lead to differences in the strength of the finished concrete. In addition, discrepancies in the tests will lead to apparent differences in strength.

If sufficient number of tests (more than about 40) are available, the strengths will generally approximate a normal distribution. The normal distribution curve is symmetric about the mean value, $\bar{x}$, of the data. The dispersion of the data can be measured by the sample standard deviation, *s*, using Eq. (1).

$$s = \sqrt{\frac{\Sigma\left(x_i - \bar{x}\right)^2}{n-1}} \qquad (1)$$

where *n* is the number of samples.

The coefficient of variation, *v*, is obtained using Eq. (2).

$$v = \frac{s}{\bar{x}} \qquad (2)$$

This makes it possible to express the degree of dispersion on a fractional or percentage basis rather than on an absolute basis. If the data truly correspond to a normal distribution, their distribution can be predicted from the properties of such a curve. Figure 1 shows the values of the mean concrete strength, f_{cm}, required for various values of the coefficient of variation if no more than 1 test in 10 is to have strength less than 20.5 N/mm^2. As shown in this figure, as the coefficient of variation is reduced, the value of the mean strength, f_{cm}, required to satisfy this requirement can also be reduced.

Building Codes Definition of Compressive Strength

Based on the consideration that eventual failure in a structure occurs at the weakest location in a region of higher internal action effects, the concrete classes are classified on the basis of the characteristic compressive and not on the mean compressive strength. The relationship between the average and the characteristic values is given by:

$$f_{ck} = f_{cm} - 1.64s \qquad (3)$$

where,

s = standard deviation
f_{ck} = specified characteristic strength
f_{cm} = mean compressive strength

Equation (3) gives the lowest average strength required to obtain a probability of 0.05 (a probability of 5%) that any strength measurement falls below the characteristic strength.

Different concrete classes according to EC2 (Euro-Code) [4] and EBCS2 (Ethiopian Building Code Standard) [5] are given in Table 1. According to EC2, the numbers in the grade designation denote the specified characteristic cylinder and cube compression strength respectively. The designations according to EBCS2 are based on cube compressive strengths.

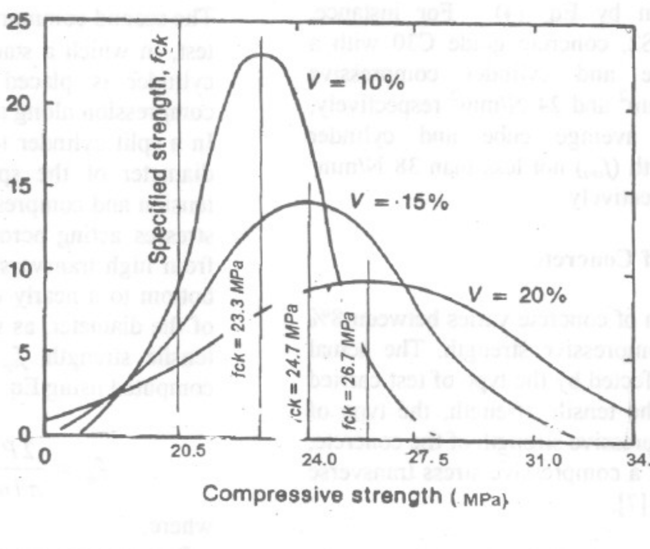

Figure 1 Normal frequency curves for coefficient of variations of 10, 15, and 20%. [3]

Table 1: Concrete Classes according EC2/EBCS2

Concrete Class Designation		Average Cylinder Strength f_{cm}(N/mm^2)	Characteristic Cylinder Compressive Strength f_{ck}(N/mm^2)		Average Tensile Strength f_{ctm}(N/mm^2)	
EC2	EBCS2	EC2	EC2	EBCS2	EC2	EBCS2
C12/15	C15	20	12	12	1.6	1.6
C16/20	C20	24	16	16	1.9	1.9
C20/25	C25	28	20	20	2.2	2.2
C25/30	C30	33	25	24	2.6	2.5
C30/37		38	30		2.9	
	C40			32		3.0
C35/45		43	35		3.2	
C40/50	C50	48	40	40	3.5	3.5
C45/55		53	45		3.8	
C50/60	C60	58	50	48	4.1	4.0

Based on the evaluations of the test results of many experiments, which have shown that, the standard deviation for all classes of concrete other than C12/15 is approximately 5 N/mm^2 [6]. Thus the Euro-code recommends the following relationship between the characteristic and the average strengths:

$$f_{ck} = f_{cm} - 8 \text{ N/mm}^2 \tag{4}$$

Thus for a specified minimum characteristic strength of concrete, which is identical to the class designation, both according to EC2 and EBCS2, the required mean strength must be greater or equal to the value given by Eq. (4). For instance, according to EBCS2, concrete grade C30 with a characteristic cube and cylinder compressive strength of 30 N/mm^2 and 24 N/mm^2 respectively, should have an average cube and cylinder compressive strength (f_{cm}) not less than 38 N/mm^2 and 32 N/mm^2 respectively.

Tensile Strength of Concrete

The tensile strength of concrete varies between 8% and 15% of its compressive strength. The actual value is strongly affected by the type of test carried out to determine the tensile strength, the type of aggregate, the compressive strength of the concrete, and the presence of a compressive stress transverse to the tensile stress [7].

Two types of tests are widely used to determine the tensile strength of concrete. The first of these is the modulus of rupture or flexural test in which a plain concrete beam, generally 150mm×150mm×750mm long, is loaded in flexure at the third points of a 600 mm span until it fails due to cracking on the tension face. Assuming the concrete is linearly elastic, the flexural tensile strength or modulus of rupture, f_r, is calculated from a modulus of rupture test using Eq. (5).

$$f_r = \frac{6M}{bh^2} \tag{5}$$

where,

M = moment
b = width of specimen
h = overall depth of specimen

The second common tensile test is the split cylinder test, in which a standard 150 mm × 300 mm test cylinder is placed on its side and loaded in compression along a diameter as shown in Fig. 2a. In a split cylinder test, an element on the vertical diameter of the specimen is stressed in biaxial tension and compression, as shown in Fig. 2c. The stresses acting across the vertical diameter range from high transverse compressions at the top and bottom to a nearly uniform tension across the rest of the diameter, as shown in Fig. 2d. The splitting tensile strength, f_{sp}, from a split cylinder test is computed using Eq. (6).

$$f_{sp} = \frac{2P}{\pi l d} \tag{6}$$

where,

P = maximum applied load in the test [kN]
l = length of specimen [mm]
d = diameter of specimen [mm]

