Selected Technological Factors Influencing the Modulus of Elasticity of Concrete

Klara Krizova, Rudolf Hela

***Abstract*—**The topic of the article focuses on the evaluation of selected technological factors and their influence on resulting elasticity modulus of concrete. A series of various factors enter into the manufacturing process which, more or less, influences the elasticity modulus. This paper presents the results of concrete in which the influence of water coefficient and the size of maximum fraction of the aggregate on the static elasticity modulus were monitored. Part of selected results of the long-term programme was discussed in which a wide scope of various variants of proposals for the composition of concretes was evaluated.

***Keywords*—**Mix design, water-cement ratio, aggregate, modulus of elasticity.

I. Introduction

THE most common technologies used influence not only compression strength, but also the elasticity modulus of the concrete are factors which can be influenced during the proposal for the composition of concrete. In particular, it concerns the kind of cement used, partial replacement of mainly Portland cement by mineral mixture, modification of the water ratio and dominant factors influence the kind and fraction of the aggregate.

Factors Influencing the Elasticity Modulus of Concrete

The resulting value of the elasticity modulus of concrete is influenced by a series various factors which are described in the professional literature. The basic factors can be divided into two groups [1]:

- **Technological**, composition of the concrete (cement, ingredients, kind of the aggregate, additives, ratio of water and cement , ITZ), technology for manufacturing and the processing of concrete
- **Testing**, firm and the size of the testing body (cylinders, beams), age of the testing body, speed of loading, eccentricity, etc.

From the viewpoint of concrete composition, the elasticity modulus is significantly influenced by the type of aggregate and the mixing ratio and from the viewpoint of testing, factors like requirements for testing bodies, speed of loading, precision of measuring instruments are stated in the standard ČSN ISO 6784 [1], [2].

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A. Porosity of the Concrete

The concrete which is commonly used in the building industry is the porous material. Similarly as in other materials, in this case, the porosity significantly influences, in addition to the strength and the elasticity modulus, also additional properties, like permeability and the durability of concrete [3].

Solid components of the hardened cement paste consist of non-hydrated grains of cement, surface amorphous products in the form of C-S-H gels and porous CH products, representing crystals. In addition to firm substances, it contains pores and hollows [4]. In concrete there are pores, in the form of pores of trapped air, due to the influence of compaction of fresh concrete, present in grains of aggregate, pores originated due to aerating, capillary pores and gel pores occurred mainly in C-S-H with the site 1–10μm [3].

The capillary pores are pores originated between grains of the hydrating cement and have irregular form and the size from 0.1 to 10μm. The occurrence of these pores depends on water-cement ratio and on the manner of treatment of the concrete together with the stage of hydrating [3]. The porosity of the cement paste with the increasing water-cement ratio increases the content of free water in fresh concrete due to which its porosity increases [5], [6]. The capillary porosity significantly influences the strength of the concrete in pressure and in its nature identically elasticity module [3]. The elasticity modulus is approximately proportional to the third power of the ration gel/space. When considering capillary porosity of the cement mixture, the following equation is applied [7], [8]:

$$E_p = E_g \left(1 - P_c\right)^k \tag{1}$$

where: *Ep* and *Eg* are elasticity modulus of the hardened cement mixture and the elasticity of the hardened cement mixture at the zero porosity, *Pc* capillary porosity and the constant indicating the value depending of the elasticity module of the hardened cement mixture, where *Eg* = 72 5000 N/mm^2, when k = 3 and k = 4 at *Eg* = 85 000 N/mm^2 [6], [12]. The elasticity modulus increases with the age of the stone and is higher by 10 to 20 % when placing of water environment compared with the temperature of surrounding air [8].

B. Aggregate

The mechanical and physical properties of rock and aggregate can be derived from the mineralogical composition of the texture and the structure and the level of staleness of the rock. In the case of aggregate, in addition, there is also the influence of the preparation, in particular crushing. The most important properties of rock are: compression strength, deformation properties, i.e. elasticity modulus and completion of formation, frost resistance, thermal conductance, etc. [9].The elasticity modulus of aggregate, due to its volume in concrete, has significant influence on the elasticity modulus of concrete [7]. As a rule, the elasticity modulus of aggregate is higher than the elasticity modulus of concrete [9]. The elasticity modulus of aggregate influences the mineralogical composition, the texture and the structure of the rock from which the aggregate is produced and very much depend on the porosity of the rock, similarly as in the case of the strength of the aggregate.

Properties and the concentrate of the aggregate influence either the strength, as well as the flexibility modulus of concrete and their influence on the elasticity modulus is higher than on the strength. For this reason, the concrete produced from less firm aggregate will have a lower modulus than concrete with the same strength produced from a firmer aggregate [7]. Not only the different kind of aggregate, but also the same kind but from different localities may significantly influence the elasticity modulus of concrete. Similarly, in the case of lower volume of the rough aggregate, the decrease of the volume of the modulus is expected [10]. In the common concrete in which the elasticity modulus of aggregate is higher than the elasticity modulus of the hardened cement stone, the elasticity modulus is increased with the increased dose of aggregate. The increase of the elasticity modulus of concrete with the increased elasticity modulus of aggregate is expected. On the other hand, in the summer period, the elasticity modulus will decrease by the increased dose of aggregate [7].

II. Discussion

This experiment dealt with the evaluation of a series of proposals for the composition of concrete which mainly differed by the type and volume of the cement used, mineral ingredients, type of ingredients, number and the maximum grain of the fraction of the aggregate.

