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EXPERIMENTAL INVESTIGATION OF STRENGTH OF VARIOUS HARDENED CONCRETE MIXES

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Abstract: In this paper, the relationship between the modulus of elasticity and dynamic elastic modulus of concrete and the relationship between the modulus of elasticity and compressive strength of concrete have been formulated. These relationships are based on investigations of different types of concrete and take in to account the type and amount of aggregate and binder used. The dynamic elastic modulus of concrete was tested using ultrasonic pulse velocity method. This method could be used as a non-destructive way of estimating the compressive strength of concrete and dynamic elastic modulus. Here we show, from an extensive experimental program including non-destructive (ultrasonic pulse velocity test) and destructive tests (compressive testing machine) carried out on 54 cylindrical concrete specimens with three different concrete mixtures and three different sizes, the size independence of elastic properties of concrete regardless of the concrete mixes. This is in full contrast with the size-dependence of the compressive strength. the use of empirical expressions given in building codes (e.g., ACI 363 R-10, Eurocode 2) for estimating the elastic modulus from the compressive strength can lead to incorrect designs.

Index Terms: Concrete, dynamic elastic modulus, static elastic modulus, non-destructive testing, compressive strength.

I. INTRODUCTION

The compressive strength and modulus of elasticity are the most important properties of concrete from the viewpoint of structural design. Commonly, these parameters are determined by the uniaxial compression of cylindrical according to standard procedures, and so values obtained that way are considered to be the reference values. However, it is not always possible to use these methods in practice because they are destructive and require the collection of numerous test samples during concreting operations. In addition, properly conducted modulus of elasticity testing using cylindrical specimens is a relatively time-consuming process. Therefore, we seek non-destructive methods in order to estimate these parameters for hardened concrete, such as ultrasonic pulse velocity method.

Technological developments and better access to more appropriate apparatus has resulted in significant progress in the dynamic testing methods used in structural health monitoring. These methods could also be used in concrete material parameter testing (especially compressive strength) or to monitor its increase over time. A significant disadvantage of non-destructive methods is the fact that the values are achieved indirectly, i.e., the results of each test have to be converted to a certain parameter (e.g., the compressive strength of concrete) using a previously assumed relationship between these values.

Many empirical predictions for estimating the elastic modulus from the compressive strength have been proposed for different types of concrete by several researchers. In most concrete design codes, the modulus of elasticity is also predicted by using empirical expressions that assume a direct dependence of this modulus on compressive strength. Following these expressions, an increase of the compressive strength would necessarily imply an increase of the modulus of elasticity. Modulus of elasticity increases with increasing compressive strength. Therefore, the sample size dependence of compressive strength would imply, from these empirical expressions i.e., size of concrete sample also affects modulus of elasticity. Nevertheless, in a composite material like concrete, the elastic properties are mainly affected by the volume fraction, the density and the elastic modulus of its two components which are the hydrated cement paste and the aggregates. A large number of mechanical tests performed on concrete specimens with different sizes and different mixtures to obtain a statistically significant result. Conclusion regarding the size effects on the Young's modulus of concrete is difficult to make clear and strong.

II. BACKGROUND

The static Young's modulus (E) is defined as the ratio of the axial stress to axial strain for a material subjected to uni-axial load. It is important that E of concrete be known because engineers increasingly use this value in the structural design process. For example, E is needed to analyses the cross-sectional response of a reinforced concrete beam. In recent years building specifications have even required a specific E of concrete to be met, mostly to limit excessive deformation and sway in tall buildings.

However, once a structure is erected the in-situ elastic properties cannot be measured directly without damaging the structure itself. Most often E is inferred from the compressive strength (fc) of companion cylinders, rather than being measured directly, through the application of established empirical relations. This approach often leads to overly conservative results because, in order to meet the minimum E requirement, concrete with much higher fc is used than the specification requires, which leads to unnecessarily high material costs. Enhanced understanding of the relation between E and compressive strength, with respect to different types of concrete, would improve the efficacy of the estimation of E from strength.

For equation of the modulus of elasticity and compressive strength of concrete, numerous empirical equations have been proposed by many researchers most of them given a correlation between compressive strength and static elastic modulus which are measured by uni-axial compression test and another correlation is between compressive strength and dynamic elastic modulus which are measured by ultrasonic pulse velocity or resonant frequency. The standard ACI 363 R – 10 (2010) [5] gives the following equation of static elastic modulus and compressive strength.

$$E_c = 3320(f'_c)0.5 + 6900 \tag{1}$$

Where, E_c is static elastic modulus in MPa. f'_c is the specified compressive strength of cylindrical concrete samples in MPa. Equation (1) is valid for compressive strength between 21MPa & 83MPa.

According to Eurocode 2 (2008) [6], the relationship between the static elastic modulus and compressive strength of light weight concrete is described by the following equation.

$$E = 22000\left(\frac{f}{10}\right)0.3\eta_E \tag{2}$$

Where, E = Static elastic modulus, $\eta_E = (\rho/2200)2$,
ρ = Upper limit value of the concrete density, f is compressive strength of light weight concrete. Equation (2) is valid for compressive strength between 35MPa & 60MPa. Both the ACI 363 R – 10 (2010) (equation 1) based on specified compressive strength in MPa. and Eurocode 2 (2008) (equation 2) based on average compressive strength in MPa.

As for the ACI building codes, the Architectural Institute of Japan (AIJ) [7] propose the following equation to estimate the static elastic modulus Y_S for normal strength concrete with the specified design strength (f_c) up to 36 MPa.

$$E = 2.1 * 10^5\left(\frac{\Upsilon}{2.3}\right)^{1.5}\left(\frac{f_c}{200}\right)^{0.5} \tag{3}$$

In equation (3), E is static elastic modulus, fc is compressive strength and ϒ is unit weight in kg/m3.

