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Approach to Design of Composition of Current Concrete with Respect to Strength and Static Elasticity Modulus

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Abstract**—**The paper reflects current state of popularization of static elasticity modulus of concrete. This parameter is undoubtedly very important for designing of concrete structures, and very often neglected and rarely determined before designing concrete technology itself. The paper describes assessment and comparison of four mix designs with almost constant dosage of individual components. The only difference is area of origin of small size fraction of aggregate 0/4. Development of compressive strength and static elasticity modulus at the age of 7, 28 and 180 days were observed. As the experiment showed, designing of individual components and their quality are the basic factor influencing elasticity modulus of current concrete.

Keywords**—**Concrete, Aggregate, Strength, Elasticity Modulus, Quality

I. Introduction

DEVELOPMENT of technology of concrete brings many changes of relationships among basic physico-mechanical parameters of hardened concrete. This trend should be eventually reflected in re-evaluation of dependencies ruling static design of concrete structures. In previous times, compressive strength as a basic characteristic of concrete was a sufficient datum form which other calculated characteristics were empirically calculated, like tensile bending strength, cross tension and static elasticity modulus. As a result of recent changes and new trends in the field of designing and application of concrete structures, durability and defined deformation properties of concrete have become complementary and sometimes even dominant requirements. In general, material with higher elasticity modulus shows less deformation. Measure of deformation depends on measure of stress, deformation properties of aggregate and cement stone, density, humidity and age of concrete. Values of material properties necessary for calculation of instantaneous and long-term deformation of concrete depend not only on strength class of concrete, but mainly on properties of aggregate and other parameters connected with mix composition. [1]

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II. Elasticity Modulus of Concrete

A. Current State of Approach to Elasticity Modulus of Concrete in the Czech Republic

Elasticity modulus is one of the basic characteristics of concrete. It has strong influence on deformation properties of concrete structures, like deflection or permanent deformation. If the value of elasticity modulus is higher, deformation of concrete decreases, risk of formation of cracks in tension area of concrete is lower. Nowadays, designers use mostly the strength class of concrete for dimensioning of steel reinforced concrete structures. In general, values of static elasticity modulus are only rarely stated in projects, pretensioned elements is the only exception, otherwise there is usually no reference in implementation documentation. Static elasticity modulus should be more important for structures, which are demanding from the static point of view; in such cases, the value of static elasticity modulus should be designed at the very start of the project work. Static elasticity modulus is mostly determined as directly dependent on compressive strength of concrete. Current experience with static elasticity modulus determined by means of mere calculation from cube strength in accordance with outdated empirical relationships used even in EuroCodes [2] show, that these empirical relationships are valid only in the field of conventional vibrated concrete with strength class up to ca C 45/50. These conventional concrete does not usually utilize new-generation superplasticizers and high proportions of active additives which have become very important for designing current concrete.

B. Factor Influencing Elasticity Modulus of Concrete

Concrete as composite material with different content and type of coarse aggregate or different mix-design shows various elasticity modulus [3]. Elasticity modulus of concrete is influenced by quality and proportions of individual components. Natural aggregate always shows higher value of elasticity modulus than hardened cement paste. Elasticity modulus of concrete lies between elasticity modulus of aggregate and elasticity modulus of cement stone [4]. Elasticity modulus of cement paste lies between 5 and 25 GPa, elasticity modulus of natural stone from 30 to 100 GPa depending on mineralogical composition. Elasticity modulus of hardened cement paste is influenced by the same factors and compressive strength. Porosity has strong influence on elasticity modulus of cement stone. Type of aggregate can also considerably influence elasticity modulus. It is not only kind of aggregate but also the quarry where the stone was mined, which can have strong impact on elasticity modulus of concrete [3]-[5].

C. Determination of Static Elasticity Modulus of Concrete

Static elasticity modulus of common concrete is mostly related to compressive strength. Static elasticity modulus can also be expressed with empirical relationship [5] in accordance with EN 206-1 [6] as follows:

$$E = 22\left(\frac{fc}{10}\right)^{0,3} \quad (1)$$

An illustrative example of dependence between the value of elasticity modulus and compressive strength of conventional concrete is given in Figure 1 [4].

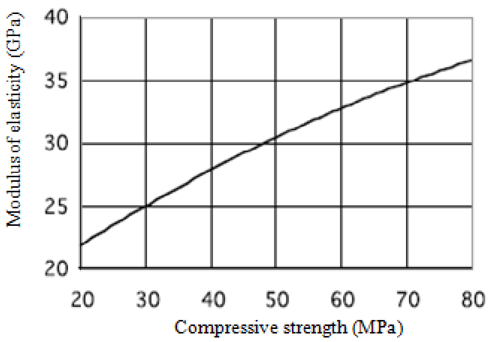

Fig. 1 Dependence between elasticity modulus and compressive strength based on empirical relationship according to Neville for common concrete [4]

Empirical models of elasticity modulus and compressive strength are valid only for concrete with conventional composition However, these relationships can be considerably different for concrete with different composition, different granulometric curves, different cements (than CEM I) and different proportions and types of additives and admixtures. Calculated values of elasticity modulus then does not correspond to real values of compressive strength. Dependency between elasticity modulus of concrete and its compressive strength is defined e.g. in EN 1992-1-1 [2]. Thus, the value of static elasticity modulus automatically corresponds to the strength class. Percentage decrease of given values related to different type of aggregate is also stated. EN 1992-1-1 [2] takes into consideration only material of used aggregate but not the type of amount of addition and admixture use, water cement ratio, way of transport or placing [7].