A. Influence of Water-Cement Ratio and the Maximum Grain of the Aggregate on the Elasticity Modulus of Concrete

The achieved values during the evaluation of the dependence between the water-cement ratio and the status of elasticity modulus did not mean any dependence between the mentioned parameters. The mentioned conclusions were confirmed [11], when the higher water-cement ratio increases the capillary porosity of concrete is increased and the transit zone becomes more porous. This phenomenon leads to the simpler origination of micro cracks and as a result, there is a decrease in the elasticity modulus in concrete. It is evident from Fig. 1 that values of the water-cement ratio varied in three basic areas. The first area with the value of the water-cement ratio within the range of 0.32–0.37, for which a relatively high elasticity modulus was achieved increasing up to 44 000 N/mm^2. These concretes were characterised by a relatively high volume of cement, therefore, for the achievement of a relatively low water-cement ratio, it was necessary to use high effective plasticisation ingredients. The widest spectrum of results was achieved with the water-cement ratio within the range 0.42–0.52. Here, the significant decrease of the elasticity modulus was achieved which was on the border of 36 000 N/mm^2 and values of the elasticity modulus were cumulated mainly around 30 000–34 000 N/mm^2. The last range 0.6–0.64 of the water-cement ratio was characterised by the lowest stated modulus of elasticity around the border of ± 32 000 N/mm^2.

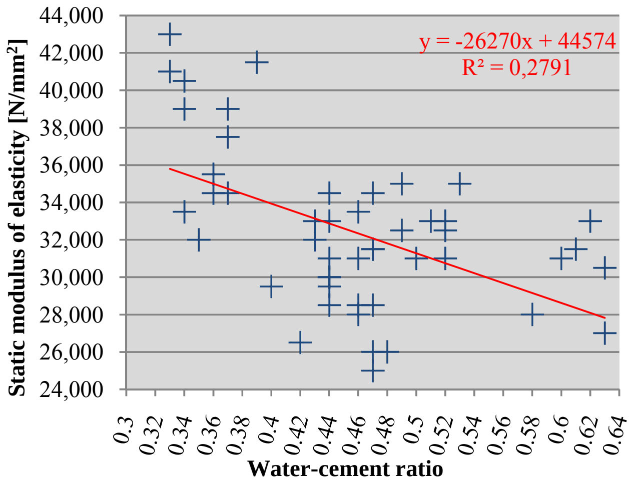

Fig. 1 Influence of the water-cement ratio on static elasticity modulus of concrete

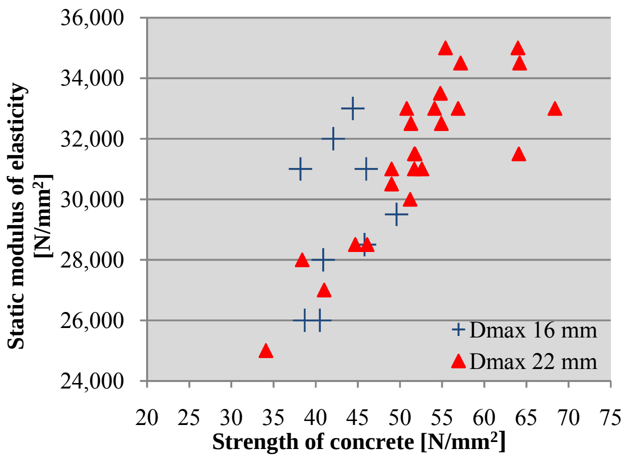

Fig. 2 The influence of maximum grain of the aggregate on the strength and the static elasticity modulus

The important influence on the elasticity modulus was recorded for the size of maximum used fraction of aggregate in the concrete. Fig. 2 compares the influence of the brushed fraction Dmax 16mm and 22mm on the dependence between the compression strength and the static elasticity modulus. The positive influence Dmax 22mm was monitored mainly from the viewpoint of compression strength where it was higher than in the case of the fraction Dmax 16mm. Together with the increasing compression strength, the elasticity modulus of the concrete was increased. The highest strength of the concrete varied at the border of the strength classes C 40/50 and C 50/60. But in this case, the requirement for the specific elasticity modulus 35 000 N/mm^2 and 37 000 N/mm^2 was not fulfilled. It results from the achieved results that with the fraction 22mm it is possible to achieve higher compression strengths easier and also the elasticity modulus. Nevertheless, values varied at the recommended limit and it is necessary to take into consideration selection of further components of the concrete.

III. Conclusion

The following knowledge obtained from results of the experiment.

- A very significant influence on the elasticity modulus is mainly the quality of rough fraction of aggregate and maximum grain of aggregate. The work confirmed the important influence of the different mining locality of the aggregate for concrete with the comparable volume representation of individual components of the concrete. In the representation of both rough fractions 8-16mm and 11-22mm, it is possible to point out that the max. grain 22 mm has a positive influence on the elasticity modulus of concrete. This measure in combination with the suitable composition of other components could be certain guarantee for the achievement of a higher elasticity modulus.
- For the increase of the elasticity modulus, a decrease in the water-cement ratio is recommended. Therefore, it is recommended to use high effective super-plasticisation ingredients which, together with the increase of the compression strength, increase the elasticity modulus to a certain degree. The lower volume of mixing water, depending on the reduction of the volume of cracks originated from drying, may reduce the risk of decreasing the elasticity modulus.
- Most experimental results did not achieve the levels of elasticity modulus according to Eurocode 2 [12] particularly in the concrete strength class. Real elasticity modulus report decrease up to the values for lower strength classes of the concrete. From the viewpoint of existing construction practice, this negative phenomenon was reflected mainly in the most frequently used concrete strength classes C 30/37, C 35/45 and C 40/50.

Selected results confirmed the presence of different values of the elasticity modulus depending on the composition of the concrete. Technological factors influence a series of concrete properties and, therefore, it is necessary to pay increased attention during the primary proposal for composition of the concrete.

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