Concretes with the same target compressive strength (i.e. strength grade) may have different elastic moduli. Other empirical formulas relating the compressive strength to the elastic modulus can be found in other current building codes and from other studies, such as those presented in Table 1. Even though these empirical formulas could provide good agreements for specific kinds of concrete mixes, they do not always give the same results and cannot cover the whole data. The major reason for this is that the mechanical properties (i.e. compressive strength and elastic modulus) of concrete are highly dependent on the qualities, specified properties and proportions of all concrete components. Although there is no agreement on the precise form of the relationship between the compressive strength and the static modulus of elasticity of concrete, all these previous studies agree that the static elastic modulus and the compressive strength are always positively correlated [1,2,3,4]. A similar trend is also reported in for the dynamic elastic modulus which is determined by means of Non-Destructive Testing (NDT) methods (e.g. Ultrasonic pulse velocity (UPV) test [8,9,10,11], Resonant frequency test [12], and other wave propagation tests. A few formulas have also been proposed in the literature to describe the relationship between and the compressive strength of concrete, as listed in Table 2. These empirical equations were found by converting the dependency of the static modulus on the dynamic modulus into the relationship between the static modulus and the compressive strength [8,9,10,11,12]. However, both the value of the dynamic elastic modulus and its relation with the compressive strength vary with the NDT methods [8,9,10,11], the mix proportion [19], the volume content and the size of aggregates [19], the type of cement and aggregate [19], the water-to-cement ratio [19], the age of concrete and curing condition. The empirical equation for correlation between dynamic elastic modulus and the compressive strength are generally specified to concrete mixes or various non – destructive testing methods, the relationship between static elastic modulus and dynamic elastic modulus. To analyses the correlation between the static elastic modulus and dynamic elastic modulus, a considerable number of studies have been performed. Non-destructive methods of concrete testing are commonly based on experimentally derived relationships. The accuracy of the methods mentioned is highly dependent on the assumptions made. The literature survey, as well as experimental tests, demonstrated that widely used relationships are not appropriate to all types of concrete, especially in the case of concrete containing mineral additives. To account for relationship between static elastic modulus and dynamic elastic modulus, some empirical equations have been proposed in building codes. Few studies suggest that the relation between static elastic modulus and dynamic elastic modulus is linear [15] while few studies suggest that the correlation is non-linear. Logan Trifone [14] observed that only four different concrete mixes were tested. Additional concrete mixes, and an overall larger sample size should be studied to acquire more accurate results.

Table 1: Empirical relations of static elastic modulus with compressive strength.

References	Equation for static elastic modulus	Range of Concrete strength
K. Jurowski (2018)	$E_{cs} = 43.\rho^{1.5}.f_c^{0.5}.10^{-6}$	$20.00 < f_c < 120$ MPa
E. Kadhem (2018)	$E_c = 14000(f'_c)^{0.25}$	$70.00 < f_c < 140$ MPa
T. V. Gowri (2018)	$y = 303.38x^{1.199}$	20.0 $f_c < 70$ MPa
A. R. Nazhivi (2014)	$E_s = (f_c/11.05)^{1.5}$	$25.10 < f_c < 180$ MPa
ACI 363 – 10(2010)	$E_c = 3320(f'_c)^{0.5}+6900$	$21.00 < f_c < 83$ MPa
Eurocode 2 (2008)	$E = 22000(f/10)^{0.3}\eta_E$	$35.00 < f_c < 60$ MPa
T. Noguchi	$E = 2.1 \times 10^5(Y/2.3)^{1.5}(f_c/200)^{0.5}$	Up to 36 MPa

E_{cs}, E_c, Y, E_s, E = static elastic Modulus.
F_c, f'_c, X = Compressive strength.
$\eta_E = (\frac{\rho}{2200})^2$, ρ = Upper limit value of the concrete density.
ϒ = Unit Weights.

Table 2: Empirical relations of dynamic elastic Modulus with compressive strength.

References	Equation for dynamic elastic modulus	Type of Concrete	NDT method
F. G. Moghadam (2021)	$E_d = 0.0016(cs)^2-0.1521(cs)+45.87$	MRPC Concrete	UPV test
R. R. Kumar (2019)	$y = 0.5078\ e^{0.0774x}$	Normal Concrete	UPV test
P. P. Chavhan (2015)	$y = -0.0197x^3-1.0623x^2+828.17x$	SSC	UPV test
Y. Zohu (2015)	$E_d = f^n_c + b$	Young Concrete	UPV test
S. Hun Han (2004)	$E_d = [(f'_c/\alpha)^{1/\beta}]/[1-0.708e^{-0.0268Ed}]$	Normal Concrete	Resonant Frequency test

E_d, Y = Dynamic elastic Modulus (Gpa)
C_s, x, f'_c = compressive strength of concrete in (Mpa).
a = More related to the volume content of aggregate (V_{agg}) and maximum coarse aggregate size (M_{agg}).
b = Coefficient b is influenced by the volume content of aggregate, maximum Coarse aggregate size and water-to-cement ratio (w/c).
α & β = Constant.
MRPC = Modified reactive powder concrete.
SCC = Self -compacting concrete.

Due to time constraints, the specimens were only studied up until 28-days. Specimens should be tested at much longer lengths of time to determine if the relationships between moduli values remains constant, or if they continue to converge even more at later ages. Dr. Mohammed M. Salman [17] observed that there is a simple linear relationship between the static and dynamic elastic moduli, which leads to predict that using dynamic elastic modulus may remove the problems in measuring the static elastic modulus of concrete. Byung Jae Lee [13] observed that with an established equation between static and dynamic elastic modulus, the dynamic elastic modulus can be used to estimate the compressive strength of cylinders. It demonstrated that the predetermined equations relating dynamic to static elastic modulus are effective for estimating compressive strength within reasonable errors. Other empirical formulas relating the static elastic modulus and dynamic elastic modulus is presented in Table 3.

