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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

INVESTIGATION ON THE STATIC MODULUS OF ELASTICITY OF CONCRETE IN COMPRESSION MADE USING LOCALLY AVAILABLE COARSE AGGREGATES

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science (Structural Engineering)

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INVESTIGATION ON THE STATIC MODULUS OF ELASTICITY OF CONCRETE IN COMPRESSION MADE USING LOCALLY AVAILABLE COARSE AGGREGATES

By

Yealemnegus Fufa

This is to certify that the thesis prepared by Yealemnegus Fufa, entitled "*investigation on the static modulus of elasticity of concrete in compression made using locally available coarse aggregates"* is submitted in partial fulfillment of the requirements for the Degree of Master of Science (Structural Engineering), complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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I, the undersigned, declare that this thesis entitled *"investigation on the static modulus of elasticity of concrete in compression made using locally available coarse aggregates"* is my original work. This thesis has not been presented for any other university and is not concurrently submitted in candidature of any other degree, and that all sources of material used for the thesis have been duly acknowledged.

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- ASTM-American standard for testing materials
- BS-British standard
- Ecom-initial secant modulus
- Ec2 -modulus at the second loading cycle
- Ecm-stabilized secant modulus
- Fcm-mean compressive strength
- s- Standard deviation
- Cov-coefficient of variation

ABSTRACT

The primary objective of this study was to determine the static moduli of elasticity of concrete mixes made of three different coarse aggregate types found locally and to compare the results of the study with the recommended values by Euro code which we are adopting. To see the effect of static compression modulus of elasticity on the stability of a structure a case study was also conducted.

The coarse aggregate types considered in this study were basaltic, limestone based and scoria based coarse aggregates. The standard method stated in BS EN 12390-13:2013 is the methodology followed to determine the static moduli of the concrete mixes. Mixes were prepared for three water-to-cement ratios (0.59, 0.56 and 0.51) for each aggregate type. Mix design was done considering the physical properties of basaltic coarse aggregate type whereas the mixes prepared for limestone and scoria based coarse aggregate types have the same amount of water, cement and fine aggregate except for the coarse aggregate portion where volume based replacement is made to see the effect of coarse aggregate type. The specimens used were cylindrical molds with diameter of 10cm and height of 20 cm. The specimens were kept in a curing chamber until one day before the test. The specimens with strain measuring transducers attached were subjected to loading according to the loading and unloading sequence stated in BS EN 12390-13:2013. For the case study 40/60 saving house having 22 stories was modeled using ETABS 15.2.2, and a response spectrum analysis was done on the model.

Four Specimens for 7th day and five specimens for 28th day were tested for compressive strength and static compression moduli of elasticity. Based on the 28th day test result, the recommended correction factor by Euro code for basaltic coarse aggregate type, which is commonly used in Addis Ababa, resulted in an approximate value for water to cement ratios of 0.56 and 0.51 whereas it resulted in a higher value for water to cement ratio of 0.59 when compared to the actual Computed value. The recommended correction factor for limestone based coarse aggregate resulted in a much lower value than the actual computed values for the limestone based coarse aggregate type considered in this study. The recommended correction factor for light weight aggregate concrete overestimates the actual value of static compression moduli of light weight aggregate concrete made of scoria based coarse aggregate considered in this study. The recommended correction factor by the code for light weight aggregate

concrete in general are 0.84, 0.88 and 0.89 for 0.59, 0.56 and 0.51 water-to cement ratios respectively. However, the result of this study shows the correction factors to be 0.64, 0.64 and 0.68.

Based on the result of the case study, a 20% increase in static compression modulus of elasticity resulted in a 16% reduction on the stability index. Based on the result of the current study it is recommended to check not only the compressive strength but also the static compression modulus of elasticity of concrete mixes.

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CHAPTER 1: INTRODUCTION

1.1. General

Concrete is a highly consumed construction material in the world these days. The cost of preparing the material, easy of molding it in any shape required, its ability to resist fire and other advantageous properties over other construction materials makes it preferable.

Concrete is made of easily available ingredients except cement. By volume, about 65-75% of concrete is aggregate (coarse and fine aggregates). From the total volume of aggregate the coarse aggregate portion is higher. There are different types of coarse aggregates which can be used to produce concrete with the required compressive strength (Abebe Dinku, 2006).

In Ethiopia the most widely used coarse aggregate type is the basaltic one. It could be used to produce normal strength concrete and high strength concrete. To get high strength concrete smaller water/cement ratio is required which would result in a concrete that do not satisfy the required workability hence the use of super plasticizer is necessary.

Scoria is another available coarse aggregate type which can be used to produce light weight normal strength concrete. To get a normal strength concrete from this type of coarse aggregate the use of smaller water cement ratio is required when compared to the use of basaltic coarse aggregate.

1.2. Background

The mechanical properties of concrete are functions of the properties of the matrix and that of aggregate. The most important property of concrete that is essential in the design of concrete structures is its stress strain relationship.

The modulus of elasticity of concrete in compression having a certain compressive strength varies from place to place due to the fact that the types of aggregates used in the production of concrete are different. Aggregates classified as the same type but from different source results in different modulus of elasticity of concrete because they are formed at different places and through different condition thus they possess different property.

Concrete is a typical example of a material with non-linear and non-elastic material property. Due to the reason stated in the previous sentence the word Young's Modulus (applicable to only to materials with linear material property) is not applicable to define its stress-strain relationship rather we use various kinds of modulus of elasticity to express the stress strain relationship.

Modulus of elasticity of concrete can be either static or dynamic. The static modulus of elasticity of concrete is determined from uniaxial compressive test whereas dynamic modulus of elasticity of concrete is determined by dynamic test methods like ultrasonic velocity and resonance frequency tests by which we can measure the longitudinal and transverse frequency of cylinders respectively.

The static modulus of elasticity of concrete can be defined in different ways. Initial tangent modulus is the slope of the tangent line at the origin of the stress-strain curve. Tangent modulus of elasticity is the slope of the tangent line at any point on the stress-strain curve. Secant modulus of elasticity is the slope of the line drawn between the origin and any point along the curve.

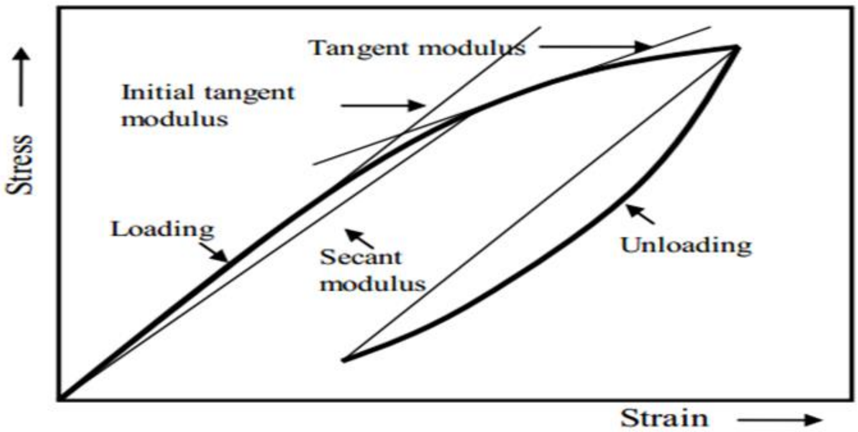

Figure 1-1 stress-strain relationship for concrete when loading and unloading

Concrete is assumed to have a linear elastic property with in a stress range of zero up to service load stress. The value of the service load stress used in the determination of the static modulus of elasticity of concrete varies in different standards. For example, in ASTM (American society for Testing Materials) the value of the service load stress is taken as 40% of the ultimate strength of the concrete whereas in BS EN 12390-13:2013(British Standard) it is one third of the compressive strength of concrete.