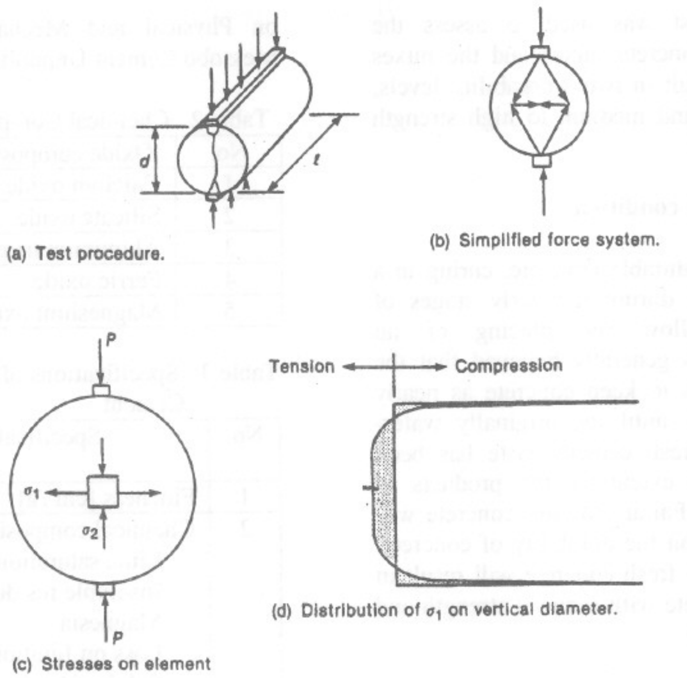

Figure 2 Split cylinder test

Various types of tension tests give different strengths. In general, the strength decreases as the volume of concrete that is highly stressed in tension is increased. It was reported that a third-point loaded modulus of rupture test on 150 mm-square beam gives a modulus of rupture strength f_r that averages 1.5 f_{sp}, while a 150 mm-square prism tested in pure tension gives a direct tensile strength that averages about 86% of f_{sp} [8].

Relationship between Compressive and Tensile Strengths of Concrete

Although the tensile strength of concrete increases with an increase in the compressive strength, the ratio of tensile strength to the compressive strength decreases as the compression strength increases. The splitting tensile strength can be related with the characteristic compressive strength using Eq. (7) [9]:

$$f_{sp} = 0.53\sqrt{f_{ck}} \tag{7}$$

Similarly, the mean modulus of rupture, f_r, can be expressed using the following equation [7]:

$$f_r = 0.69\sqrt{f_{ck}} \tag{8}$$

In the above equation f_{sp}, f_{ck} and f_r are all in N/mm^2.

TEST PARAMETERS

Aggregate size

Concrete contains about 70-75% aggregates and therefore, the strength and durability of concrete is greatly influenced by the properties of aggregates used in the concrete production. The selection of concrete making materials should maintain a balance between reasonable economy and requirement for placeability, strength, durability and appearance of the fresh and hardened concrete. In this research work three different sizes of coarse aggregate and one type of fine aggregate were used to produce concrete of different qualities.

Workability

Workability is a property of fresh concrete by which the consistency of the mix be such that the concrete can be transported, placed and finished sufficiently easily and without segregation. The water content of the mix, the amount of cement, particles shape and properties of aggregates mainly affect the workability of concrete.

Workability can be assessed using numerous test methods, among which, the slump test, compaction factor test, flow table test are widely used. In this study the slump test was used to assess the workability of the concrete mixes and the mixes were designed to result in two workability levels, i.e. low to medium and medium to high strength category were treated.

Curing duration and condition

In the production of durable concrete, curing in a suitable environment during the early stages of hardening must follow the placing of an appropriate mix. It is generally believed that the objective of curing is to keep concrete as nearly saturated as possible, until the originally water-filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement. Failure to cure concrete will have adverse effects on the durability of concrete, as loss of moisture in fresh concrete will result in poor quality of concrete with reduced strength and increased permeability.

Various concrete curing techniques are employed depending on the speed of construction, atmospheric conditions, available technology and other influencing factors. The techniques range from covering the fresh concrete with polythene sheets to the use of curing membranes. In this investigation, test specimens were cured in the following three conditions: a) cured in water until testing at the ages of 3, 7, 14 and 28 days, b) cured for only 3 days in water and stored in the laboratory, exposed to laboratory ambient conditions, until they are tested at the ages of 7, 14 and 28 days, and c) cured for only 7 days in water and stored in the laboratory, exposed to the laboratory ambient conditions, until they are tested at the age of 28 days.

MATERIAL PROPERTIES

Cement

The binding material used in the test program was ordinary Portland Cement produced by Messebo Cement Factory. According to the test results obtained from the Messebo Cement Factory testing laboratory, it conforms to the requirements of BS-12: 1989 [9]. The cement considered was stored in a dry place until it is used for concrete production. The chemical composition and specification of the Messebo Ordinary Portland Cement, as determined and reported by the Factory's laboratory, is summarized in Tables 2 and 3, respectively [Report on Physical and Mechanical Characteristics of Messobo Cement Unpublished report].

Table 2: Chemical Composition of Messebo OPC

No.	Oxide composition	Percentage
1	Calcium oxide	64.15
2	Silicate oxide	21.23
3	Aluminum trioxide	5.24
4	Ferric oxide	3.87
5	Magnesium oxide	1.72

Table 3: Specifications of Messebo Ordinary Portland Cement

No.	Specification	Test result
1	Fineness [cm^2/g]	3,000
2	Chemical composition (%):	
	Lime saturation factor	0.94
	Insoluble residue	0.50
	Magnesia	1.49
	Loss on Ignition	0.96
	Sulphuric anhydride (expressed in SO3)	2.50
3	Compressive strength (MPa) (average of 3 mortar cubes):	
	3 days	33.50
	7days	46.02
	28 days	56.97
4	Setting time(min.)	
	Initial	187
	Final	298
5	Soundness	1.86

Fine aggregate

The fine aggregate used for the investigation was obtained from the local source, Chancho, which is located about 150 km East of Addis Ababa. Sieve analysis tests were carried out on representative samples and it was initially found that the sand was coarser than required to be used for concrete production, according to ASTM C33-78 [10]. It was, therefore, required to sieve finer sand separately and blend with the coarser in order to meet the ASTM requirements. Accordingly, 75% passing sieve size 9.5mm and 25% passing 600 μm sieves are blended and the mean results are tabulated as shown in Table A1 in the Appendix.

The sand was also checked for silt content and it was found that it consists of a mean of 15.6% (15.8, 15.4, 15.4 and 15.8) for sand passing 9.5mm and 15.8% (17.6, 14.8, 14.3, and 16.6) for sand passing 4.75mm. It was then decided to wash the sand until the silt content was lowered to an allowable limit of less or equal to 6%. After washing the sand, the silt content was reduced to an average value of 2.71% (2.53 and 2.88).