By analysing the literature several important questions arises:

i. Is there any dependency of elastic modulus of concrete on sizes of samples?

ii. Is there impact on relationship between static and dynamic modules of elasticity of concrete with sample sizes?

iii. Considering well-established size effects on compressive strength and suggested empirical relationships between compressive strength and elastic modulus, what could be the inference in terms of the estimation of elastic properties of concrete from data by strength? And consequently, in terms of design of concrete structural elements?
iv. Does the elastic modulus of concrete depend on material used and it sizes?

By analysing and considering we have carried experimental program on 54 cylindrical specimens with three different concrete mixes and three different sample sizes the detail of this experimental research is described in next section.

III. EXPERIMENTAL WORK

To answer the question of present research a testing plan was design to explore the size effect on compressive strength, static elastic modulus and dynamic elastic modulus of concrete as shown in flow chart of fig 1. For experimental studies total 54 specimens of cylindrical shape with different sizes (ϕ = 63mm, 90mm & 130mm) were prepared in the laboratory. The specimens made up of three different concrete mixes based on three different aggregate sizes (dg = 3.36mm, 15mm, 24mm). In the present work concrete cylinders with a constant height-to-diameter ratio (h/ϕ = 2). Concrete was cast in standard plastic moulds with dimensions of (ϕ = 63mm, 90mm). 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. After weighting all raw composition materials, cement and aggregates are firstly blended for dry mix. After that, a small quantity of water is added and mixed for a while. Finally, remaining water is added and continuously mixed before pouring into the concrete molds. Immediately after mixing, the concrete which fulfilled the acceptance criteria were filled in mould and placed in a curing chamber within 30 minutes. Plastic molds were removed after 24 h. All the specimens were cut by hexa blade to ensure both the ends to be perpendicular to the sides of the sample and avoid flexural stress upon loading. specimens were cured in a water pond. Both non – destructive test and destructive test were carried out for this experimental study. The dynamic elastic modulus was determined by using non – destructive test. For this purpose, 54 P-wave velocity measurements (Sect. 3.3) were conducted on intact concrete specimens and 54 uniaxial compression test i.e. destructive test was performed. Compressive failure strength and static elastic modulus for different concrete samples was collected using that destructive test. In this paper all the data are used to examine (i) the effect of size is on static elastic modulus and dynamic elastic modulus of concrete. (ii) static elastic modulus and dynamic elastic modulus of concrete correlation between these two. (iii) The relation between compressive strength and static elastic modulus. (iv) The relation between compressive strength and dynamic elastic modulus.

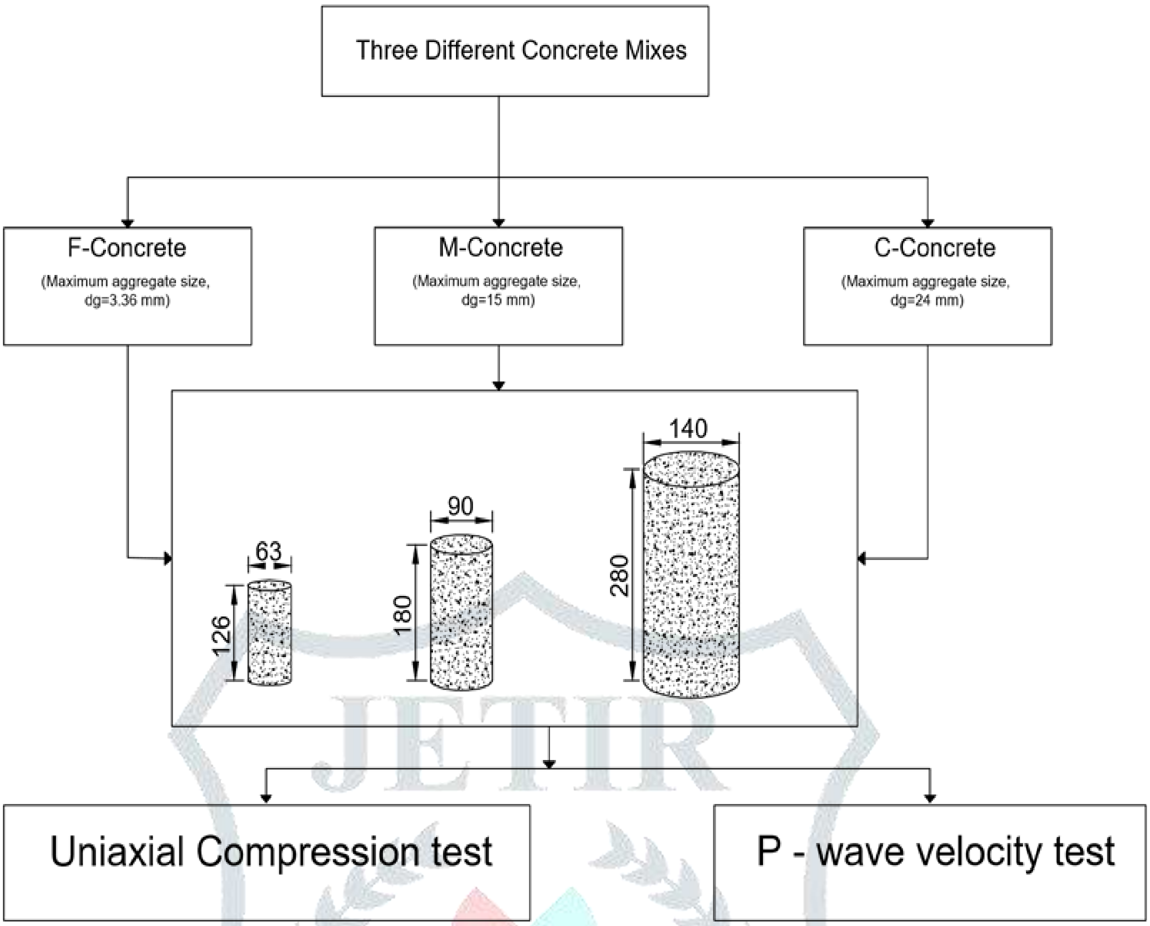
Table 3: Empirical relationship between the static and dynamic elastic moduli of concrete.