The static modulus of elasticity of concrete cannot be directly measured like that of compressive strength rather it is calculated based on the result obtained from a uniaxial compressive strength test with strain measuring instruments attached to the specimens to be tested. From this test we can get the stress strain relationship for the concrete at hand.

Different standards state ways of determining the static modulus of elasticity of concrete in compression. These standards state that cylindrical specimens of size either 15diameter by30cm height mold or 10cm diameter by 20Cm height molds shall be prepared and the specimens shall be cured for 28 days in normal curing condition prior to compressive strength test. Before carrying out compressive strength test with strain measuring instruments attached to the specimens it is better to do compressive strength test on companion specimens from the same mix in order to be able to define the stress range where the concrete is assumed to act as an elastic material.

The static modulus of elasticity of concrete can be determined according to standards like ASTM C469 or BS EN 12390-13:2013. The basic differences in this standards are the way of application of the load while doing the compressive strength test and the adopted upper stress level up to where concrete is assumed to be elastic

According to ASTM C469 only one cycle consisting of loading up to 40% of the ultimate strength of the concrete mix with a loading rate of 0.24±0.034MPa/s and then unloading will be carried out once after two pre loading cycles are completed which are performed to check the performance of the strain measuring instruments. From the loading part of the stress-strain curve the (strain, stress) ordinates at a strain value of 0.00005 and stress value of 40% of ultimate compressive strength are used to calculate the static modulus of elasticity of concrete.

The static modulus of elasticity is obtained from the ratio of the differences in stress and strain of the above mentioned ordinates. According to this standard the gauge length from which the strains to be calculated at each stress level is in the range between three times maximum aggregate size and two third of the height of the specimen.

According to BS EN 12390-13:2013 the specimen with strain measuring instrument should be subjected to a pre loading cycle consisting of three/two loading and unloading cycles with a loading rate of 0.6±0.2MPa/s and then the specimen will be subjected to a loading cycle consisting of three/two loading and unloading cycles with a loading rate of 0.6±0.2MPa/s.

Once after the target stress level is reached in each loading and unloading part the target stress is hold for a period of time not exceeding 20s. From the first loading cycle and the loading part we can calculate the initial secant modulus and from the last loading cycle and the loading part we can calculate the stabilized secant modulus. The degree of variation from the initial secant modulus to the stabilized secant modulus is an indication of the susceptibility of the material to stress induced micro cracking or micro cracking caused by drilling in the case of cores taken from a structure. According to this standard the gauge length from which the strains to be calculated at each stress level is in the range between two third of the diameter of the specimen or three times maximum aggregate size and half of the height of the specimen. The figure below is taken from BS EN 12390-13:2013 and it shows the recommended loading sequence for the determination of static modulus of elasticity of concrete.

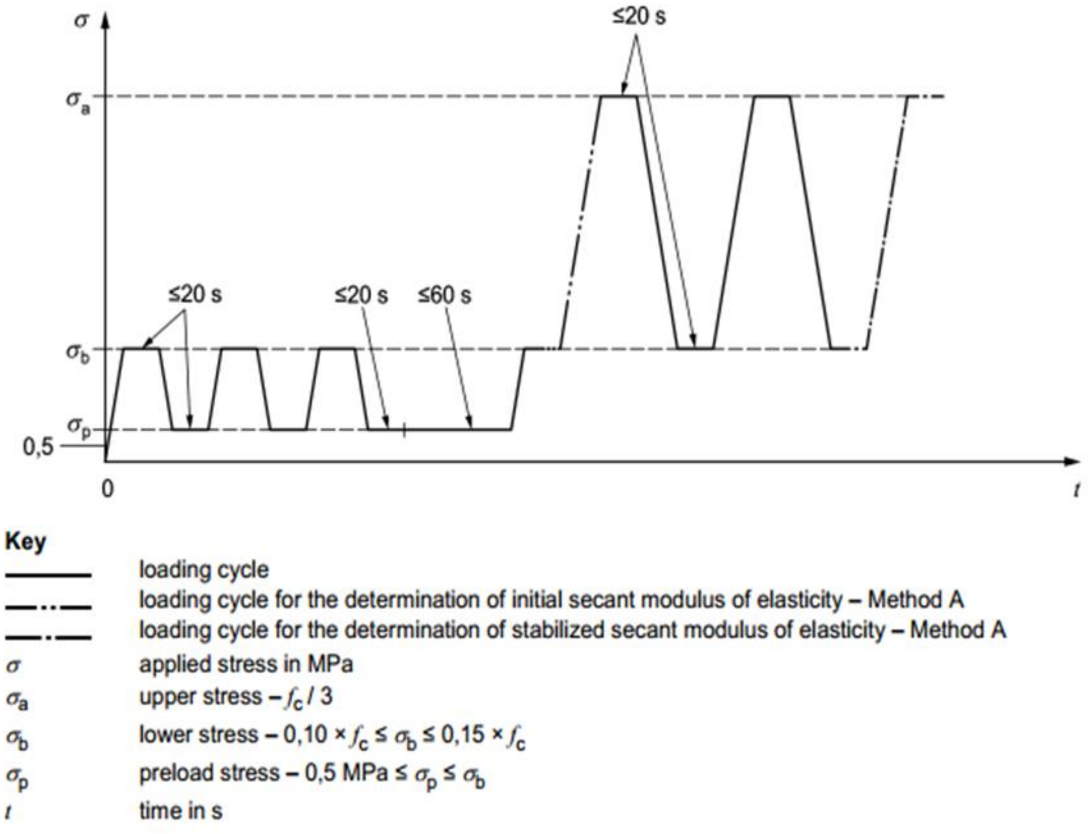

Figure 1-2 stress vs. time graph recommended by BS EN 12390-13:2013 for the determination static modulus of elasticity

1.3. Problem Statement

The construction industry in Ethiopia highly consumes concrete made of basaltic coarse aggregate type. These days the use of light weight aggregates like scoria is required so as to be able to reduce the weight of structures. Studies have shown that the range of concrete strength that could be achieved for the above aggregate types is known except the static modulus off elasticity of concrete made of the above aggregate types. To be able to determine the range of the static modulus of elasticity of concrete mixes in compression made of the aggregate types mentioned earlier this study is carried out.

1.4. Purpose of the Study

- The values of static modulus of elasticity for different grades of concrete made of locally available coarse aggregate types in Ethiopia are not experimentally determined rather they are simply adopted from the Euro code recommendations hence it is of great importance to use appropriate values for different grades of concrete made using different kinds of coarse aggregates.
- To see the effect coarse aggregate types on the static modulus of elasticity of concrete
- To verify whether the values of modulus of elasticity for different grades of concrete given in Ethiopian building code of standard are approximate or not
- To find the correction factor if the values are not approximate.

1.5. Significance of the Study

Modulus of elasticity is a basic parameter in structural analysis and design of structural members. A structure can be either determinate or indeterminate depending on the number of unknown reactions and internal member forces exceeding the number of available equilibrium equations. The analysis of determinate structures is carried out by using only the available equilibrium equations. However, the analysis of indeterminate structures requires developing additional equations integrating stiffness or flexibility of members which are functions of modulus of elasticity of the material used for producing the members.