Since it is not always possible to wash sands in construction sites, some tests were also carried out using sand containing a silt content higher than the recommended value (6%). Accordingly, four mixes (Mix A10, C10, A20 and C20) were prepared using a sand consisting of 8.55% silt, which is a mean value of 8.49, 8.83 and 8.33%. Mix A10 and C10 were prepared using a maximum aggregate size of 20 mm and were targeted to result in C-30 and C-25 concrete grades, respectively. Mix A20 and C20 were prepared using a maximum aggregate size of 37.5 mm and were targeted to result in C-30 and C-25 concrete grades, respectively.

Coarse aggregate

The coarse aggregate was obtained from the quarry in Addis Ababa and had three grades: 4-10mm; 20-40mm and 4.5-30mm. The aggregates were supplied relatively clean and had an absorption capacity less than 1%. The supplied aggregates were not of the required grading and could not be used to produce concrete without blending. It was then decide to follow ASTM Standard C33-78 and therefore the nominal size of graded aggregate 37.5 to 4.75mm (Grade B); 19.0 to 4.75mm (Grade A) and 12.5 to 4.75 mm (Grade C) were selected.

After the sieve analysis of the purchased aggregates, the results were reviewed and blended to satisfy the ASTM requirement.

Accordingly, 80% passing 19mm sieve opening and 20% 4-10mm aggregate were blended to obtain nominal size of 19.0 to 4.75 mm (Grade B); 90% passing 37.5 mm sieve opening and 10% 4-10mm were blended to obtain (Grade A) and 80% passing 12.5mm aggregate and 20% 4-10mm were blended to obtain (Grade C). The blended aggregates sieve analysis test results are shown in Tables A2, A3 and A4 in the Appendix.

MIX PROGRAM

Mix Design and the test Program

It is generally understood that mix Design is a process in which one determines the relative quantities of the ingredients of concrete prior to mixing to produce concrete of desired properties. Based on the DOE procedure, the quantities of the ingredient per cubic meter of concrete and per volume of trial Mix, 55 liters in the case considered, are established. The total number of specimens and considered parameters are shown in Table 4.

Moreover, four trial batches with maximum coarse aggregate passing 37.5 and 19 aimed at concrete grades of C25 and C30 using natural sand with higher silt content were prepared. To asses the resulting concrete grade that could be obtained

Table 4: Test parameters and required specimens

Concrete Grade	Max. coarse agg. types	workability level	No. of cubes in each batch [1]	Total no. of Cubes	Total no. of cylinders[2]
C45	3	2	25	150	18
C40	3	2	25	150	18
C35	3	2	25	150	18
C30	3	2	25	150	18
C25	3	2	25	150	18
C5	3	1	15	45	

[1] The number of cubes for each batch consists of:
- wet cured all the way tested at the age of 3,7,14 and 28 days with each 3, yields 3×4=12.
- three days wet cured tested at 7,14 and 28 days of age, 3 in each becomes 3×3=9.
- seven days wet cured, tested at age of 28 days, one size 150 mm and the other three 100 mm in size which yields 4 test specimens.

[2] For each trial batch three cylinders for tensile splitting test which Sum up to 3×3×2=18 cylinders.

when using cement content of 275 kg and 300 kg per meter cube of concrete two mixes labeled as G1 & G2 and consisting of 28 cubes and 4 cylinders, were carried out. This brings the total number of trial batches to 43, with 939 cubes and 90 cylinders. This does not include those mixes prepared and tested outside the University.

Apparatus

In this research work, the following laboratory apparatus were used: rotating pan mixer, slump mould, cube and cylinder moulds, vibrating table, curing tank made of concrete, balance and Universal Testing Machine which has a capacity of testing 1000 Ton in tension and 2000 Ton in compression.

Test Specimen Preparation

Mixing of the constituent materials was carried at room temperature of 22±3°C and relative humidity of 32% to 40%. The size of the batch for each mix was about 70% of the rated capacity of the mixer to avoid incomplete mixing and spillage. Before using the mixer, it was cleaned to ensure that no fresh concrete remains from previous batch. Moreover, all necessary measures were taken to ensure that no free water on the pan mixer was left and whenever it is dry it was wiped using a damp cloth.

For each trial mix, two sets of mixes with the same proportions were prepared on a given date of mixing. In each mix, dry mixing was carried out for about one minute and water is added within the following 30 to 60 seconds. Mixing continued for 2 minutes after all constituents of concrete were added.

When mixing was completed, the workability of each mix was measured using slump test following standard procedure. The moulds were then placed on the vibrating table and the fresh concrete was deposited in layers of approximately 1/3 of the respective mould content whereby each layer was compacted using the vibrator following standard procedure. For all cases other than those indicated by a remark in Table 5, 22 - 150mm cubes 3 - 100 mm cubes and 3 cylinder specimens were prepared from each trial mix to determine a 3,7,14 and 28 days age strengths and tensile splitting strengths.

The specimens were kept in the moulds for 24 hours after which they were labeled and placed in a tank filled with water for curing purpose and kept wet for two more days. Those specimens to be kept air-dry before the age of testing were withdrawn and placed at an open place in the laboratory. The rest were kept in the curing tank and wet cured until the date of testing.

Before testing, the specimens were removed from curing water tank or those which were air dry were immersed in water for about 5 minutes and then all were weighed, dimensions checked and recorded for density and failure stress calculation.

TESTING THE CONCRETE

Cube Compression

Compressive strength is the main measure to prescribe the quality of concrete. Before each test, the testing machine bearing surfaces were wiped clean and any loose grit or other extraneous materials were also removed from the surface of the cube, which may be in contact with the platens. The cube specimen was centrally placed on the lower platen and it was checked to ensure that the load will be applied to two opposite faces of the cube. The load was continuously applied at a nominal rate within a range of 0.2 to 0.6 MPa per sec, until no greater load can be sustained. The maximum load applied to the cube was recorded to obtain the failure stress. The mean results obtained and the calculated failure stresses at the ages of 3,7,14 and 28 days as either wet cured or air dried are provided in Table 6. The majority (over 80%) of the test results indicate that the target concrete compressive strength was achieved and consistent with the Code's recommendations.

Tensile Splitting

All three-cylinder specimens from each mix were wet cured for 28 days. Tempered hard board pads (dimensions about 330 mm by 25 mm) are placed on the bearing surfaces of the cylinder specimens and loaded symmetrically and continuously until failure at the rate of 0.02- 0.04 MPa per second. The summary of mean results is given in Table 6 and the tensile strength of the concrete specimens is generally between 6-10% of the compressive strength values.