References	Equation	Type of Concrete	Type of static elastic modulus	NDT method
B. J. Lee (2017)	$E_c = aE_d^b$	Normal strength concrete	Tangent	Resonant Frequency test
L. Trifone (2017)	$E_{UPV} = 1.16E$	Self-Compacting concrete	Secant	UPV
P. P. Chavhan (2015)	y= 1.05x	Self-Compacting concrete	Secant	UPV
J. S. Popovics (2008)	$E_s = kE_d^{1.4}.\ r^{-1}$	Light weight concrete	Secant	UPV
M. M. Salman (2006)	$Y_d=5.82(E_c)^{0.63}$	Normal strength concrete	Secant	UPV
Shraddhu S	$E_c = 1.04E_d - 4.1$	Light weight concrete	Secant	UPV

E_c, E, E_s, x = Static elastic modulus.
E_d, y, Y_d, E_{upv} = Dynamic elastic modulus.
a & b = Constant according regression analysis.
k = 0.23 for units of psi.
UPV = Ultrasonic pulse velocity.

IV. MATERIALS AND CONCRETE MIXTURES

For this project Portland pozzolana cement (PPC) 53grade cement was used for preparing all concrete mixtures. The sand used for the experimental programmed was procured in DBATU collage the sand was first sieved through 3.36 mm sieve to remove any particles greater than 3.36mm and then was washed to remove the dust. The aggregates were sieved through a set of sieves of 3.36 mm, 2.36 mm, 1.18 mm, 0.75 mm and pan to obtain sieve analysis. The similar sieve analysis was done for medium size aggregate having fineness modulus 6.78 and coarse aggregate having fineness modulus 9.07. Crush sand was used as fine aggregate. The bulk specific gravity in oven dry condition of the sand as per IS 2386 (Part III) 1963 were 2.64. The gradation of the sand was determined by sieve analysis as per IS: 383-1970. Fineness modulus of sand was 3.321. The aggregate used for this project for casting the concrete were clean and dry and their specific properties compiles with the requirement. The aggregates are distributed according to their size with the help of sieve analysis which is shown in fig 1. Normal tap water was used for mixing and curing of concrete samples in this study. we prepared three different concrete mixtures based on three different aggregate sizes (Fine (F; i.e. only sand), Medium (M), Coarse (C)). For this we have made 18 specimens of fine aggregate, 18 specimens of mixture of fine and medium aggregate and 18 specimens of mixture of fine and coarse aggregate. The maximum aggregate size dg for fine it was 3.36mm, for medium it was 15mm and for coarse it was 24mm. The water to cement ratio (w/c) was 0.5 and it was kept constant for all the specimen. In table 4, all the details of the mix proportion of three concrete mixtures are given. In this project three different sizes of concrete cylinders (ϕ x h = 63 x 126 mm; 90 x 180 mm and 140 x 280 mm). where Φ is diameter of cylindrical specimen and his height of cylindrical specimen.



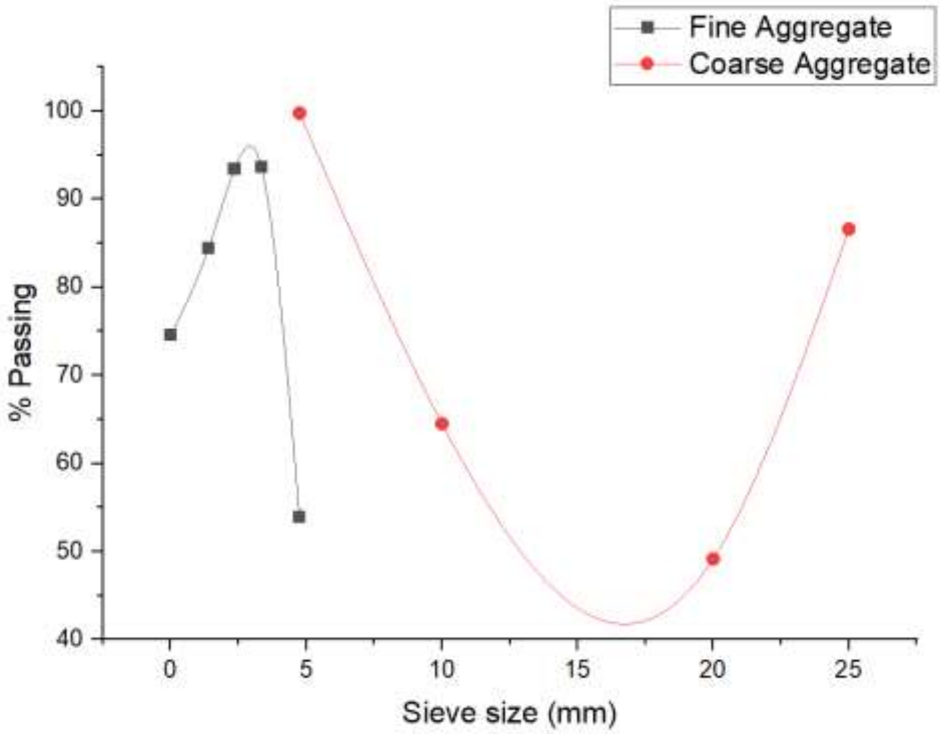


Fig 1: Size distribution of aggregates.

Table 4: Mix Proportion for three concrete groups.

Concrete Group	**Water (kg/m^3)**	**Cement (kg/m^3)**	**w/c**	**Sand (kg/m^3)**	**Medium Aggregate (kg/m^3)**	**Coarse Aggregate (kg/m^3)**	**Maximum Aggregate size (mm)**	**Finesse modulus**
F	29.88	59.778	0.5	174.9	0	0	3.36	3.321
M	29.88	59.778	0.5	59.92	116.604	0	15	6.78
C	29.88	59.778	0.5	59.92	0	116.604	24	9.07

Fig 2: The PVC pipe molds with different sizes. used for concrete samples.

Fig 3: Concrete specimens kept exposed to atmosphere after the curing period for drying.

Fig 4: Semi-automatic Compressive testing machine

Fig 5: UPV test.

