Correlation of Static and Dynamic modulus of Elasticity for Different SCC Mixes

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Abstract:- For an existing structure static modulus of elasticity of concrete cannot be determined but dynamic modulus of elasticity can be determined by using non destructive testing (NDT) method. The value obtained by NDT cannot match exactly with the static modulus of elasticity but have certain relationship with it. Hence, correlation is required. Self compacting concrete is growing trend in advanced countries. Therefore to know the quality of SCC used in the structures it was proposed to study the relation between the static and dynamic modulus of elasticity of different grades, mixes of SCC. The objective of this study is to compare the static and dynamic modulus of elasticity and the strength of self compacting concrete using silica fume and fly ash. A simple mix design for SCC Proposed by Nan-su method has been used for fixing the trial mixes.

Keywords:- *Self compacting concrete; Silica Fume; fly ash; Non destructive testing method*

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1. Introduction

1.1 Development of Self Compacting Concrete

The development of self compacting concrete (SCC) has been one of the most important development in the building industry. The purpose of this concrete concept is to decrease the risk due to human factor. The use of SCC is spreading worldwide because of its very attractive properties. Self compacting concrete has properties that differ considerably from conventional slump concrete. SCC is highly workable concrete that can flow through densely reinforced and complex structural element under its own weight and adequately fill all voids without segregation, excessive bleeding, excessive air migration or other separation and materials and without the need of vibration or other mechanical consolidation. The use of SCC is considered to have a number of advantages as:

- Faster placement
- Better consolidation around reinforcement.
- Easily placed in the walled element
- Improves the quality, durability and reliability of the concrete structures.
- Reduces the total time of construction and the cost.[1]

1.2 Static modulus of elasticity

The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformation by means of dial gauge fixed between certain gauge lengths. Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress. A series of reading are taken and the stress-strain relationship is established.

The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formulae for deflection and substituting other parameters the modulus of elasticity so found out from actual loading is called static modulus of elasticity. it is seen that even under short term loading concrete does not behave as an elastic material . however, up to about 10-15 % of the ultimate strength of concrete , the stress strain graphs is not very much curved and hence can give more accurate value. For higher stress the stress-strain relationship will be greatly curved and as much it will be inaccurate. Fig.1.1 shows stress-strain relationship for various concrete mixes.[2]

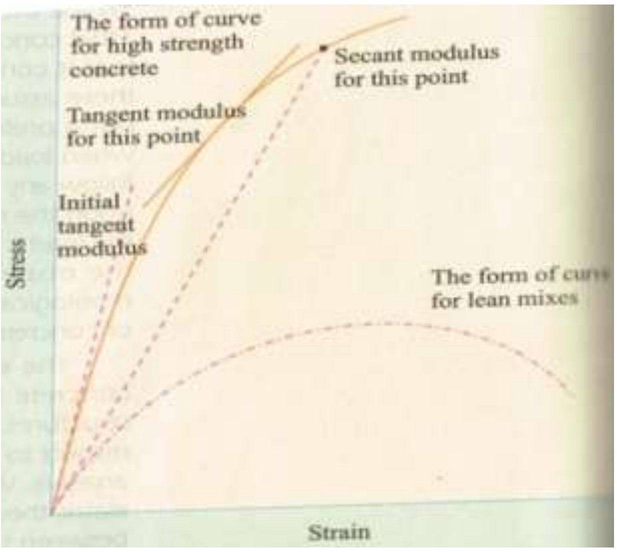

Fig. 1.1 : The different modulus of elasticity

Determination of static modulus of elasticity by Initial tangent modulus of concrete :

It is a slope of the tangent drawn from origin to the stress strain curve. Same method has been used in present investigation to determine static modulus of elasticity.

Procedure_:

Initial tangent modulus of a concrete specimen determined by following steps

i) The cylindrical specimen is subjected to a load upto 15% of its strength and stress strain curve is plotted.

ii) Draw a tangent line to the curve that starts from origin.

iii) This line should touch with the curve at origin.

iv) Determine the slope of this initial tangent which represents the static modulus of elasticity.