Table 5: Concrete mix design proportions for different classes of concrete

No	Mix Type	Max. size of coarse Agg. passing sieve [mm]	Target Concrete Strength [Mpa]	Mix Composition (kg per m^3 of concrete)				w/c ratio	Slump (mm)
				Cement	Coarse agg.	Fine agg.	Water		
1	A1	37.5	$30 + \sigma$	327.30	1342.90	567.80	180.00	0.55	15
2	B1	37.5	$30 + \sigma$	327.30	1302.00	558.00	212.75	0.65	35
3	C1	37.5	$25 + \sigma$	342.10	1248.10	614.80	195.00	0.57	52
4	C2	37.5	$25 + \sigma$	281.00	1430.10	528.90	160.00	0.57	8
5	D1	37.5	$40 + \sigma$	433.30	1222.50	549.20	195.00	0.45	24
6	D2	37.5	$40 + \sigma$	355.60	1413.30	471.10	160.00	0.45	5
7	E1	37.5	$35 + \sigma$	397.60	1184.92	624.12	195.00	0.49	32
8	E2	37.5	$35 + \sigma$	328.57	1358.06	525.37	161.00	0.49	2
9	F1	37.5	$45 + \sigma$	488.10	1143.62	563.28	205.00	0.42	39
10	F2	37.5	$45 + \sigma$	452.40	1230.32	527.28	190.00	0.42	17
11	G2	37.5		275.00	1303.00	641.90	180.00	0.65	10
12	G1	37.5		300.00	1286.40	633.60	180.00	0.60	10
13	20A1	19.5	$30 + \sigma$	370.00	1095.00	730.00	205.00	0.55	10
14	20A2	19.5	$30 + \sigma$	340.00	1271.60	598.40	190.00	0.55	15
15	C3	19.5	$25 + \sigma$	359.60	1137.90	697.50	205.00	0.57	43
16	C4	19.5	$25 + \sigma$	298.20	1313.60	618.10	170.00	0.57	3
17	D3	19.5	$40 + \sigma$	455.60	1113.20	626.20	205.00	0.45	45
18	D4	19.5	$40 + \sigma$	377.80	1315.10	537.10	170.00	0.45	6
19	E3	19.5	$35 + \sigma$	419.00	1118.90	657.10	205.00	0.49	30
20	E4	19.5	$35 + \sigma$	347.00	1318.10	564.90	170.00	0.49	7
21	F3	19.5	$45 + \sigma$	488.00	1143.70	563.30	205.00	0.42	30
22	F4	19.5	$45 + \sigma$	452.40	1230.30	527.30	190.00	0.42	14
23	D1R	37.5	$40 + \sigma$	434	1169	602	195	0.45	30
24	D2R	37.5	$40 + \sigma$	400	1274	546	180	0.45	6
25	B1R	37.5	$30 + \sigma$	382.4	1221.4	601.5	195	0.51	48
26	H1-38	37.5	$5 + \sigma$	180	1440.6	617.4	162	0.90	8
27	A3	12.5	$30 + \sigma$	380	1051.5	761.5	207	0.54	25
28	A4	12.5	$30 + \sigma$	400	975.7	798.3	226	0.54	60
29	C5	12.5	$25 + \sigma$	397	1013	764	226	0.57	64
30	C6	12.5	$25 + \sigma$	363	1098	732	207	0.57	23
31	E5	12.5	$35 + \sigma$	460	977	737	226	0.49	47
32	E6	12.5	$35 + \sigma$	422	1063	708	207	0.49	20
33	D5	12.5	$40 + \sigma$	503	969	702	226	0.45	78
34	D6	12.5	$40 + \sigma$	460	1058	675	207	0.45	26
35	F5	12.5	$45 + \sigma$	538	948.4	686.7	226.25	0.42	45
36	F6	12.5	$45 + \sigma$	494.05	1070.0	628.4	207.5	0.42	15
37	H2-20	19.5	$5 + \sigma$	150	1233	822	195	1.30	10
38	H2-12.5	12.5	$5 + \sigma$	150	1183	857	210	1.40	14
39	H2-38	37.5	$5 + \sigma$	150	1237	825	188	1.25	12

Table 6: Cube Compression and splitting tensile strength test results for mixes specified in Table 5

No.	Mix Type	Target Concrete Strength [MPa]	Average Compressive Strength [MPa]								Splitting Tensile Strength [MPa]
			3 days	7 days		14 days		28 days			
			3 days Cured	3 days Cured	7 days Cured	3 days Cured	14 days Cured	3 days Cured	7 days Cured	28 days Cured	
1	A1	30 + σ	16.50	27.30	23.30	30.86	31.63	35.62	39.53	34.90	2.88
2	B1	30 + σ	11.90	17.34	18.62	23.92	22.37	26.37	28.48	27.35	2.73
3	C1	25 + σ	17.26	24.27	22.73	30.58	29.76	37.32	35.41	36.52	2.64
4	C2	25 + σ	18.25	26.97	24.31	30.97	29.42	34.73	36.07	36.27	2.89
5	D1	40 + σ	24.61	28.60	31.17	37.25	37.79	33.24	46.75	38.88	2.99
6	D2	40 + σ	21.82	36.93	33.24	39.11	35.08	39.66	48.00	40.85	3.56
7	E1	35 + σ	20.41	32.21	29.51	36.46	33.71	35.23	44.54	42.28	2.59
8	E2	35 + σ	26.66	36.93	35.14	42.90	37.99	48.40	51.19	45.83	3.39
9	F1	45 + σ	27.98	39.40	37.95	48.13	44.50	53.21	54.08	51.44	3.28
10	F2	45 + σ	27.32	34.41	40.68	43.56	44.06	54.59	55.74	56.18	3.54
11	G2		-----	20.08	20.08	-----	-----	33.96	34.00	31.41	3.04
12	G1		-----	23.30	19.75	-----	-----	31.92	34.36	25.79	2.83
13	20A1	30 + σ	19.80	30.70	25.60	35.08	34.77	40.21	42.16	39.90	3.06
14	20A2	30 + σ	18.61	26.26	25.73	35.99	32.99	39.57	40.37	38.96	3.36
15	C3	25 + σ	17.63	25.56	23.55	33.36	28.56	36.20	38.68	35.52	2.59
16	C4	25 + σ	18.90	29.47	28.61	35.75	32.62	39.50	41.06	38.98	3.06
17	D3	40 + σ	22.65	35.91	34.26	42.30	42.33	48.29	49.28	47.70	3.55
18	D4	40 + σ	24.88	37.12	31.02	44.56	41.07	49.12	52.26	50.37	3.47
19	E3	35 + σ	20.58	33.71	32.05	41.03	37.89	43.86	46.47	46.95	3.07
20	E4	35 + σ	21.84	36.59	34.28	36.61	35.34	44.30	46.53	46.35	2.65
21	F3	45 + σ	25.95	36.54	28.44	45.48	37.67	53.38	54.83	52.62	3.56
22	F4	45 + σ	24.15	39.93	35.12	36.62	40.44	44.38	53.26	50.91	3.30
23	D1R	40 + σ	-----	34.18	32.06	-----	36.78	46.92	-----	49.05	3.36
24	D2R	40 + σ	-----	35.51	33.83	-----	39.79	45.42	-----	46.79	3.63
25	B1R	30 + σ	19.01	-----	28.81	-----	34.57	-----	-----	42.51	3.36
26	H1-38	5 + σ	8.43	-----	12.52	-----	15.62	-----	-----	18.16	-----
27	A3	30 + σ	15.41	24.48	21.94	29.33	28.65	33.07	34.83	34.48	2.77
28	A4	30 + σ	14.97	23.41	22.39	30.48	27.64	33.43	35.00	35.00	2.95
29	C5	25+ σ	15.08	22.20	22.51	29.55	23.78	34.30	35.50	35.61	2.82
30	C6	25 + σ	15.51	24.65	23.35	30.37	31.96	33.69	35.00	35.04	2.82
31	E5	35 + σ	19.06	30.45	28.17	35.34	35.70	36.76	42.62	40.82	2.81
32	E6	35 + σ	17.74	29.96	30.35	37.78	36.86	39.88	40.61	41.08	2.78
33	D5	40 + σ	19.19	28.77	25.73	32.18	31.75	43.39	46.72	45.54	3.69
34	D6	40+ σ	23.65	34.86	33.13	40.81	39.29	42.48	47.12	43.63	4.01
35	F5	45 + σ	20.18	34.67	32.26	42.56	42.23	45.91	51.34	52.13	3.98
36	F6	45 + σ	25.29	36.80	36.18	40.22	37.69	46.14	51.72	51.44	4.08
37	H2-20	5 + σ	4.69	8.12	7.25	-----	-----	10.70	-----	10.32	-----
38	H2-12.5	5 + σ	3.97	6.49	5.18	-----	-----	8.94	-----	8.90	-----
39	H2-38	5 + σ	4.7	6.76	6.56	-----	-----	10.87	-----	10.8	-----