Structural members can be designed for different internal member forces. Internal member forces cause axial compression, axial tension, bending, diagonal compression or diagonal tension (from shear force). The resistance of members to these effects depends mainly on member size, strength and modulus of elasticity of the material from which the member is produced.

Most of the structures in our country are made of reinforced concrete material hence knowing the value of modulus of elasticity for different grades of concrete helps us to get approximate analysis results and members could be designed based on approximate material properties.

1.6. Scope of the Study

- This study is limited to the determination of the static modulus of elasticity of concrete.
- The concrete mixes are prepared from three different coarse aggregate types (Basaltic, Limestone and scoria) where all other ingredients of concrete are taken from the same source.
- Only one maximum nominal coarse aggregate size of 19mm is used.

1.7. Organization of the Thesis

This thesis is organized in to six chapters, reference and appendix. The first chapter is an introduction part where the required background information for the study is stated and the problem, the purpose, the significance and the scope of the study are defined. The second chapter consists of the literatures reviewed which are in relation to this study. The third chapter is about the methodology followed for the study. The fourth chapter shows the result and discussion part where the results obtained from the experimental work and the discussion made based on the result of the experimental work are presented. The fifth chapter is the conclusion part of the paper. The six chapter states the recommendations made and directions for future work.

CHAPTER 2: LITERATURE REVIEW

2.1. General

There is no much research work done in Ethiopia regarding the modulus of elasticity of concrete as a result the literatures reviewed in this paper are meant to show the factors that affect the modulus of elasticity of concrete.

The value of the static modulus of elasticity of concrete is affected by many factors. It is highly affected by the compressive strength of concrete, the type of aggregate used, unit weight of concrete, the use of admixtures and age of concrete. The effect of these factors has been studied by many researchers and the results of the studies of some researchers are briefly presented in this chapter.

2.2. Effect of Aggregate Type on the Static Modulus of Elasticity of Concrete

C.C. Yang (1995) studied the effect of aggregate on elastic moduli of cement-based composite materials. The study considered three water/cement ratios (W/C=0.286, 0.294 and0.315), volume fractions (A/T=0.1, 0.2 and 0.3) and steel, glass, gravel and crushed stone aggregates. For the same water/cement ratio, the concrete mix with steel coarse aggregate type resulted in highest elastic modulus then glass then gravel and then crushed stone.

Effect of aggregate type on the mechanical properties of high strength concrete was investigated by Mustafa (1998). The mechanical properties studied were compressive strength, tensile split strength, flexural strength, static and dynamic moduli of elasticity and poison’s ratio of concrete mixes with strength ranging from 47.5 to 71.2 MPa. The mixes were prepared from four different aggregate types (Limestone, Diabase, Granite, and River Gravel). The study determines the above mechanical properties at different ages of concrete. The static modulus of elasticity of concrete made of Diabase is the largest at all ages of concrete (7th day, 28th day and 90 day) then comes limestone then granite then river gravel. The study had come up with an equation relating the static modulus of elasticity and compressive strength (E=3.55fc0.6) and the study shows that there is insignificant variation of equation for different aggregate types.

Statistical analysis of over 3000 data sets which were collected by many investigators was made in a study by Takumi Noguchi et al. (2009). The compressive strength of concrete made of different aggregate types in the data set ranges from 40 to 160 MPa. The study proposes an equation for the estimation of static modulus of elasticity which is a function of compressive strength, unit weight at the time of compression test and correction factor for coarse aggregate type (K1) and mineral admixture (K2). The proposed equation is E=K1K2 1.486*10-3fc 1/3 γ2. The correction factor K1 ranges from 0.902 to 1.207 and K2 ranges from 0.818 to 1.143. The correction factor for admixture depends on the type of admixture and the amount of admixture used.

A study on compressive strength, static and dynamic modulus of young concrete by Yong Zhou et al. (2015) pointed out that the type of aggregate used has a significant effect on the static modulus of elasticity. Aggregates with higher modulus of elasticity will result in concrete having higher static modulus of elasticity.

2.3. Effect of Curing Condition on the Static Modulus of Elasticity of Concrete

According to the study entitled a fundamental study on compressive strength, static and dynamic elastic moduli of young concrete by Yong Zhou et al. (2015) curing temperature has an effect on the rate at which the static modulus converges to its final value. The higher the temperature of curing the static modulus converges quickly at early ages

2.4. Effect of Age of Concrete at the Time of Testing on the Static Modulus of Elasticity of Concrete

Mustafa (1998) studied the effect of age of concrete on the static modulus of elasticity of concrete. According to his study at 7th day the static modulus of elasticity is about 75% of that of at 28th day and that at 90th day is 5% greater. Yong Zhou et al. (2015) indicates that the static modulus of elasticity of concrete increases rapidly at early ages of 12hrs to 3days.The static modulus of elasticity of concrete reaches 80% of the value at 28 days at the age of 3 days. It increases at a slow rate at the age of 3 to 28 days.

2.5. Effect of Aggregate Content on the Static Modulus of Elasticity of Concrete

C.C. Yang (1995), the result of the study shows that the modulus of elasticity of cement based composite material increases with increasing volume fraction (coarse aggregate volume/total volume) keeping the water/cement ratio constant. Yong Zhou et al. (2015) increasing the volume content of aggregate leads to the increase of static modulus of concrete.

2.6. Effect of Compressive Strength of Concrete on the Static Modulus of Concrete

Yong Zhou et al. (2015) studied the effect of water to cement ratio on the static moduli of concrete which has a direct relation with compressive strength has also a significant effect on the static modulus of elasticity. As the water to cement ratio is decreased the static modulus of elasticity increases.

2.7. Effect of Cylinder Size on the Static Modulus of Elasticity of Concrete

Effect of cylinder size on the modulus of elasticity and compressive strength of concrete from static and dynamic test was assessed by Byung Jae Lee et al. (2015) and the study indicates that the effect of cylinder size on the compressive strength and static modulus of elasticity for normal grade concrete up to 30 MPa is insignificant.

Figure 2-1 Equations proposed to estimate the static modulus of normal weight concrete

Code	Estimating equation	Units
ACI 318-08	$E_C=4700\sqrt{fc}$	f_c; MPa, E_c: MPa
ACI 363-08	$E_C=3300\sqrt{fc}+6900$	f_c; MPa, E_c: MPa
NZS 3101-2006	$E_C=3320\sqrt{fc}+6900$	f_c; MPa, E_c: MPa
CSA A23.3-04	$E_C=4500\sqrt{fc}$	f_c; MPa, E_c: MPa
EC-2	$E_C=22((fc/10)^{0.3}$	f_c; MPa, E_c: GPa
GB 50010	$E_C=\frac{100}{2.2+34.7/fc}$	f_c; MPa, E_c: MPa

As it can be seen in the above table and the literatures reviewed the value of the static modulus of elasticity of concrete for a certain compressive strength varies from place to place which is due to the fact that the type of aggregate used for the production of concrete differs in their property. Due to the fact stated above this study is necessary.

According to Euro code 2 the modulus of elasticity of concrete made of limestone is obtained by reducing the value obtained using the formula recommended by 10% and for concrete with basaltic aggregate is obtained by increasing the value obtained using the formula by 20%. The code also recommends an empirical formula to estimate the modulus of elasticity at any time ($E_{cm}(t) = [f_{cm}(t)/f_{cm}]^{0.3} * E_{cm}$). The code also recommends a correction factor for light weight aggregate concrete which is the function of the density of concrete ($\eta_E=(\rho/2200)^2$).