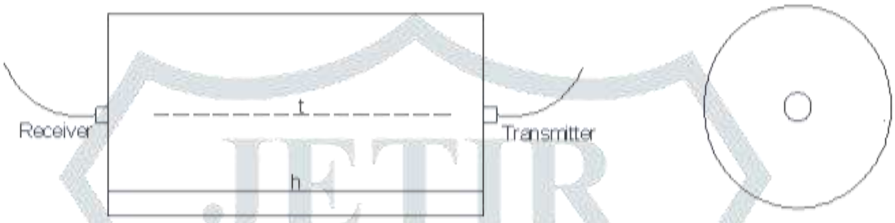
V. P - WAVE VELOCITY MEASUREMENTS

The P-wave ultrasonic measurement mainly uses the arrival time of a stress wave and has two types of methods: direct (pulse-echo and through-transmission) and indirect transmission, as illustrated the direct transmission uses the transfer of P-wave energy passing through a cross section between the transmitter and receiver. In the pulse-echo method, the transmitter/receiver transducer performs both sending and receiving of the pulsed waves reflected from the back wall of specimen. In the through-transmission, a transmitter sends ultrasound waves through one surface, and a receiver detects them on the opposite surface. On the other hand, the indirect transmission uses the P-wave path near surface. It is mainly used when only one face of the concrete is accessible or when the depth of a surface crack is to be determined. It is the least sensitive of the transducer arrangement for a given path. The surface response caused by the arrival of reflected or transmitted waves is monitored by the same or a different transducer acting as a receiver. The receiver output is displayed on an oscilloscope as a time-domain waveform. The round-trip travel time of the pulse can be calculated by determining the time from the transmitted pulse to the reflected echo. If the wave speed in the material is known, this travel time can be used to compute the depth of the reflecting interface. Transducers associated with short-duration, low-frequency focused waves are generally used for testing concrete.

According to ASTM C597-02, the dynamic Young's modulus of concrete can be estimated from the P-wave velocity, V_P of a compression wave travelling through an elastic concrete body, the Poisson's ratio, υ, and the density of the concrete sample, ρ, as follows:

$$Y_d = V_p^2\left[\frac{\rho(1+\upsilon)(1-2\upsilon)}{(1-\upsilon)}\right] \quad (4)$$

Consequently, the measurement of the shear modulus, and so of the Poisson's ratio (υ), was not possible from the AE measurements carried out in this study. The value of Poisson's ratio for normal weight concrete is generally in a range 0.20 to 0.25. Moreover, available data do not show any significant impact of various factors (e.g. W/C ratio, curing condition, aggregate gradation) on Poisson's ratio. In this study, an averaged value of υ= 0.22 was assumed as the value of Poisson's ratio for all our concretes to estimate the dynamic modulus of elasticity (Yd)from Eq. (4). As our specimens both the surface were accessible, we have used a direct method of ultrasonic pulse velocity. In order to detect the arrival time of P-wave of concrete, a pair of piezoelectric transducers (AE sensors) with frequency bandwidth of 54 kHz, Pulse width 9.2 µS and medium sensitivity was used. These two transducers were fixed by holding at the end surface of cylinders. The test was conducted on 54 specimens. The values of travel time, Pulse velocity and dynamic elastic modulus are given in table 5.



VI. COMPRESSION TEST

After completing the non-destructive test i.e. Ultrasonic pulse velocity on 54 specimens, the mechanical properties including the compressive strength and modulus of elasticity were calculated using compression test. Compression testing is a very common testing method that is used to establish the compressive force or crush resistance of a material and the ability of the material to recover after a specified compressive force is applied and even held over a defined period of time. Compression tests are used to determine the material behavior under a load. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined. The machine used for this test was semi-automatic compression testing machine with screen touch indicator which is given in fig 4. The loading capacity of compression machine was 2000KN. The peak load gets automatically stop when the specimen got failed. When peak load gets stop, every time the reading has been noted down. The results of all specimen are given in table 6. The compressive strength was calculated using the following formula,

$$6 = 4\,x\,\frac{Peak\ load}{Area}$$

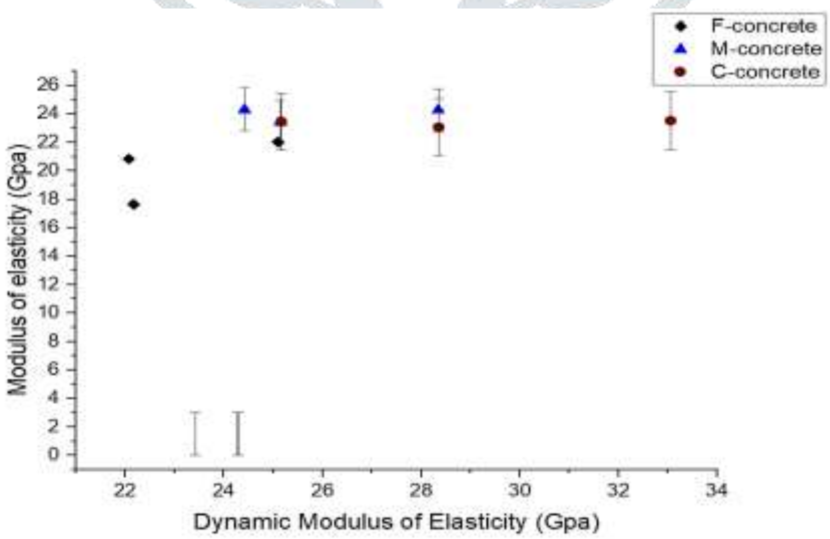
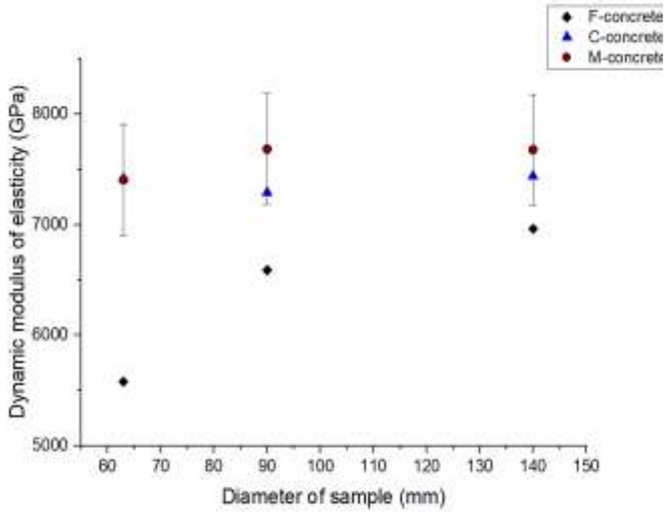


Fig 6: Dynamic modulus of elasticity Vs Modulus of elasticity.