Other Comparative Tests

Independent testing of similar mixes

In order to compare and confirm the results obtained in this test series, few trial mixes were selected and tested in a different laboratory set up by independent technicians. To this effect, the Mix proportions labeled as E1, C1, D1R and A1 were repeated using the Laboratory of the Ethiopian Standard Authority (ESA). The Authority's technicians conducted the tests, under close supervision of the research team and an engineer from the Messebo Cement Factory. The Mixes E1,C1, D1R and A1 were relabeled as A, B,C and D, and the mix proportions and test results obtained are summarized in Tables 7 and 8, respectively.

Table 7: Mix proportions for comparative study (ESA)

No	Mix label	Target strength	Mix components kg/m^3 Concrete: Cement	Coarse Agg.	Fine Agg	Free Water	Water cement ratio	Slump [mm]	Previous Mix label
1	A	C35	398	1184.8	624.4	195$^+$	0.49	13	E1
2	B	C25	331.2++	1247.6	621.6	195$^+$	0.57	24	C1
3	C	C40	433.2	1222.4	549.2	195$^+$	0.45	15	D1R
4	D	C30	327.6	1325.6	568.0	180$^+$	0.55	12	A1

\+ since the coarse aggregate at the time of testing was air dry its moisture content was checked to bring it to SSD condition level. 1% extra water is added above the free water shown in this Table

++ the cement content due to technical reason is reduced by 3% from the original Mix label C1.

Table 8: Mean cube compressive strength results of the concrete mixes shown in Table 7

No.	Mix label Eth.St.	Mean cube compressive strength (MPa): 7 days ESA	7 days AAU	28 days ESA	28 days AAU	% increase: ESA to AAU lab. 7 days	28 days
1	A	32.29	29.51	48.30	42.28	+9.4	+14.2
2	B	22.88	22.73	38.23	36.52	+0.7	+4.7
3	C	35.37	32.06	49.07	49.05	+10.3	0.0
4	D	26.50	23.30	41.07	34.90	+13.7	+17.7

Despite a 1% addition of water, a lower slump and a higher compressive strength test results were obtained consistently from the Laboratory of the Ethiopian Standards Authority than those obtained from Addis Ababa University laboratory. These may be attributed to the following: i) the aggregates may have lost surface moisture during transportation and thus resulted in lower workability. To compensate for this, extra vibration time (5 to 10 seconds) were allowed in the laboratory of the Ethiopian standards to remove the entrapped air; ii) the rate of loading applied in the Addis Ababa University laboratory is within the standard range while a constant rate of loading is employed in the Ethiopian Standards Laboratory and iii) human factor, as different persons have conducted the tests at different time. In all cases, however, the test results are all consistent and inline with the values obtained in the Addis Ababa University laboratory indicating the reliability of the test results.

Sand with Higher Silt Content

As discussed in above, the fine aggregate (sand) used was washed to reduce its clay content. However, there are situations encountered at site where it may not be possible to achieve the specified lower percentage of silt content. To check the effect of silt on the strength of concrete, four mixes were prepared using 37.5 mm and 19mm coarse aggregate sizes and sand with silt content in the range of 8 to 9%. The mix proportions and obtained test results are summarized in Tables 9 and 10, respectively.

Table 9: Mix design with higher silt content

No.	Mix label	Target strength	Mix components kg per m^3 of concrete: Cement	Coarse Aggregate	Fine aggregate	Free Water	Slump [mm]	Previous Mix label
1	C10	C25+	359.6	1137.9	697.5	205	16	C3
2	A10	C30+	370.0	1095.0	730.0	205	12	20A1
3	C20	C25+	342.1	1248.1	614.8	195	10	C1
4	A20	C30+	327.3	1325.0	568.3	180	4	A1

Table 10: Mean cube compressive strength result with higher silt content

No.	Mix Label	Average Cube compressive Strength [MPa]				
			7 days age		28 days age	
		3 days	3 days wet	7 days wet	3 days wet	28 days wet
1	C10	13.31	22.34 (25.56)	21.50 (23.55)	29.80 (36.20)	30.91 (35.52)
2	A10	15.41	23.14 (30.70)	21.95 (25.60)	31.54 (40.21)	33.31 (39.90)
3	C20	18.90	28.40 (24.27)	25.74 (22.73)	31.40 (37.32)	35.57 (36.52)
4	A20	19.95	28.99 (27.30)	26.87 (23.30)	36.24 (35.62)	39.62 (34.90)

The values in the bracket are compressive strengths obtained from similar mixes containing lesser silt content. The test results prove that increased silt content reduces the compressive strength of concrete especially for lower aggregate sizes.

ANALYSIS OF RESULTS

Water/Cement Ratio

The water/cement ratio (w/c) is the most critical factor, which affects the strength of concrete. The effect of water/cement ratio on compressive strength at the age of 28 days is summarized in Fig.3. From the obtained test results, it is easier to observe the trend that compressive strength of concrete decreases with increase in water cement ratio due to the fact that the quantity of water required for the chemical reactions is very small compared with that required for workability, and the excess water evaporates resulting in an increased porosity of paste.