This value gives stress strain relationship for working loads.

1.3 Dynamic modulus of elasticity

The stress strain relationship of concrete exhibits complexity particularly due to the peculiar behavior of gel structure and the manner in which the water is held in hardened concrete. The value of E is found out by actual loading of concrete i.e the static modulus of elasticity does not truly represent the elastic behavior of concrete. Due to the phenomenon of creep the elastic modulus of elasticity will get affected more seriously at higher stress when the effect of creep is more pronounced.

Attempts have been made to find out the modulus of elasticity from the data obtained by non-destructive testing of concrete. The modulus of elasticity can be determined by subjecting the concrete member to longitudinal vibration at their natural frequency. This method involves the determine of either resonant frequency through a specimen of concrete or pulse velocity travelling through the concrete by making use of the above parameters modulus of elasticity can be calculated from the following relationship.

$$Ed = kn^2 L^2 P$$

where,

Ed - is the dynamic modulus of elasticity

K - is constant

N- is resonant frequency

L- is length of specimen

P - is the density of concrete.

The value of dynamic modulus of elasticity can also be computed from UPV method as below.

Ultrasonic Pulse velocity method

This can be sub divided into two parts

a) Mechanical sonic pulse velocity method which involves measurement of the time travel of longitudinal or compression waves generated by a single impact hammer blow or repeated blows.

b) Ultrasonic pulse velocity method , which involves measurement of the time of travel of electronically generator mechanical pulse through the concrete.

Out of these two, the ultrasonic pulse method has gained considerable popularity all over the world. When mechanical impulses are applied to a solid mass, three different kind of waves are generated. These are generally known as longitudinal waves, shear waves and surface waves. These three waves travel at different speeds. The longitudinal or compression waves travel about twice as fast as the other two types the shear or transverse waves are not so fast, the surface waves are the slowest.

The pulse can be generated either by hammer blows or by the use of an electro acoustic transducer. electro acoustic transducer are preferred as they provide better control on the type and frequency of pulse generated. The instrument used is called " soniscope ".

Ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse, passing through the concrete to be tested the pulse generator circuit consist of electronic circuit for generating pulse and a transducer for transforming these electronic pulse into mechanical energy having vibration frequencies in the range of 15 to 50 kHz. The time travel between initial onset and the reception of the pulse is measured electronically the path length between transducer divided by the time of travel gives the average velocity of wave propagation.

Determination of dynamic modulus of elasticity by UPV

From measurement of ultrasonic waves velocity it is possible to calculate the elastic dynamic modulus E_d as follows

$$E_d = v^2 Q * (1+n)*(1-2n)/(1-n)$$

Where,

V = velocity in km/s

Q = concrete density in kg / m^3

N = poisson's ratio (for high strength concrete N = 0.15 , For low strength concrete N = 0.30)

E_d = dynamic elastic modulus.

2. MATERIALS AND THEIR PROPERTIES

2.1 Materials

2.1.1 Cement

In this experimental study, Ordinary Portland Cement 53 grades, conforming to IS: 8112-1989 was used. The different laboratory tests conducted on cement to determine the physical and mechanical properties of the cement used are shown in Table-1

Table 1: Properties of Cement

Physical Property	Result
Normal Consistency	**29%**
Vicat initial setting time (minutes)	**75 min.**
Vicat final setting time (minutes)	**482 min.**
Specific gravity	**3.15**

2.1.2 Aggregates

Locally available natural sand with 4.75 mm maximum size conforming to class II- IS 383 was used as fine aggregate, having specific gravity, fineness modulus and unit weight as given in Table 2 and crushed stone with 16mm maximum size having specific gravity, fineness modulus and unit weight as given in Table-2 was used as coarse aggregate. Table-2 gives the physical properties of the coarse and fine aggregates.