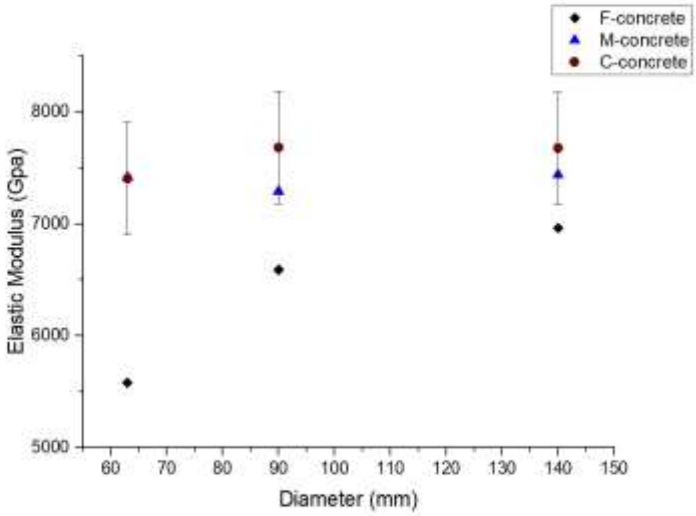


Fig 7: Diameter of sample V_S Dynamic modulus of elasticity.

Fig 8: Diameter V_S Elastic modulus.

VII. SIZE EFFECT ON ELASTIC MODULI

Concrete exhibits a size-dependent behavior on the nominal compressive strength. In this paper, we have focused on the modulus of elasticity behavior accordance with change in size of aggregates and specimen size. This work includes both the modulus of elasticity and dynamic modulus of elasticity. The variation of modulus of elasticity and dynamic modulus of elasticity with sample diameter of three concrete groups is given in fig 7, 8**.** The variations of modulus of elasticity and dynamic modulus with the sample diameter for the three concrete groups are respectively presented in a fig 6. The mean values and corresponding standard deviation (SD) of modulus of elasticity and dynamic elastic modulus for our three concrete mixtures with three different sizes are given in table 5. The finer material (F-concrete) shows the lower values of both mean and standard deviation (SD) than that of coarse concrete (M and C concrete). For given concrete mixture modulus of elasticity and their standard deviation.do not exhibit any significant sample size effect.

In non-destructive measurements we observe that, the finer material (F-concrete) shows the lower values of both mean and standard deviation (SD) than that of coarse concrete (M and C concrete). The mean values and standard deviation (SD) of P wave velocity of three different concrete mixture with different sample sizes are given table 5. the dynamic elastic modulus observed to be greater than the modulus of elasticity. There is no linear relationship between dynamic modulus of elasticity and modulus of elasticity Indeed, by means of a non-destructive technique, the dynamic modulus of elasticity is determined prior to loading and so without microcracking However, for a given concrete group, we did not observe any significant sample size effects on density (see their values in Table 5). This means that density neither have a significant influence on the size-dependency of the elastic modulus of concrete, nor on the correlation between the modulus of elasticity and dynamic elastic moduli.

Table 5: Density, P-wave velocity, modulus and dynamic modulus of different sample sizes and different concrete groups.

Concrete group	Sample size (Ø mm x h mm)	Density ρ (kg/m^3)		Modulus of elasticity		P-Wave velocity, Vp (m/s)		Dynamic Modulus of elasticity	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
FS	63 x 126	2104.49	80.90	17.65	2.42	3453.65	270.87	22.17	4.17
FM	90 x 180	2064.75	28.72	20.84	2.21	3488.42	190.30	22.07	2.42
FC	140 x 280	2102.72	28.77	22.02	1.27	3689.23	122.98	25.10	1.81
MS	63 x 126	2176.24	40.36	23.42	1.6	3631.38	92.48	25.14	1.21
MM	90 x 180	2136.68	29.73	24.3	1.18	3605.99	224.41	24.42	3.06
MC	140 x 280	2160.36	18.82	24.28	2.34	3869.99	61.15	28.35	0.96
CS	63 x 126	2206.80	25.04	23.46	2.01	3605.05	192.12	25.16	2.49
CM	90 x 180	2168.87	31.67	23.06	2.82	3863.22	50.90	28.36	0.84
CC	140 x 280	2206.28	28.98	23.53	2.81	4134.16	158.84	33.06	2.30