Further attempts have been made to obtain suitable functional relationship to describe the effect of water/cement ratio (w/c) on compressive strength using equations similar to Abram's law. In order to obtain suitable relations only the 28 days wet cured concrete specimens produced using maximum aggregate size passing sieve 37.5, 19, 12.5 mm were considered and the values are summarized in Table 11.

It is clear to observe that the relation between compressive strength and water cement ratio is non-linear and thus require exponential expression. The relationships are expressed using Eq. 9. The regression equations for the maximum coarse aggregate passing sieve 37.5, 19 and 12.5 mm, have a correlation coefficient (r^2) of 0.96, 0.99 and 0.97 respectively.

$$f_{cm,37.5} = 16.8 \times w/c^{-1.33}; \quad r^2 = 0.936 \qquad (9a)$$

$$f_{cm,19} = 20.91 \times w/c^{-1.07}; \quad r^2 = 0.936 \qquad (9b)$$

$$f_{cm,12.5} = 16.37 \times w/c^{-1.29}; \quad r^2 = 0.94 \qquad (9c)$$

The actual test result data were compared with those predicted using Eq. 9a to c and are given in Table 12.

Table 11: Summary of mean compressive strength, f_{cm} against w/c ratio*

w/c	0.42	0.42[1]	045	0.45[1]	0.49	0.49[1]	0.55	0.55[1]	0.57	0.57[1]
$f_{cm,37.5}$	51.44	56.18	49.05	46.79	42.28	45.83	34.90	-	36.52	36.27
$f_{cm,19}$	52.62	50.91	47.70	50.37	46.95	46.35	39.90	38.96	35.52	38.98
$f_{cm,12.5}$	52.13	51.44	45.54	43.63	41.08	40.82	34.48*	35.00*	35.61	35.04

* a water cement ratio of 0.54 are used for these tests.

[1] concrete mixes of medium-higher workability while others are low-medium workability concrete mixes.

Table 12: Comparison of actual and predicted comp. strength test values for the three aggregate sizes.

w/c	0.42	0.45	0.49	0.55	0.57	Remark
$f_{cm,\,test}$	53.81	47.92	44.06	34.90	36.40	Test result
$f_{cm,37.5}$	53.30	48.59	43.39	37.21	35.48	computed using Eq. 9a
$f_{cm,\,test}$	51.77	49.04	46.65	39.43	37.48	Test result
$f_{cm,19}$	52.90	49.14	44.86	39.64	38.16	computed using Eq. 9b
$f_{cm,\,test}$	51.79	44.59	40.95	34.74	35.33	Test result
$f_{cm,12.5}$	50.13	45.86	41.09	35.39	33.81	computed using Eq. 9c

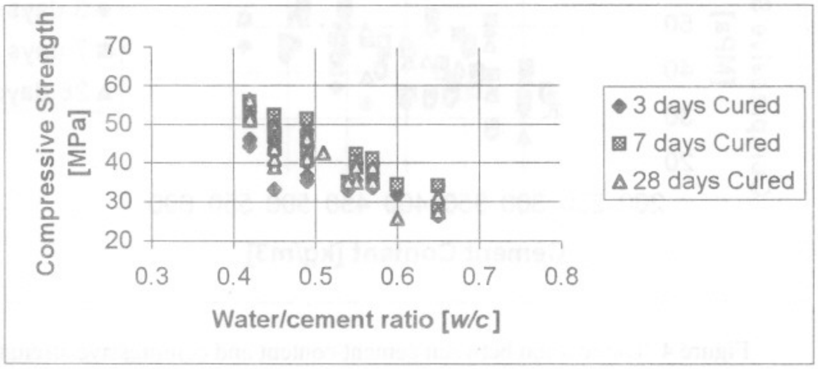

Figure 3 Effect of w/c ratio on compressive strength

Workability

Among the factors influencing workability are water cement ratio, type and grading of aggregate, ratio of fine to total aggregate and use of admixture. Since, grading of aggregate is the same in all cases and no admixture has been used, the effect of water cement ratio and ratio of fine to total aggregate expressed as percentage has been used to check the workability of the Mix.

Relation between 7 days and 28 days compressive strength

Regression equations, relating the 28 day mean compressive strength to the 7 day mean compressive strength, were developed for concrete specimens cured for 7 and 28 days and are given in Eq. (10). The relations have reasonable correlation coefficients (r^2).

$$f_{c,28} = 1.10 f_{c,7} + 10.27\ r^2 = 0.938 \quad (10a)$$

when maximum aggregate passing sieve 37.5 mm

$$f_{c,28} = 1.075 f_{c,7} + 12.72;\ r^2 = 0.54 \quad (10b)$$

when maximum aggregate passing sieve 19 mm

$$f_{c,28} = 1.33 f_{c,7} + 5.343;\ r^2 = 0.77 \quad (10c)$$

when maximum aggregate passing sieve 12.5 mm,

where $f_{c,28}$ and $f_{c,7}$ are in MPa and these relations can be applied for concrete grades between C-25 and C-45. In general, the test results indicate that about 70% of the 28 day compressive strengths were obtained at the age of 7 days, which is important especially for construction planning and scheduling, such as form-work striping time and manpower allocation.

Minimum Cement Content

Cement is a binding material and when mixed with graded aggregate produces concrete of desired strength. Since it is an expensive ingredient, it should be proportioned to obtain the desired strength with minimum amount. Normally it is chosen on the basis of two considerations. Primarily it should ensure sufficient alkalinity (pH-value) to provide a passive environment against corrosion to reinforcement and in the second place, it should result in sufficient volume of cement paste to fill the voids in the compacted aggregate.

The cement content per cubic meter of concrete used in the mix program is plotted against the compressive strength test result and are shown in Figure 4. It is observed from the figure that the general trend is the required cement content increased proportionately with desired increased compressive strength.

The contribution of harmless and acceptable percentage of silt content in concrete produced using large aggregate sizes should be, however, studied further since it may have a pore filling effect and might contribute to slight increase in strength properties.

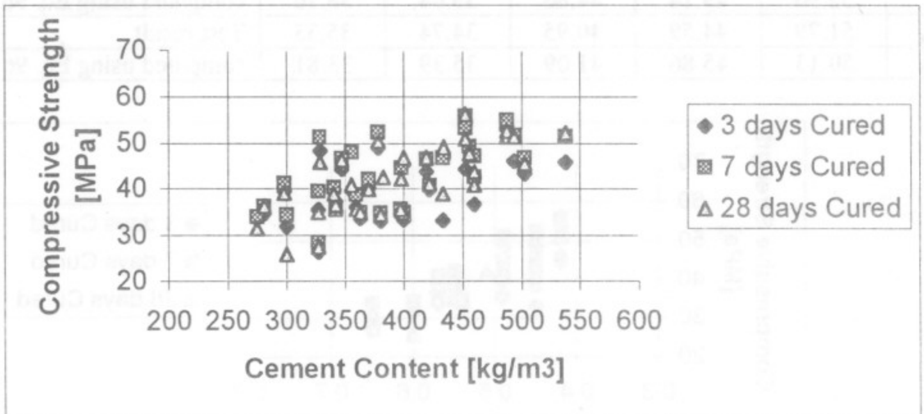

Figure 4 The relation between cement content and compressive strength

Splitting tensile Strength

Cylinder splitting tests were used to determine the tensile strength of concrete. Usually codes of practices provide empirical expressions to approximate tensile strengths from compressive strength values. Based on the test results, attempts have been made to develop relations between f_{sp} and f_{cm} and f_{ctm} and f_{cm}. However, the relations have lower correlation coefficients indicating that they are sensitive to variations in concrete classes/grades and thus not discussed further.