CHAPTER 3: EXPERIMENTAL PROGRAM AND MATERIALS

3.1. Introduction

This study is an experimental and a case study. The experimental study is meant to determine the static compression moduli of concrete mixes made of locally available coarse aggregate types whereas the case study is carried to show the effect of static compression moduli of elasticity on the drift of buildings and the stability index of stories.

3.2. Experimental Program

This study is mainly an experimental study designed to determine the static compression moduli of elasticity of concrete mixes made of three different aggregate types. The types of coarse aggregates used were basaltic coarse aggregate, limestone based coarse aggregate and scoria based coarse aggregate.

The elastic moduli of concrete mixes were determined according to the procedures, standards and test setups described in BS EN 12390-13 2013.The physical properties of the ingredients of concrete were determined prior to mix design. Mix design was done using the properties of the basaltic coarse aggregate and volume based replacements were done for the other two types of aggregates.

3.2.1. Specimen Preparation

For the experimental study, nine mixes were prepared. The mixes were prepared using mixer. Three different mixes consisting of Basaltic coarse aggregate type, three different mixes consisting of Limestone based coarse aggregate type and three mixes consisting of scoria based coarse aggregate type were prepared for water-to-cement ratios of 0.59, 0.56 and 0.51.

From each mix, nine cylindrical specimens with diameter of 10cm and height 20cm were prepared. Four of the specimens were used to measure compressive strength and static compression modulus of elasticity of the mix at 7th day. Two out of four specimens were used for compressive strength test and the rest two were used for static compression modulus of elasticity test. Five of the nine specimens were used to measure the compressive strength and static compression modulus of elasticity of the mix at 28th day. Two out of five specimens were used for compressive strength test and the rest three were used for static compression modulus of elasticity test.

One day after the mixes were prepared, the specimens were taken out of the cylindrical molds and then placed in a curing chamber where they are subjected to normal curing condition.

One day before tests were carried out the specimens were taken out of the curing chamber and then capping using cement paste was prepared for top face each specimen as shown in the figure below.

Figure 3-1 capping preparation

3.2.2. Testing Method and Setup

Prior to static compression modulus of elasticity test, companion specimens were subjected to uniaxial compressive load in order to be able to determine the characteristic cylindrical compressive strength of the mixes. The characteristic cylindrical compressive strengths obtained were used to define the loading and unloading sequence for the static compression modulus of elasticity test (compressive strength test on two specimens from the same mix was done and average of the two results was considered as the compressive strength of the mix).

For the static compression modulus of elasticity test, a machine shown below which is capable of applying compressive load was used. In the static compression modulus of elasticity test, the stress and corresponding strain values has to be measured to compute the static compression modulus of elasticity of the mix.

Figure 3-2 Machine used and test setup

In order to measure the strain values at different stress levels during loading and unloading of the specimen three magneto resistive type transducers were vertically attached to the specimens. The transducers are capable of measuring the vertical deformation of the specimen which will be used to calculate the strain by dividing the deformation by the gauge length. The gauge length is the vertical distance between the points to which the pins of the transducers were attached. The points to which the transducers were attached were marked on the specimen surface as shown in the figure below. The gauge length used in the tests for this study was 9cm.

Figure 3-3 procedure for marking the points to which the transducers are to be attached

The determination of the static modulus of elasticity is made according to the standard procedures and methods described in BS EN 12390-13 2013. The sample to be tested was placed at the center of the lower plate and then the transducers were connected to compressive strength testing machine. The loading and unloading cycles were determined using compressive strength obtained from companion specimens. The compressive strength machine made to do the loading unloading by the use of software called E- module. Once the loading and unloading cycles were completed the compressive strength of the specimen is tested after removal of the transducers to confirm that the deviation of the compressive strength of the specimen from the compressive strength used to define the loading and unloading cycles is within ± 20% range. Average of the results of two and three static compression modulus of elasticity tests for 7th and 28th day were taken as the static modulus of elasticity of the concrete for 7th day and 28th day respectively. Correction factors for the code's recommendation were obtained. During the test the deviation of the measured strains from their average value has to be within 20 % range and the reliability of the measured strains is confirmed from the graphs shown in the figure below which are captioned during the test, however this was not always the case. In all the tests the deviation of the strain when the stress is held at upper and stress lower level was with in ± 20% but in most of the cases the variation is higher when the stress is at preload stress level due to the reason that opposite face of cylinders were skewed and the reading of the gauges varies even though the readings of the gauges were smaller.

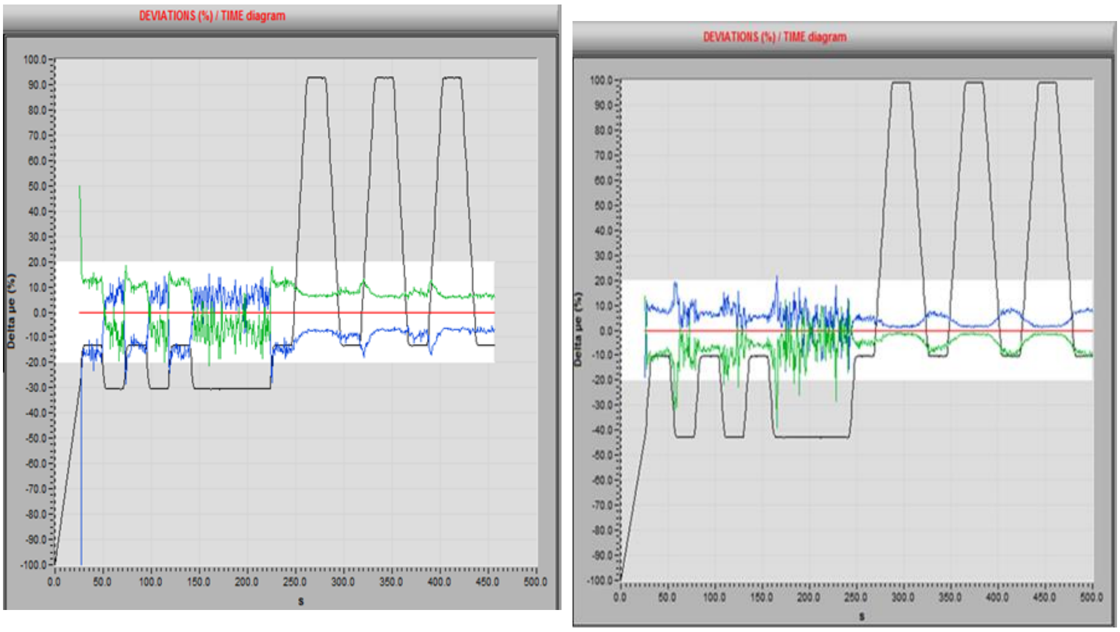

Figure 3-4 deviations vs. time graph

For the experimental study the values of different parameters used are shown in the table below.

Table 3-1 parameters used to define the loading and unloading sequence

Parameter	Value
Fck	Fcm-8
Loading rate	0.4MPa/s
Upper stress (σa)	Fck/3
Lower stress (σb)	0.15 fck
Preload stress (σp)	0.5≤ σp≤ σb
Gauge length	9cm

3.3. Materials Used

The materials used for the production of concrete includes water, ordinary Portland cement, river sand and three different coarse aggregates. The coarse aggregate types used are basaltic coarse aggregate, limestone based coarse aggregate and scoria based coarse aggregate. The basaltic coarse aggregate is the commonly used coarse aggregate in Addis Ababa. The limestone used was brought from a digital balance found around Entoto where over loaded trucks transporting the limestone boulders to Derba cement factory unload the extra weight. The scoria based coarse aggregate used was brought from a quarry found around Kality.