Table 2: Physical Properties of Coarse and Fine Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.5	2.85
Fineness Modulus	2.8	7.44
Particle shape	Rounded	Angular

2.1.3 Water

Ordinary potable water available in the laboratory was used.

2.1.4 Fly Ash:

Fly ash is a by-product obtained by burning coal at thermal power plants. For this study FA was obtained from Dirk India Company pvt. Ltd. Eklehra, Nashik. The physical properties of fly ash have been shown in Table-3 and chemical properties have been shown in Table-4.

Table 3: Physical Properties of Fly Ash:

Sr. No.	Physical Properties	Test Results
1	Colour	Grey
2	Specific Gravity	2.13

Table 4: Chemical Properties of Fly ash:

Sr. No.	Chemical Properties	Test Results
1	Loss on ignition	4.17
2	Silica(SiO_2)	58.55
3	Iron Oxide(Fe_2O_3)	3.44
4	Alumina (Al_2O_3)	28.20
5	Calcium Oxide (Cao)	2.23
6	Magnesium Oxide (MgO)	0.32
7	Total Sulphur (SO_3)	0.07

2.1.5 Silica Fume:

Silica fume is obtained from Elkem Ind. Pvt. Ltd. Vashi Navi Mumbai. SF having specific gravity 2.2 as a filler material has been used. Chemical composition of SF is given in table-5.

Table 5: Chemical composition of Silica Fume:

Sr. No	Constituents	Quantity (%)
1	SiO_2	91.03
2	Al_2O_3	0.39
3	Fe_2O_3	2.11
4	CaO	1.5

2.1.6 Super plasticizers

Super plasticizers or high range water reducing admixture is an essential component of SCC. It is used to provide necessary workability. Glenium B233 (modified P.C. based) was obtained from BASF India Limited, Nagpur.

3. EXPERIMENTAL WORK

3.1. Mix Design:

The mix proportion was done based on the method proposed by Nan Su et al. [3]. The mix designs were carried out for concrete grades 60. This method was preferred as it has the advantage of considering the strengths of the SCC mix. The final mixes were arrived after making some changes to meet the strength and self-compacting ability criteria. The details of mixes are given in table-6. All the ingredients were first mixed in dry condition in a mixer. Then 70% of calculated amount of water was added to the dry mix and mixed thoroughly. Then 30% of water was mixed with the super plasticizer and added in the mix. Then the mix was checked for self compacting ability by slump flow test, v-funnel test and L-box test.

Table 6: Mixture proportion for 1m^3 of SCC

Specimen	Cement (kg/m^3)	Sand (kg/m^3)	Course aggregate (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	Water (kg.)	Super plasticizer (kg.)
S_0	437	1048	927.4	150	0	176	5.283
S_{10}	437	1048	927.4	135	15	176	5.413
S_{20}	437	1048	927.4	120	30	176	5.625
S_{30}	437	1048	927.4	105	45	176	5.895
S_{40}	437	1048	927.4	90	60	176	6.025
S_{50}	437	1048	927.4	75	75	176	6.231
S_{60}	437	1048	927.4	60	90	176	6.416
S_{70}	437	1048	927.4	45	105	176	6.538
S_{80}	437	1048	927.4	30	120	176	6.687
S_{90}	437	1048	927.4	15	135	176	6.819
S_{100}	437	1048	927.4	0	150	176	7.044

3.2 Design of mix:- The design mix is carried out by the specified method by NAN-SU Scientist in Japan.

3.3 Batching ingredients:- The various ingredients required for SCC mix were taken by weight batching.

3.4 Mixing of ingredients:- All the ingredients taken by weight batching. Then in mixer all the ingredient are mix in dry condition. Then 70% of calculated amount of water was added to the dry mix and mixed it thoroughly. Then 30% of water was mix with super plasticizer and added in mixer. Then the mix was check for self compacting ability by different tests.