III. Experimental Program

Experimental part focused in particular on comparison of result values of static elasticity modulus. 4 recipes were prepared, whose composition was identical for each of these, only there was a difference in weight dosing of individual components.

A. Materials

Recipes are designed with a binder CEM II / A-LL 42.5 R, aggregate fraction 0/4 (two different locations production aggregate type I and II), 4/8 and 8/16 and superplasticizer. The fraction 4/8 and 8/16 it was the crushed stone from the quarry. Dose binder 390 and 410 kg/m^3, water coefficient w = 0.47 and 0.44. Dosage of individual components and mix-design is given in Table I.

TABLE I
Dosage of Components of Individual Concretes

Component [kg/m^3]	C-1	C-2	C-3	C-4
CEM II/A-LL 42.5 R	390	410	390	410
Aggregate 0-4 mm - type I	830	810	-	-
Aggregate 0-4 mm - type II	-	-	835	815
Aggregate 4-8 mm	220	215	220	215
Aggregate 8-16 mm	670	685	670	685
Superplasticizer	2.8	3.1	2.8	3.1
Water	185	180	185	180

B. Evaluation Tests of Compressive Strength and Elasticity Modulus of Concrete

Consistency of fresh concrete was determined in the category S3, i.e. within the range 100-150 mm of slump. Test specimens were made from individual mixes to determine properties of hardened concrete. Testing cubes of side 150 mm were made for compressive strength test and testing beams of dimensions 100 x 100 x 400 mm were made for static elasticity modulus test. Test specimens were placed in laboratory conditions until the time of testing. Tests were carried out after required periods, i.e. 7, 28 and 180 days. Static elasticity modulus was determined in accordance with CSN ISO 6784 [8].

Fig. 2 Measuring of static elasticity modulus

TABLE II
COMPRESSIVE STRENGTH AND STATIC ELASTICITY MODULUS FOR CONCRETE DETERMINED AT THE AGE 7, 28 AND 180 DAYS

Concrete	Compressive strength [MPa]			Static elasticity modulus [MPa]		
	7 days	28 days	180 days	7 days	28 days	180 days
C-1	28.1	34.1	38.5	22000	25000	27500
C-2	37.9	43.1	44.6	25500	28500	30000
C-3	45.3	57.2	62.2	31000	34500	37000
C-4	55.9	68.4	69.7	31000	33000	34500

C. Comparison of Static Elasticity Modulus and Guiding Values

Static compressive elasticity modulus after 28 days were compared to guiding values stated in CSN EN 1992-1-1 [2]. For this reason, compressive strength values were ranged into individual strength classes of concrete. Consequently, matching values stated in the Table of static elasticity modulus were compared according to individual strength classes. The results of comparison or real and tabulated values of static elasticity modulus are given in Table III.

TABLE III
EVALUATION OF ELASTICITY MODULUS AT THE AGE OF 28 DAYS FOR INDIVIDUAL CONCRETES

Concrete	Compressive strength	Strength class	Measured static elasticity modulus	Guiding value static elasticity modulus
C-1	34.1	C 25/30	25000	31000
C-2	43.1	C 30/37	28500	32000
C-3	57.2	C 40/50	34500	35000
C-4	62.2	C 50/60	33000	37000

IV. CONCLUSION

Test results on compressive strength and elasticity modulus of concrete reached quite surprising values. Even in the case of compressive strength is apparent significant difference between the resulting values.

Development of compressive strength of all mix-designs was observed. The difference of 20 kg/m^3 of cement makes the difference of ca 10 MPa of compressive strength after 7 days for concrete with identical type of aggregate of size fraction 0/4, i.e. type I or type II. Development of strengths of mix-designs C-3 and C-4 with aggregate 0/4 of type II was surprising: strength after 7 days was in average by 17 MPa higher. Difference of values of static elasticity modulus was expected, as compressive strength differed. This parameter was determined at the age of 7, 28 and 180 days. Measured values of elasticity modulus again show considerable difference among mix-designs C-1, C-2 and C-3, C-4, where the difference was only in the origin of aggregate of fraction 0/4 type I or type II. On average, determined value of elasticity modulus was 24 GPa pro for concrete with aggregate of type I size fraction 0/4 and 31 GPa for concrete with aggregate of type II at the age of 7 days. This trend continued at the age of 28 days. Development in the period between 28 and 180 days shows no considerable difference in elasticity modulus of all four mix-designs. Value of increase was maximally 1.5 GPa. As it was mentioned in the introduction, real values of elasticity modulus are lower than the values calculated from theoretical values derived from compressive strength or strength classes of concrete. The difference of the values of mix-designs C-1, C-2 and C-4 was quite considerable; real values are mostly much lower, than derived values. The difference is between 3.5/C-2, 4/C-4 and 6/C-1 GPa. Only mix-design C-3, where real value of elasticity modulus is 34.5 GPa, is close to theoretical value 35 GPa.

Although not a large set of samples is evident, it is necessary to take into account when designing the concrete to the quality of raw materials and their origin. From the perspective of the elasticity modulus of concrete can not be recommended based on the tables referring to the standard values as shown in practice may be quite different from the fair value of the currently implemented concrete structures.

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