3.3.1.Physical Properties of Materials

The physical properties of the materials used for the test were determined prior to mix design and the results of physical property tests of coarse and fine aggregates is presented in the tables below. The cement used is ordinary Portland cement.

Table 3-2 Fine aggregate property

Silt content	0.01724
Absorption capacity	0.01419
Saturated surface dry Specific gravity	2.577
Fines modulus	3.152

Table 3-3 Fine aggregate particle size distribution

Sieve size (mm)	Weight of retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	Grading requirement
9.5	0	0	0	100	100
4.75	10	2	2	98	95-100
2.36	27	5.4	7.4	92.6	80-100
1.18	105	21	28.4	71.6	50-85
600	256	51.2	79.6	20.4	25-60
300	93	18.6	98.2	1.8	43038
150	7	1.4	99.6	0.4	42776
Pan	2	0.4	100	0	

3.3.2.Coarse Aggregate Properties

The properties of the coarse aggregates used for producing the concrete mixes were determined in the laboratory and the proportion of each aggregate size was decided according to the requirements for well graded aggregate.

Table 3-4 Gradation for coarse aggregate

Sieve size (mm)	Retained %
19	10
12.5	30
9.5	35
4.75	25

Table 3-5 Physical properties of basaltic coarse aggregate

Absorption capacity	1.84
Saturated surface dry Specific gravity	2.7
Nominal aggregate size	19

Table 3-6 Physical properties of limestone coarse aggregate

Absorption capacity	1.83
Saturated surface dry Specific gravity	2.57
Nominal aggregate size	19

Table 3-7 Physical properties of scoria coarse aggregate

Absorption capacity	16.16
Saturated surface dry Specific gravity	1.66
Nominal aggregate size	19

3.3.3.Mixture Design

Mixture design for the basaltic coarse aggregate one was made according to DOE mixture design procedure. Three different proportions of ingredients of concrete for three different water-to-cement ratios were obtained from the mixture design. For the other two types of aggregates; mixes were prepared for the three water-to-cement ratios by replacing the volume of the basaltic coarse aggregate obtained from the mix design by the same volume of the two aggregates types. The equivalent volumes of limestone and scoria coarse aggregates were determined using their respective saturated surface dry Specific gravity. This was done to see the effect of coarse aggregate type on the static modulus of elasticity of concrete. The result of the mix design is presented in the table below. The full mix design is found at the appendix part of this paper.

The table below shows the summary of mix design. It shows the amount of each material required for one cubic meter of concrete for three different water-to-cement ratios.

Table 3-8 proportion of ingredients of concrete used for making the specimens

Aggregate type	Water to cement	Water (Kg)	Cement (Kg)	Fine (Kg)	Coarse (Kg)
basaltic	0.59	210	356	718	1076
	0.56	210	375	639	1136
	0.51	210	412	608	1130
Limestone	0.59	210	356	718	1026
	0.56	210	375	639	1083
	0.51	210	412	608	1077
Scoria	0.59	210	356	718	662
	0.56	210	375	639	699
	0.51	210	412	608	695

3.4. Case study

For the case study two structural models having all the dimensions and material properties the same except the static compression modulus of elasticity (SCME) were modeled using ETABS15.2.2. For the case study a 22 story building (40/60 saving house) was used. A concrete with a cubic strength of 25 MPa was used. For one of the models a SCME value of 30Gpa was defined and for the other the SCME is increased by 20 percent and 36 GPa was used. A response spectrum analysis of the models was done.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 General

The results obtained from the experimental work followed by discussion based on the results are presented in this chapter. The experimental variability of the test data for unit weight, compressive strength and static compression modulus was evaluated using coefficients of variation.

4.2. Result of Experimental Study

As it can be seen in the figure below concrete exhibits linear stress strain relationship up to a service load stress. However, there exists residual strain at the end of each loading and unloading cycles. The figure below shows a sample loading and unloading cycle defined for the test and the stress vs. strain relationship due to the loading and unloading cycle.

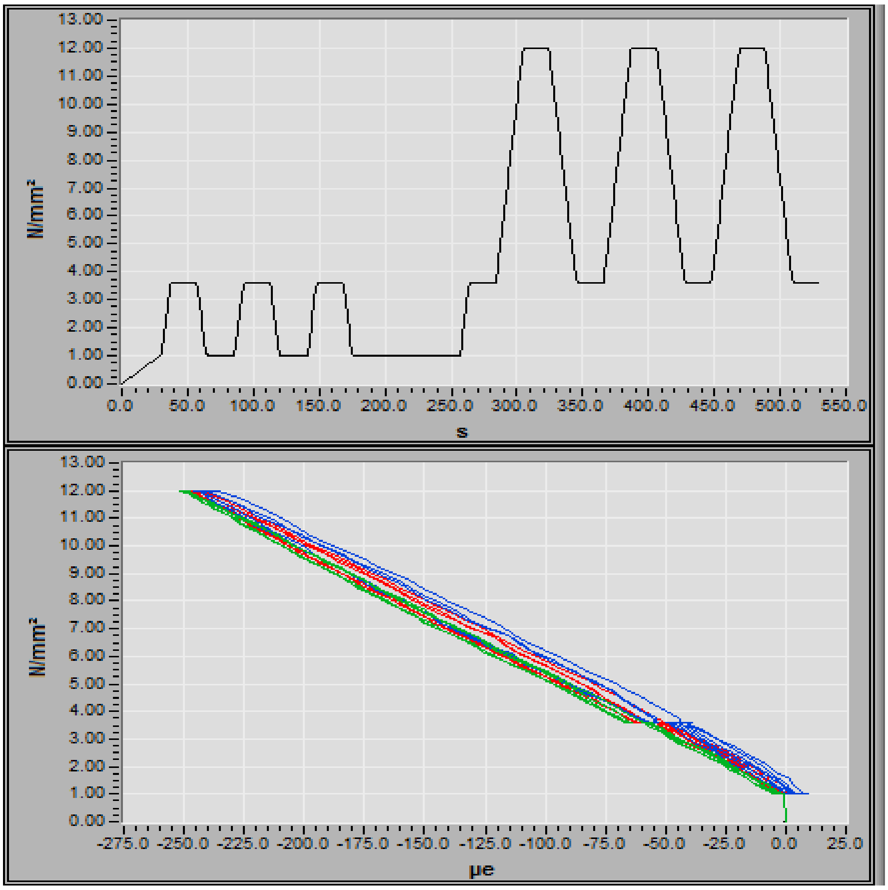

Figure 4-1 sample stress vs. time and stress vs. strain of the experimental study

Prior to compressive strength and static compression modulus of elasticity test, the weight of each specimen has been measured and the unit weights of the respective specimens are obtained. The table below shows the average unit weight of the specimens from the same mix batch.