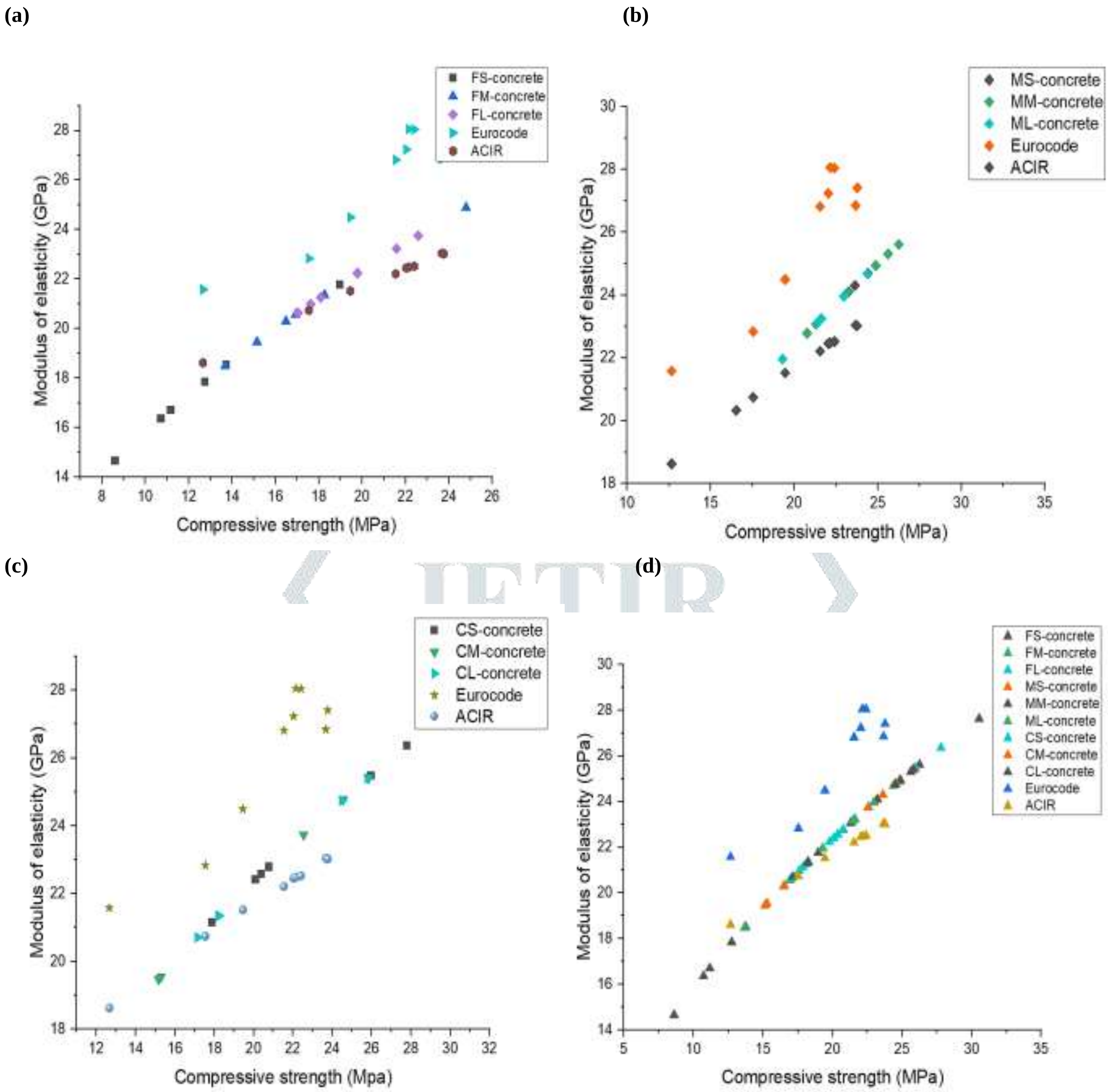


Fig 9: Relationship between the compressive strength and the elastic modulus of concrete sample: **a** for F – concrete; **b** for M – concrete; **c** for C - concrete and **d** for all concrete samples.

VIII. RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND MODULUS OF ELASTICITY

As it is given in table 1, table 2 table 3 there are numerical expression given in the building code and. In this study, only the expressions proposed in the most popular building codes (i.e. the standards EN 1992 [2] and ACI 318-05 [3]) are used in order to compare with our results Fig, shows the correlation between compressive strength modulus of elasticity and dynamic modulus for all our concrete samples. The relationships obtained using the expressions (Eqs. (1) and (3)) given in the codes mentioned above are also plotted in Fig. 8 by taking f 0 c ¼ rf and of cm ¼ rfÞ. From this, we observed that,

(i). The empirical expression of Eurocode (2008) have much larger values than dynamic elastic modulus and modulus of elasticity, without dependency on concrete mixtures and sample size.

(ii). The dynamic modulus of elasticity (Yd) experimental data are above the empirical predictions of Eurocode 2008 for C concrete and experimental data are below the empirical predictions for F concrete and M concrete

(iii). The dynamic modulus and modulus of elasticity for F concrete, M concrete and C concrete, ACI 363-10(2010) underestimate the value of Yd.

Table 6: Compressive strength and its correlation coefficient with the elastic modulus.

Concrete group	Sample sizes Ø x h (mm x mm)	Compressive strength		σ vs Y	σ vs Y_d
		Mean	SD		
FS	63 x 126	12.66	3.56	0.72	0.57
FM	90 x 180	17.54	3.88	0.84	0.79
FL	140 x 280	19.45	2.26	0.88	0.78
MS	63 x 126	22.03	2.87	0.94	0.88
MM	90 x 180	23.67	2.29	0.97	0.97
ML	140 x 280	23.77	4.8	0.98	0.84
CS	63 x 126	22.15	3.85	0.94	0.88
CM	90 x 180	21.54	5.04	0.93	0.76
CL	140 x 280	22.4	5.38	0.95	0.68

(iv). The mean value of the dynamic modulus of elasticity, Y_d, seems to slightly increase with increasing compressive strength, σ_f, for F and M-concretes. This is not the case for C-concrete.

(v). Merging strength data for all sample sizes of a given concrete group, the absence of correlation is clear as well for an individual dataset (fixed concrete mixture and sample size), the correlations of compressive strength σ_f with both dynamic moduli Yd and modulus of elasticity are either very weak or insignificant.

IX. CONCLUSION

In this paper, from the experimental investigation on compressive strength of various hardened concrete with different concrete mixtures and different sample sizes: we (i) studied potential effect of sample size and concrete mixtures on elastic properties and (ii) studied the relationship between compressive strength and elastic modulus. The following main conclusions are given below,

(i). The finer concrete shows a smaller elastic modulus than the coarser ones This is consistent with the fact that the elastic modulus of concrete is affected by the elastic modulus of the aggregate and by the volumetric proportion of aggregate in the concrete.