3.5 **Self Compactability tests on mixes:-** Various tests are conducted on the trial mixes to check for their acceptance and self Compactability properties. The tests included slump Flow test and V-funnel tests for checking the filling ability and L-box test for the passing ability. The mixes are checked for the SCC acceptance criteria suggested by EFNARC (2002) given in table no. 7.

Table 7: SCC - Acceptance Criteria

Method	Properties	Range of values
Flow value	Filling ability	650-800mm
V-funnel	Viscosity	6-12 sec
L-box	Passing ability	0.8-1.0

3.5.1 Slump Flow Test:

Slump flow &T500 time is a test to assess the flow ability & the flow rate of SCC in the absence of obstructions. It is based on the slump test described in EN 1235-2. The result is an indication of the filling ability of SCC, & the T500 time is a measure of the speed of flow &hence the viscosity.

In this experimental work, the slump value of fresh concrete was obtained in the range of 680mm to 730mm. The result shows in Table-8.

3.5.2 L-Box

L- Box test is used to assess the passing ability of SCC to flow through tight openings including spaces between reinforcing bars & other obstructions without segregation of blocking. The passing ability is calculated from the following equation: PA=H2/H1. In this experimental work, the. L-Box value of fresh concrete was obtained in the range of 0.8cm to 0.94cm.The result shows in Table-8.

3.5.3 V- Funnel Test

The V-funnel test is used to assess the viscosity & filling ability of SCC. T_v is the V-funnel flow time. In this experimental work , The V- Funnel value of fresh concrete was obtained in the range of 8.65 to 11.35 sec. The result shows in Table-8.

3.6 Preparation of Cylinders: At a time 3 cylinders were cast in the laboratory of size 15 cm x 30 cm. The casting of cylinder was done as follows. First of all the moulds used for casting purpose were oiled from inside so that the concrete does not stick to the surface. Immediately after mixing, the concrete which fulfilled the acceptance criteria of SCC were filled in cylindrical mould. The temperature of water and test room was as specified i.e. 27^0 C + 2^0C during the above operations.

3.7 Curing of cylinders:- The prepared cylinders were kept at a temperature of 27^0C ± 2^0C in an atmosphere of at least 90% relative humidity for 24 hrs from the time of addition of water to dry ingredients. At the end of this period concrete cylinders were taken out of mould for curing purpose. The method of curing was by pounding. In this method after taking out cylinders from the moulds they were immediately submerged in clean and fresh water for curing and kept for 28 days till they were taken out for testing purpose.

3.8 Testing of cylinders:- These cylinders were removed turn by turn and the UPV was tested after 28 days of curing of each set of cylinders. The static modulus of elasticity of cylinders was tested in compressive testing machine.

a) **Static modulus of elasticity**
Cylindrical specimens were used to determine static modulus of elasticity. The cylinders were attached with the dial gauge. The contraction in the length of the cylinder was measured at every 20 KN load interval up to 180 KN. The stress and strain for each reading were calculated and the stress-train curve for every specimen was drawn.

The initial slope of the stress strain diagram gives static modulus of elasticity.

b) **Dynamic modulus of elasticity**

By the direct transmission of ultrasonic pulse the dynamic modulus of elasticity was determined.

4. TEST RESULTS

4.1 Fresh Properties of SCC Mixes

Various tests were conducted on the trial mixes to check for their acceptance and self compacting properties. The tests included slump flow test and V-funnel tests for checking the filling ability and L-box test for passing ability. The mixes

ISSN: 2321-8169
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were checked for the SCC acceptance criteria suggested by EFNARC (2002) given in table-7.