Table 4-1 Average unit weight of specimens

Aggregate type	Water to cement ratio	Unit weight 7th day(KN/m^3)	Unit weight 28th day(KN/m^3)
basaltic	0.59	24.77	24.82
	0.56	25.02	25.59
	0.51	25.09	25.39
limestone	0.59	23.55	23.98
	0.56	24.04	24.32
	0.51	24.23	24.37
scoria	0.59	19.51	20.11
	0.56	20.10	20.63
	0.51	20.32	20.78

From the table above we can see that the unit weight is reduced by 18% and 4 % when the basaltic coarse aggregate is replaced with scoria based coarse aggregate and limestone based coarse aggregate respectively. The reduction of unit weight when using scoria based coarse aggregate is significant. This reduction is due to the lower specific gravity of the aggregates than the basaltic coarse aggregate. The specific gravity of limestone based coarse aggregate is 4.8% lower than that of basaltic coarse aggregate which is consistent with the reduction in unit weight of concrete made of limestone based coarse aggregate. Based on the classification of concrete as light weight aggregate concrete in section eleven of Euro code 2, it is appropriate to consider concrete made of scoria based aggregate as light weight aggregate concrete although the unit weights obtained at 28th day are little bit higher than the upper boundary of classification of light weight aggregate concrete which is due to a thicker capping provided for the specimens. The correction factors for the static compression moduli of elasticity used for comparison are obtained by the empirical formula recommended for light weight aggregate concrete.

Table 4-2 7th and 28th day Average cylindrical compressive strength, initial secant modulus and stabilized secant modulus

Aggregate type	Water-to-cement ratio	Average compressive strength, fcm, cylindrical (MPa)		Average Initial secant modulus, Ecom (GPa)		Average stabilized secant modulus, Ecm (GPa)	
		7th	28th	7th	28th	7th	28th
Basaltic	0.59	22.43	41.26	33.04	35.78	32.21	34.55
	0.56	36.77	42.35	39.36	40.39	38.85	39.61
	0.51	37.45	48.74	39.94	44.22	39.03	42.86
limestone	0.59	20.35	30.35	25.69	33.67	25.45	33.06
	0.56	31.90	36.49	30.07	38.29	30.01	37.08
	0.51	33.67	50.44	31.43	40.42	31.21	39.52
Scoria	0.59	16.95	20.53	11.46	17.60	11.38	16.92
	0.56	19.32	25.58	14.62	18.62	14.10	17.93
	0.51	23.88	28.27	16.17	20.53	16.11	19.98

The results of the study show that concrete at 7th day attains about 70% of the static compression elastic modulus at 28th day. For the same water cement ratio in general the basaltic coarse aggregate used in this study results in higher compressive strength and static compression modulus of elasticity than both limestone and scoria based coarse aggregate.

Table 4-3 Result of concrete made of basaltic coarse aggregate with water to cement ratio of 0.59

Basaltic coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.59	24.53	40.22	35.76	34.78	34.68
	24.77	40.77	35.63	34.32	33.96
	24.60	40.87	35.94	35.28	35.02
	24.95	42.16	companion specimen		
	25.26	42.27			
Average	24.82	41.26	35.78	34.79	34.55
S	0.29	0.91	0.16	0.48	0.54
Cov	1.19	2.20	0.44	1.38	1.57

Table 4-4 Result of concrete made of basaltic coarse aggregate with water to cement ratio of 0.56

Basaltic coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.56	25.83	41.14	41.68	41.22	40.87
	25.67	42.84	39.37	38.63	38.49
	25.62	41.24	40.13	39.32	39.47
	25.49	43.33	companion specimen		
	25.31	43.21			
Average	25.59	42.35	40.39	39.72	39.61
S	0.20	1.08	1.18	1.34	1.20
Cov	0.77	2.54	2.91	3.38	3.02

Table 4-5 Result of concrete made of basaltic coarse aggregate with water to cement ratio of 0.59

Basaltic coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.51	25.75	46.16	43.68	42.35	42.14
	25.27	47.48	45.82	44.61	44.67
	25.34	48.87	43.15	41.93	41.76
	25.39	49.76	companion specimen		
	25.20	51.44			
Average	25.39	48.74	44.22	42.96	42.86
S	0.21	2.04	1.41	1.44	1.58
Cov	0.84	4.18	3.20	3.36	3.69

As it can be seen in the tables above the compressive strength of the concrete mixes with water to cement ratio of 0.59 and 0.56 are almost the same but the static compression modulus of elasticity of the two concrete mixes significantly varies. The possible reason for this variation in the static compression modulus of elasticity is the coarse aggregate volume. The coarse aggregate volume for concrete mix with water to cement ratio of 0.59 is lower than for the concrete mix with water to cement ratio of 0.56. The above result shows that for a certain concrete grade the static compression modulus of elasticity can be increased with increase in volume of coarse aggregate which requires further study.

Table 4-6 Result of concrete made of limestone based coarse aggregate with water to cement ratio of 0.59

Limestone based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.59	23.92	29.54	32.47	31.88	32.17
	24.10	29.76	34.99	34.56	34.23
	24.02	28.89	33.54	32.95	32.78
	23.89	32.10	companion specimen		
	23.98	31.47			
Average	23.98	30.35	33.67	33.13	33.06
S	0.08	1.36	1.26	1.35	1.06
Cov	0.34	4.50	3.76	4.07	3.20

Table 4-7 Result of concrete made of limestone based coarse aggregate with water to cement ratio of 0.56

Limestone based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.56	24.40	37.63	39.35	38.19	38.23
	24.17	35.28	37.90	37.01	36.79
	24.35	35.56	37.63	36.73	36.21
	24.34	36.52	companion specimen		
	24.31	37.45			
Average	24.32	36.49	38.29	37.31	37.08
S	0.09	1.07	0.93	0.77	1.04
Cov	0.36	2.92	2.42	2.08	2.81

Table 4-8 Result of concrete made of limestone based coarse aggregate with water to cement ratio of 0.51

Limestone based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.51	24.40	50.15	40.81	39.79	39.49
	24.36	49.26	40.13	39.41	39.29
	24.34	50.05	40.32	40.11	39.78
	24.38	50.16	companion specimen		
	24.38	52.58			
Average	24.37	50.44	40.42	39.77	39.52
S	0.02	1.25	0.35	0.35	0.25
Cov	0.09	2.49	0.87	0.88	0.62

Table 4-9 Result of concrete made of scoria based coarse aggregate with water to cement ratio of 0.59

Scoria based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.59	20.12	19.32	16.73	16.39	16.27
	20.18	20.53	18.23	17.84	17.62
	20.26	19.50	17.85	17.24	16.87
	19.97	21.66	companion specimen		
	20.01	21.65			
Average	20.11	20.53	17.60	17.16	16.92
S	0.12	1.12	0.78	0.73	0.73
Cov	0.59	5.48	4.43	4.25	4.25

Table 4-10 Result of concrete made of scoria based coarse aggregate with water to cement ratio of 0.56

Scoria based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.56	20.69	25.43	18.72	17.66	17.86
	20.60	25.81	18.90	17.20	18.37
	20.69	24.94	18.23	17.84	17.56
	20.53	26.55	companion specimen		
	20.61	25.15			
Average	20.63	25.58	18.62	17.57	17.93
S	0.07	0.63	0.35	0.33	0.41
Cov	0.34	2.48	1.86	1.88	2.28

Table 4-11 Result of concrete made of scoria based coarse aggregate with water to cement ratio of 0.51

Scoria based coarse aggregate					
water to cement ratio	unit weight (KN/m3)	compressive strength(MPa)	Ecom(GPa)	Ec2(GPa)	Ecm(GPa)
0.51	20.64	28.46	20.57	19.79	19.57
	20.74	29.81	21.48	21.18	21.15
	20.71	27.58	19.53	19.40	19.23
	21.01	27.40	companion specimen		
	20.83	28.10			
Average	20.78	28.27	20.53	20.12	19.98
S	0.14	0.96	0.98	0.94	1.02
Cov	0.68	3.39	4.75	4.65	5.13

In most of the results obtained the static compression modulus of elasticity of concrete reduces from one cycle to the next one which is an indication that concrete is susceptible to formation of stress induced micro cracks. The largest reduction of static compression modulus of elasticity occurs after the first loading cycle.