Effects of silt content on the compressive strength of concrete

The test results indicate that reduction of silt content (from ~9% to ~3%) improves workability and has the advantage of increasing the compressive strength (by up to 28 %). This is attributed by the fact that silts decrease the bond between aggregate and cement paste and absorbs the share of water required for cement hydration and thus results in lower compressive strength and workability. One can imagine the effect of higher silt content (15-25% which is usually the case in very silty sands) in compressive strength reduction of concrete structural elements.

CONCLUSIONS

Based on the intensive laboratory investigations, the following conclusions are drawn:

1. The suitability of the Messebo Ordinary Portland Cement (OPC) for structural use of concrete has been verified through tests and it has been found that the product can be utilized to obtain concrete strength grades up to C 45.
2. It has been found generally that the concrete specimens produced using Messebo OPC achieved about 70% of the 28 days compressive strengths at the 7^{th} day and thus helps in reducing form-work stripping time. The higher early strength development has a positive effect on subsequent construction activities.
3. Values of cement and aggregate content per 100 kg of cement corresponding to desired workability have been established. Accordingly, cement content in kg per m^3 of concrete for different classes/grades of concrete are provided in Table 13 and proportions of total aggregate and corresponding percentage of fine aggregate per 100 kg of cement are provided in Table 14.

4. Excessive silt content than specified by the code (6%) reduces the compressive strength of hardened concrete and workability of fresh concrete.

5. The recommendations given on Tables 13 and 14 can only be used in practice provided:

   a) proper compaction of the concrete is made,

   b) proper curing method is employed for at least 7 days to ensure sufficient hydration of the cement,

   c) the coarse aggregate used is basaltic crushed stone or its equivalent and

   d) the fine aggregate is free from impurities with silt content not exceeding 6%.

6. The relations established in Eqs. (9) and (10) can serve as a rule of thump to approximate desired parameters.

Table 13: Cement content required in kg per m^3 of concrete

Concrete Grade	Maximum Aggregate Size: 37.5 mm, Low Slump[1]	37.5 mm, Medium Slump[2]	19.5 mm, Low Slump[1]	19.5 mm, Medium Slump[2]	12.5 mm, Low Slump[1]	12.5 mm, Medium Slump[2]	*w/c* ratio
C 5	150		150		150		1.30
C 25	280	320	300	350	350	400	0.57
C 30	300	350	340	370	380	420	0.53
C 35	360	400	360	400	430	470	0.48
C 40	400	440	400	450	460	500	0.44
C 45	450	490	460	500	510	550	0.40

Low slump[1] = 0-20 mm
Medium slump[2] = 20-80 mm

Table 14: Total Aggregate in kg and percentage of fine to total aggregate per 100 kg of cement

Concrete Grade	Max. agg. Size (mm) / Limit on slump (mm)	37.5: 0-20	37.5: 20-80	19: 0-20	19: 20-80	12.5: 0-20	12.5: 20-80
C 5	Total Agg. (kg)	1380	1380	1370	1370	1360	1360
	fin/tot. agg. (%)	40	45	40	45	40	50
C 25	Total Agg. (kg)	700	600	640	530	520	440
	fin/tot. agg. (%)	30	35	35	40	42	45
C 30	Total Agg. (kg)	650	540	550	500	470	420
	fin/tot. agg. (%)	30	35	35	40	42	45
C 35	Total Agg. (kg)	520	450	520	450	410	360
	fin/tot. agg. (%)	28	33	30	35	38	42
C 40	Total Agg. (kg)	460	400	460	390	370	330
	fin/tot. agg. (%)	28	33	28	33	37	42
C 45	Total Agg. (kg)	400	350	380	350	330	300
	fin/tot. agg. (%)	25	30	25	30	33	40

RECOMMENDATIONS

a) Before concrete mix preparation, attention should be given to critically assess the silt content, density, absorption capacity and grading of aggregates.

b) Curing is a very important factor in producing good quality of concrete and a 7 days of curing must be the absolute minimum curing duration for structural members.

c) Design engineers should give more attention to concrete production and should try to help contractors in getting improved quality of concrete.

d) The additions of concrete additives, such as plasticizers, should be encouraged to improve the property of concrete.

e) Business of standard aggregate supplying and ready mix concrete production and supply should be encouraged for various reasons since it improves quality, reduce storage requirements, and a lesser work force (laborers) is required on site.

f) Further research work is proposed to establish mix design proportions in order to produce better quality and higher grade of concrete with other cement and aggregate types.

ACKNOWLEDGEMENTS

The authors are indebted to Messobo Cement Factory for the financial support in the research work and for supplying the Messobo OPC free of charge for the purpose of the research work. The authors also appreciate the keen interest and participation of Ato Mekonnen Fisseha and Ato Hagos Seyoum, who were senior engineers during the construction of Messebo Cement Factory, in the research work. Dr. Fisseha Woldu is acknowledged for his interest in the subject and for his administrative support in facilitating the research project. Finally the laboratory services offered by the Ethiopian Standards Authority is also appreciated.

REFERENCES

[1] **ACI Standards** for concrete mix design: 211.1-77 and 211.3.75.

[2] **DOE Method** of Mix Design, Department of Environment, UK.

[3] **ACI Committee 214**, Recommended Practice for Evaluation of strength Test Results of Concrete, (ACI 214-77), 1977.

[4] EC2 - Eurocode 2:

[5] Ethiopian Building Code Standard, **EBCS2, 1995**.

[6] **Koenig G. and Tue N.,** Grundlagen des Stahlbetonbaus, Teubner Studienbucher Bauwesen, 1998.

[7] **Raphael J.M.**, Tensile strength of Concrete, ACI Journal, 1984.

[8] **Neville A.M.**, Properties of Concrete, 3rd ed., Longmann Scientific & Technical Series, 1986.

[9] **BS-12**, 1989 Ordinary and Rapid hardening Portland cement.

[10] **ASTM C33-78**, Specifications for concrete aggregates.

[11] **Klieger P.**, Effect of Mixing and Curing Temperatures on Concrete Strength, ACI Journal Proceedings, Vol. 54. No. 12, June 1958.