(ii). The ratio of dynamic elastic modulus and modulus of elasticity for all specimens with different sizes and different concrete mixtures, is always less than one. This ratio directly depends on the methodologies applied for measuring the deformation of specimens during the loading and for estimating the elastic modulus.

(iii). The compressive strength has increases with increase in size of F concrete and M concrete. This is in full contrast with elastic properties of concrete that is there is no sample size effect on the elastic properties of concrete.

(iv). There is no direct relationship between elastic modulus and compressive strength of concrete. Consequently, the authors will recommend non-destructive test such as Ultrasonic pulse velocity measurements on concrete specimen to directly measure the elastic modulus of concrete.

X. REFERENCES

[1] Krystian Jurowski and Stefania Grzeszczyk (2018) Influence of Selected Factors on the Relationship between the Dynamic Elastic Modulus and Compressive Strength of Concrete. Opole University of Technology,45-758 Opole, Poland; s.grzeszczyk@po.opole.pl, Correspondence: k.jurowski@po.opole.pl

[2] Eyad Kadhem, Ammar Ali and Sameh Tobeia (2018) Experimental comparative study of reactive powder concrete: mechanical properties and the effective factors Building and Construction Engineering Department, University of Technology, Baghdad, Iraq Corresponding author: dr_eyad_alhachamee@yahoo.com

[3] T. Vijaya Gowri, P. Sravana, P. Srinivasa Rao, T. Chandrasekhar Rao (2018) Strength properties of high volumes of slag concrete for rigid pavements. www.sciencepubco.com/index.php/IJET

[4] Ali Reza Najibi, Mohammad Ghafoori, Gholam Reza Lashkaripour, Mohammad Reza (2014) Empirical relations between strength and static and dynamic elastic properties of Asmari and Sarvak limestones, two main oil reservoirs in Iran http://dx.doi.org/10.1016/j.petrol.2014.12.010

[5] ACI 363R-10 (2010) Report on High-Strength Concrete. American Concrete Institute.

[6] EN 1992 (2017) Eurocode 2 EC2 Worked Examples (rev A 31-03-2017) http://www.europeanconcrete.eu/publications/eurocodes.

[7] T. Noguchi, K. M. Nemati Relationship between compressive strength and modulus of elasticity of High-Strength Concrete. University of Tokyo, Japan

[8] Farid Ghaffari Moghaddam, Abbas Akbarpour & Afshin Firouz (2021) Dynamic modulus of elasticity and compressive strength evaluations of modified reactive powder concrete (MRPC) by non-destructive ultrasonic pulse velocity method https://doi.org/10.1080/13467581.2020.1869020

[9] R Rajesh Kumar, D Siva Kumar (2019) An Experimental Investigation on Dynamic Modulus of Elasticity of Fly Ash Based Normal Strength Concrete, International Journal of Chem Tech Research http://dx.doi.org/10.20902/IJCTR.2019.120338

[10] Priyanka P. Chavhan, Manoj R. Vyawahare (2015) "Correlation of Compressive strength and Dynamic modulus of Elasticity for high strength SCC Mixes International Journal of Engineering and Technical Research (IJETR), www.erpublication.org

[11] Yong Zhou, Jie Gao, Zhihui Sun, Wenjun Qu (2015) A fundamental study on compressive strength, static and dynamic elastic moduli of young concrete www.elsevier.com/locate/conbuildmat

[12] Sang-Hun Hana, Jin-Keun Kim (2004) Effect of temperature and age on the relationship betweendynamic and static elastic modulus of concrete https://www.sciencedirect.com/science/article/abs/pii/S0008884603004344

[13] Byung Jae Lee, Seong-Hoon Kee, Taekeun Oh and Yun-Yong Kim (2017) Evaluating the Dynamic Elastic Modulus of Concrete Using Shear-Wave Velocity Measurements, https://www.hindawi.com/journals/amse/2017/1651753/

[14] Logan Trifone (2014) A Study of the Correlation Between Static and Dynamic Modulus of Elasticity on Different Concrete Mixes https://researchrepository.wvu.edu/etd

[15] Priyanka P. Chavhan, Manoj R. Vyawahare (2015) Correlation of Static and Dynamic modulus of Elasticity for Different SCC Mixes http://www.ijritcc.org

[16] John S. Popovics, Ph.D., P.E., FACI. Civil & Environmental Engineering, University of Illinois, Urbana, IL, A Study of Static and Dynamic Modulus of Elasticity of Concrete https://www.acifoundation.org/Portals/12/Files/PDFs/CRC_43.pdf

[17] Asst. Prof. Dr. Mohammed M. Salman, Eng. Ali H. Al-Amawee (2006) The Ratio between Static and Dynamic Modulus of Elasticity in Normal and High Strength Concrete, https://www.iasj.net/iasj/download/956dac6a37cea3ff

[18] Shraddhu S. Modulus of elasticity of Concrete/ Concrete Technology, https://www.engineeringenotes.com/concrete-technology/concrete/modulus-of-elasticity-of-concrete-concrete-technology/31499

[19] Chi-Cong Vu, Je´ro^me Weiss, Olivier Ple, David Amitrano (2021) The potential impact of size effects on compressive strength for the estimation of the Young's modulus of concrete, https://link.springer.com/article/10.1617/s11527-021-01795-7

[20] Young Hak Lee and Taekeun Oh (2016) The Measurement of P-, S-, and R-Wave Velocities to Evaluate the Condition of Reinforced and Prestressed Concrete Slabs, https://www.researchgate.net/publication/307948120_The_Measurement_of_P-_S-_and_RWave_Velocities_to_Evaluate_the_Condition_of_Reinforced_and_Prestressed_Concrete_Slabs

]21] Amin K. Akhnoukha, Hala Eliab (2019) Developing high performance concrete for precast/prestressed concrete industry, https://www.sciencedirect.com/science/article/pii/S2214509519303924