Within test variability of unit weight measured are in the excellent (cov<3) range according to ACI 214-02. Within test variability of compressive strength is between excellent to fair (cov<6) range and for static compression modulus of elasticity is between excellent to fair.

Table 4-12 average unit weight, average compressive strength, average first cycle loading, average second cycle loading and average third cycle loading SCME

aggregate type	water to cement ratio	average unit weight (KN/m3)	average compressive strength (MPa)	average Ecom(GPa)	average Ec2(GPa)	average Ecm(GPa)
Scoria based coarse aggregate	0.59	20.11	20.53	17.60	17.16	16.92
	0.56	20.63	25.58	18.62	17.57	17.93
	0.51	20.78	28.27	20.53	20.12	19.98
Limestone based coarse aggregate	0.59	23.98	30.35	33.67	33.13	33.06
	0.56	24.32	36.49	38.29	37.31	37.08
	0.51	24.37	50.44	40.42	39.77	39.52
Basaltic coarse aggregate	0.59	24.82	41.26	35.78	34.79	34.55
	0.56	25.59	42.35	40.39	39.72	39.61
	0.51	25.39	48.74	44.22	42.96	42.86

Table 4-13 comparison of code recommended correction factor and current study's correction factors

aggregate type	water to cement ratio	average compressive strength	average Ecom(GPa)	modulus of elasticity by code recommended equation	code recommended correction factor	experimentally obtained correction factor
Scoria based coarse aggregate	0.59	20.53	17.60	27.30	0.84	0.64
	0.56	25.58	18.62	29.16	0.88	0.64
	0.51	28.27	20.53	30.05	0.89	0.68
Limestone based coarse aggregate	0.59	30.35	33.67	30.70	0.90	1.10
	0.56	36.49	38.29	32.44	0.90	1.18
	0.51	50.44	40.42	35.75	0.90	1.13
Basaltic coarse aggregate	0.59	41.26	35.78	33.66	1.20	1.06
	0.56	42.35	40.39	33.92	1.20	1.19
	0.51	48.74	44.22	35.38	1.20	1.25

From the above table we can see that the recommended correction factor for light weight aggregate concrete overestimates the static compression modulus of elasticity of concrete made using scoria based coarse aggregate. According to this study the correction factor recommended by the code overestimates by a factor of 0.2 (which will be around 5Gpa).

The correction factors recommended by the code for concrete made using limestone coarse aggregate underestimates the static compression modulus of elasticity of the concrete. According to the results of this study the correction factor should increase the static compression modulus of elasticity obtained by the code recommended empirical equation rather than reducing it.

The recommended correction factor for concrete made using basaltic coarse aggregate are more or less approximate to the result of this study except for the correction factor obtained by this study for water cement ratio of 0.59 which is lower (which should be verified with another study).

Figure 4-2 Fracture surface for concrete made using limestone based coarse aggregate

The picture above shows the fractured surface of concrete made using limestone based coarse aggregate. The fractured surface shows that both the paste and the coarse aggregate fractures when the concrete specimens are subjected to axial compressive load until failure. The fractured surface indicates that both the strength and static compression modulus of elasticity of both paste and the aggregate controls the strength and static compression modulus of elasticity of concrete made using lime stone base coarse aggregate.

Figure 4-3 Fracture surface for concrete made using scoria based coarse aggregate

The above picture shows the fractured surface of concrete made of scoria based coarse aggregate. The fractured surface shows that the coarse aggregate is the one through which the path of the crack passes the most. The compressive strength and static compression modulus of elasticity of concrete made using scoria based coarse aggregate are highly dependent on the compressive strength and static compression modulus of elasticity of the coarse aggregate which is indicated in the experimental result. Even though the compressive strength increases significantly increase the static compression does not show that significant increase.

Figure 4-4 Fracture surface for concrete made using basaltic coarse aggregate

The picture above shows the fractured surface of concrete made using basaltic coarse aggregate. The fractured surface consists of mainly the paste which is an indicator that basaltic coarse aggregate has a higher compressive strength and static compression modulus of elasticity than the paste therefore we can say that the compressive strength and static compression modulus of elasticity of concrete made using basaltic coarse aggregate is mainly controlled by the properties of the paste.

4.3. Result of the case study

The table below shows the result of the analysis of the 22 story structure. The stability index is calculated from the story shear, axial load, height of story and drift of the story (Q=Pd/VH). Where P is the axial load, d is the story drift, V is the story shear and H is the story height.

Table 4-14 stability index for a modulus of elasticity of 30Gpa and 36Gpa (20% increase) and reduction of stability index

Stability Index			% Reduction in Stability Index
Story	**Q (E_{EBCS})**	**Q (1.2E_{EBCS})**	
Roof	0.0119	0.0101	15.3457
18th Floor	0.0082	0.0069	15.4378
17th Floor	0.0097	0.0081	15.6819
16th Floor	0.0109	0.0092	15.9061
15th Floor	0.0121	0.0101	16.0875
14th Floor	0.0139	0.0116	16.5462
13th Floor	0.0161	0.0134	16.8663
12th Floor	0.0182	0.0152	16.8614
11th Floor	0.0203	0.0169	16.7366
10th Floor	0.0222	0.0185	16.6094
9th Floor	0.0240	0.0200	16.5502
8th Floor	0.0254	0.0212	16.6004
7th Floor	0.0265	0.0221	16.6466
6th Floor	0.0270	0.0225	16.7865
5th Floor	0.0269	0.0223	16.9015
4th Floor	0.0260	0.0216	16.9840
3rd Floor	0.0242	0.0201	16.9315
2nd Floor	0.0219	0.0182	16.8426
1st Floor	0.0200	0.0166	16.7662
Ground Floor	0.0146	0.0121	16.7954
Basement 1	0.0076	0.0063	16.9498
Basement 2	0.0052	0.0043	16.7082

The result of the case study shows that a 20% increase in the static compression modulus of elasticity reduces the stability index by around 16% which is an indication that the story drift is reduced. A frame with a stability index of less than or equal to 0.1 is classified as non-sway which means the global second order effect is negligible. A frame which was initially sway could be made non sway by using a concrete with higher static compression modulus of elasticity.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The objectives of this study were to see the range of values of static compression modulus of elasticity of concrete mixes made using different coarse aggregate types found locally, to see the effect of coarse aggregate type on the static compression modulus of elasticity of concrete and to compare the correction factor recommended by Euro code with the result obtained.

Based on to the results of this study the following conclusions are drawn.