[12] **Troxell G.E., Davis H.E., and Kelly J.W.**, Composition and Properties of Concrete, 2d ed., McGraw-Hill, New York, 1968.

[13] **MacGregor J.G.**, Reinforced Concrete, Mechanics & Design, Prentice hall, Engelwood cliffs, 3rd Ed., 1997.

[14] **Gonnerman H. F. and Lerch W.**, Changes in Characteristics of Portland Cement as Exhibited by Laboratory Tests over the Period 1904 to 1950, ASTM Special Publication 127, ASTM, Philadelphia, 1951.

[15] **Schneider, K.-J.,** Stahlbeton und Spannbeton nach EC2, 12th ed., Werner Verlag, 1996.

[16] **Thomas, T. C. Hsu, P. O. Slate, G. H. Sturman and George Winter**, Micro-cracking of Plain Concrete and the Shape of the Sress-Strain Curve, ACI Journal, 1963.

[17] **Newman K. and Newman J. B.**, Failure Theories and Design Criteria for Plain Concrete, Solid Mechanics and Engineering Design, 1972.

[18] **Richart F.E., Brandtzaeg A. and Brown R. L.**, A study of the Failure of concrete under combined Compressive Stresses, University of Illinois Engineering Experiment Station, 1928.

Table A1: Sieve analysis of blended sand, 75% passing 9.75mm and 25% passing 600 μm.

a) Sample 1

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained sand [g]	Mass of Retained Sand [g]	Percentage Retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
9.5	596.9	596.9	0	0	0	100	100
4.75	578.2	594.6	16.4	3.28	3.3	96.7	95-100
2.36	531.7	575.6	43.9	8.78	12.1	87.9	80-100
1.18	538.3	613.2	74.9	14.97	27.0	73.0	50-85
0.6	518.6	630.1	111.5	22.29	49.3	50.7	25-60
0.3	488.1	651.8	163.7	32.73	82.0	18.0	10-30
0.15	482	557.9	75.9	15.17	97.2	2.78	2-10
Pan	420.1	434	13.9	2.78	100	0	
		Σ =	500.2				

b) Sample 2

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained sand [g]	Mass of Retained Sand [g]	Percentage Retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
9.5	596.9	596.9	0	0	0	100	100
4.75	578.2	591.7	13.5	2.70	2.7	97.3	95-100
2.36	531.7	574.2	42.5	8.50	11.2	88.8	80-100
1.18	538.3	614.4	76.1	15.22	26.4	73.6	50-85
0.6	518.6	631.7	113.1	22.62	49.0	51.0	25-60
0.3	488.1	653.1	165	32.99	82.0	18.0	10-30
0.15	482	557.3	75.3	15.06	97.1	2.92	2-10
Pan	420.1	434.7	14.6	2.92	100	0	

The blended aggregates grading satisfy ASTM Standard C33-78 and used for subsequent concrete production.

Table A2 Sieve analysis of blended aggregate, 80% passing 19mm sieve opening and 20% [4-10]mm.

a) Sample 1

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage Retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
19	1427.1	1427.1	0	0	0	100	90-100
12.5	1193.5	1989.8	796.3	40.9	40.9	59.12	-
9.5	1194.9	1634.9	440	22.6	63.5	36.53	20-55
4.75	1202	1904.3	702.3	36.1	99.5	0.48	0-10
Pan	1064.5	1073.9	9.4	0.48	100.0	0	-
			Σ = 1948				

b) Sample 2

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage retained	Percentage Coarser	Percentage Passing	ASTM requirement
19	1427.1	1427.1	0	0	0	100	90-100
12.5	1193.5	2003.4	809.9	39.88	39.9	60.12	-
9.5	1194.9	1669.8	474.9	23.39	63.3	36.73	20-55
4.75	1202	1925.4	723.4	35.62	98.9	1.10	0-10
Pan	1064.5	1086.9	22.4	1.10	100.0	0.0	-
			Σ = 2030.6				

The blended aggregates satisfy ASTM standard C33-78 for 19 to 4.75mm aggregates and used for subsequent concrete production.

Table A3: Sieve analysis of blended aggregate, 90% passing 37.5mm sieve opening and 10% [4-10]mm.

a) Sample 1

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
37.5	1088.3	1088.3	0.0	0.0	0.0	100.0	95-100
25.0	1190.8	1212.7	21.9	0.7	0.7	99.3	-
19.0	1427.0	2312.3	885.3	29.6	30.3	69.7	35-70
12.5	1193.6	2408.8	1215.2	40.6	70.9	29.1	-
9.5	1195.1	1556.4	361.3	12.1	83.0	17.0	10-30
4.75	1202.8	1685.8	483.0	16.1	99.1	0.9	0-5
Pan	1064.6	1091.9	27.3	0.9	100.0	0.0	-
			Σ = 2994.0				

b) Sample 2

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
37.5	1088.3	1088.3	0.0	0.0	0.0	100.0	95-100
25.0	1190.8	1209.7	18.9	0.6	0.6	99.4	-
19.0	1427.0	2144.8	717.8	24.0	24.6	75.4	35-70
12.5	1193.6	2629.7	1436.1	47.9	72.5	27.5	-
9.5	1195.1	1559.5	364.4	12.2	84.7	15.3	10-30
4.75	1202.8	1644.1	441.3	14.7	99.4	0.6	0-5
Pan	1064.6	1081.5	16.9	0.6	100.0	0.0	-

$\sum$ = 2995.4

The blended aggregates satisfy ASTM standard C33-78 for 37.5 to 4.75mm aggregates and used for subsequent concrete production.

Table A4: Sieve analysis of blended aggregate, 80% passing 12.5mm sieve opening and 20% [4-10]mm.

a) Sample 1

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage Retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
12.5	586.0	586.0	0	0	0	100	90-100
9.5	597.0	1278.9	681.9	34.08	34.08	65.92	40-70
4.75	578.3	1792.0	1213.7	60.65	94.73	5.27	0-15
pan	425.5	530.4	105.4	5.28	100	-	

$\sum$ = 2001.0

b) Sample 2

Sieve opening [mm]	Mass of sieve [g]	Mass of sieve with retained aggregate [g]	Mass of Retained Aggregate [g]	Percentage Retained [%]	Percentage Coarser [%]	Percentage Passing [%]	ASTM requirement [C33-78] [%]
12.5	586.0	586.0	-	-	-	100	90-100
9.5	597.0	1268.1	671.1	33.53	33.53	66.47	40-70
4.75	578.3	1800.4	1222.1	61.05	94.58	5.42	0-15
pan	425.5	533.9	108.4	5.42	100	-	

$\sum$ = 2001.6

The aggregates grading satisfy ASTM standard C33-78 for 12.5 to 4.75mm aggregate and used for subsequent concrete production.