Table 8: SCC Test Results of SCC Mixes

Specimen	Slum flow (mm)	V-funnel (sec.)	L-box (cm)	Segregation	Remark
S_0	700	9.76	0.91	No	SCC
S_{10}	710	11.35	0.91	No	SCC
S_{20}	700	10.43	0.85	No	SCC
S_{30}	720	11.1	0.86	No	SCC
S_{40}	730	10.5	0.92	No	SCC
S_{50}	680	11.6	0.88	No	SCC
S_{60}	730	9.36	0.87	No	SCC
S_{70}	685	10.11	0.92	No	SCC
S_{80}	700	9.74	0.89	No	SCC
S_{90}	730	11.1	0.87	No	SCC
S_{100}	700	8.65	0.94	No	SCC

The result of the self compact ability tests are tabulated in table-8. All the mixes satisfied the acceptance criteria for self compacting concrete. Hence these mixes were chosen as the successful mixes.

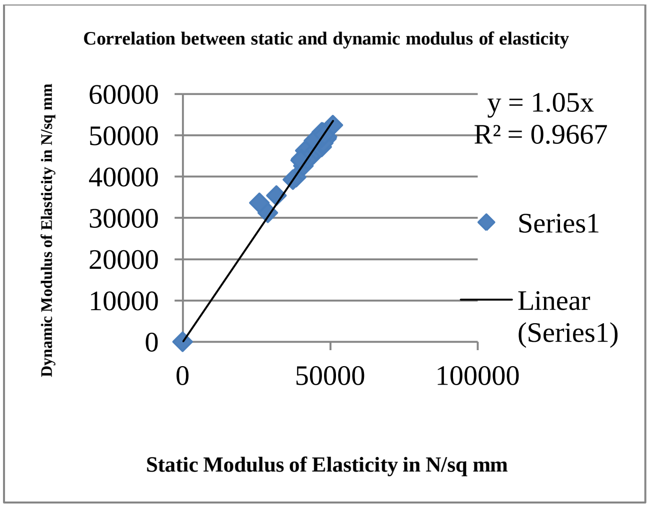
Static modulus of elasticity (Ec) : - The result of static modulus of elasticity have been shown in table 9. The range of static modulus of elasticity of different SCC specimens was between 26035 MPa and 50945 MPa.

Dynamic modulus of elasticity(Ed):- It can be observed that E_d for every specimen is greater than Ec . The correlation between dynamic and static modulus of elasticity has shown in following table and graph shows The correlation is represented by straight line with equation **Ed = 1.05 Ec.** i.e. **Ed is 5% greater than Ec.** the correlation can be considered as very good as the coefficient of correlation R^2 is very near to 1 i.e. having value equal to 0.966.

The self compacting concrete has uniform consistence and hence the values of static and dynamic modules could be correlated. The even distribution of matrix due to uniformity in concrete mass is possible in SCC than in normally vibrated concrete. That is why the results are so consistent.

Table 9: Result of Ec and Ed

specimen	Static Modulus of Elasticity Mpa	Dynamic Modulus of Elasticity (Mpa)
S0	0	0
S0-A	50945	52487
S0-B	45766	48298
S10-A	47174	50744
S10-B	48762	49204
S20-A	46777	47658
S30-A	48949	49629
S30-B	44077	45314
S30-C	38495	39873
S40-A	45621	46557
S40-B	31817	35420
S40-C	47158	47206
S50-A	44622	46212
S50-B	41610	46317
S60-A	47684	48154
S60-B	44064	45409
S70-A	43167	44985
S70-B	47073	49387
S80-A	40247	44302
S80-B	37408	39279
S80-C	40966	42634
S90-A	45648	48927
S90-B	42258	44125
S90-C	28894	31247
S100-A	26035	33658
S100-B	44529	48714
S100-C	40038	43969



graph 1. Correlation of static modulus and dynamic modulus of elasticity

ISSN: 2321-8169
4914 - 4919

6. CONCLUSIONS

- The UPV test can be effectively used to determine dynamic modulus of elasticity of high Strength SCC.
- On site determination of modulus of elasticity of pre existing SCC members by UPV method can be considered reliable.
- Dynamic modulus of elasticity and static modulus of elasticity can be correlated and E_d is 5% greater than Ec for high strength SCC.
- There exists linear relationship between static and dynamic modulus of elasticity of high strength SCC.

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