1. Type of aggregate has an effect on the value of compressive strength, static moduli and unit weight of concrete in compression.
2. The recommended empirical equation in Euro code approximately estimates the static modulus of elasticity of concrete made using basaltic coarse aggregates on the safe side.
3. Although the correction factor recommended by the code for concrete made using limestone aggregate considered in this study is lower it is on the safe side.
4. The recommended correction factor for light weight aggregate in general in Euro code results in higher static moduli for concrete made of scoria as coarse aggregate.
5. According to this study the correction factor for a concrete made of scoria aggregate recommended by the code is on the unsafe side.
6. The static compression modulus of elasticity is of great importance for the response structures. It significantly reduces the story drift of a structure if higher value of static compression modulus is used

5.2. Recommendation

The value of the static modulus of elasticity of concrete depends on many factors as it is discussed in the literature review. To be able to accurately estimate the static modulus of elasticity of concrete used in our country the effect of all other factors has to be studied and this study shall be repeated with larger sample size using 150mm diameter and 300mm height cylindrical molds for all possible grades of concrete.

5.3. Future Work Recommendation

- Effect of fine aggregate type on the static modulus of elasticity can be a case to be studied since this study might help because different types of fine aggregate are known to be suitable for concrete production but their effect on the static modulus is yet to be determined.
- The magnitude of the Effect of use of admixtures on the static modulus of elasticity of concrete. These days the use of admixtures to accelerate the hydration of cement and to get the required strength at short period of time is getting popularity.
- Effect of volume of coarse aggregate on the static modulus of elasticity. This can be an issue since we can achieve the same compressive strength at different coarse aggregate volume but the static modulus of elasticity can differ. This would help to have a concrete with a compressive strength and maximum possible static modulus of elasticity.
- Effect of cylinder size on the compressive strength of concrete and static compression modulus of elasticity of concrete.
- For this study the amount of water was fixed for all water cement ratios. Fixing the amount of cement and studying its effect could also be a case to be studied.

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APPENDIX: Mix Design Procedure

Material properties

1. Sand

Silt content	1.724%
Absorption capacity	1.419%
Saturated surface dry Specific gravity	2.577
Fines modulus	3.152

Gradation of fine aggregate

Sieve size (mm)	Weight of retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	Grading requirement
9.5	0	0	0	100	100
4.75	10	2	2	98	95-100
2.36	27	5.4	7.4	92.6	80-100
1.18	105	21	28.4	71.6	50-85
600	256	51.2	79.6	20.4	25-60
300	93	18.6	98.2	1.8	10-30
150	7	1.4	99.6	0.4	2-10
pan	2	0.4	100	0	

- From the above table the sand fulfills the grading requirement

2. Coarse aggregate

2.1.Basaltic coarse aggregate

Absorption capacity	1.84
Saturated surface dry Specific gravity	2.7
Loose unit weight of coarse aggregate	1679.056
Nominal aggregate size	19

2.2.Lime stone coarse aggregate

Absorption capacity	1..83
Saturated surface dry Specific gravity	2.573
Nominal aggregate size	19

Grading requirement for coarse aggregate with nominal aggregate size of 19mm

Sieve	Passing %	Retained %
19	90	10
12.5	60	30
9.5	25	35
4.75	0	25

1. Cement

Cement class	42.5R
Specific gravity	3.15

Note: - it is planned to perform mix design for a concrete made of basaltic aggregate and for the rest of the two aggregate types the volume of the basaltic coarse aggregate will be replaced by the same volume of the two aggregate types (not combined).

Grade of concrete	Specified Characteristic cylindrical strength	Target mean strength
C25	20	28
C30	24	32
C40	32	40

(For 5% defectives and standard deviation of 8)

Mix design according to DOE mix design manual.

Stage 1. Selection of target water/cement ratio

Portland cement class 42.

Slump required, 30-60mm

Maximum aggregate size, 19 mm

Grade of concrete	Specified Characteristic strength	Target mean strength	Target water/cement ratio
C25	20	28	0.59
C30	24	32	0.56
C40	32	40	0.51

Stage 2. Selection of free-water content

Slump required, 30-60mm

Maximum aggregate size, 19 mm

Grade of concrete	Specified Characteristic strength	Target mean strength	Target water/cement ratio	Approximate free water content
C25	20	28	0.59	210
C30	24	32	0.56	210
C40	32	40	0.51	210

Stage 3. Determination of cement content

Grade of concrete	Specified Characteristic strength	Target mean strength	Target water/cement ratio	Approximate free water content	Cement content
C25	25	33	0.59	210	356
C30	30	38	0.56	210	375
C40	40	48	0.51	210	412

Stage 4. Determination of total aggregate content

Free water content 210

Relative density=0.6*SPCA=0.4*SPFA=0.6*2.7*0.4*2.577=2.6508

Wet density of concrete mix=2360Kg/m^3

Grade of concrete	Specified Characteristic strength	Target mean strength	Target water/cement ratio	Total aggregate content
C25	25	33	0.59	1794
C30	30	38	0.56	1775
C40	40	48	0.51	1738

Stage 5 Selection of fine and coarse aggregate contents

Percentage passing 600µm sieve=20.4%

Nominal aggregate size=19mm, and slump=30-60mm

Grade of concrete	Specified Characteristic strength	Target mean strength	Target water/cement ratio	Total aggregate content	Proportion fine aggregate %
C25	25	33	0.59	1794	40
C30	30	38	0.56	1775	36
C40	40	48	0.51	1738	35

The above result is obtained considering all the aggregates are in SSD condition as a result the amounts will be adjusted based on the moisture content an absorption capacity of the aggregates.

The above quantities of the ingredients are obtained for 1m^3 of concrete. We have 72 cylindrical samples of 10*20 cm sizes. Volume of one sample is 0.00157. We need 0.11309m3 of concrete for our samples. But considering wastage of concrete during preparing the samples we will prepare a total of 0.12723m^3 of concrete.

From the data we have on the properties of aggregates we can determine the volume of limestone aggregate required to replace the volume of basaltic aggregate whose property is used for the above mix design.

Specified Characteristic strength	Target mean strength	Target water/cement ratio	basaltic coarse (Kg/m^3)	Volume of basaltic
25	33	0.59	1076	0.3985
30	38	0.56	1136	0.4207
40	48	0.51	1130	0.4185

Aggregate type	Water/cement ratio	Required volume of concrete	Required water	Required cement	Required fine aggregate	Required coarse aggregate
basaltic	0.59	0.016	3.54	5.53	10.11	16.49
	0.56	0.016	3.54	5.99	9.41	16.73
	0.51	0.011	2.48	4.85	6.17	11.46
Lime stone	0.59	0.011	2.48	3.87	7.08	11.55
	0.56	0.011	2.48	4.19	6.59	11.71
	0.51	0.011	2.48	4.85	6.17	11.46
scoria	0.59	0.011	2.48	3.87	7.08	11.55
	0.56	0.011	2.48	4.19	6.59	11.71
	0.51	0.011	2.48	4.85	6.17	11.47

Required weight of coarse aggregate by size

Aggregate type	Water/cement ratio	Required coarse aggregate	19	12.5	9.5	4.75
basaltic	0.59	16.49	1.645	4.95	5.77	4.12
	0.56	16.73	1.67	5.02	5.85	4.18
	0.51	11.46	1.15	3.44	4.01	2.87
	0.46	11.29	1.13	3.39	3.95	2.82
	0.4	11.21	1.12	3.36	3.92	2.80
	0.32	10.78	1.08	3.23	3.77	2.69
Lime stone	0.64	11.55	1.15	3.46	4.04	2.89
	0.59	11.71	1.17	3.51	4.09	2.93
	0.51	11.46	1.15	3.44	4.01	2.87
scoria	0.64	11.55	1.15	3.46	4.04	2.89
	0.59	11.71	1.17	3.51	4.09	2.93
	0.51	11.46	1.15	3.44	4.01	2.87

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