Concerning concrete E-modulus

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I. INTRODUCTION

The usually performed tests to determine concrete modulus of elasticity in codes are with a procedure using standard concrete cylinders (height 300mm and diameter 150mm). The cylinders are compressed and the strain development is measured on it sides. However it has to be noted that there is friction between the steel loading platens and concrete cylinder. The friction hinders the cylinder top and bottom to expand, when the cylinder is loaded in compression. This leads to bending out of the cylinder sides. At mid height of cylinder side surfaces are used strain gauges for vertical strain measurements. It has to be observer that the measured compressive strain is reduced by the tensile bending strain of the side surfaces and the total compressive strain becomes less than it has to be, if there was no friction and bending. This strain reduction is disregarded as it is believed to have no influence. The effect of strain reduction becomes more pronounced for weaker concretes as the tensile strength is a greater part of the compressive strength. The E-modulus from such measurement becomes somewhat too big in comparison, when double Teflon plates are used between concrete and the loading platens to remove friction. Consequently the modulus in codes is a little bit too big and could jeopardize especially stability design.

II ELASTICITY MODULUS OF CONCRETE

The elasticity modulus base in concrete codes goes back to the tests gathered by M. Roš at EMPA in Zürich in 1937 [1], in figure 1, shown as function of the compressive strength of concrete. The specimens are cylinders or concrete prisms. There is also marked the line for the Swedish concrete code BBK mainly on the safe side concerning the modulus. The scatter of the measuring results is mainly due to different types of gravel and compaction of the tested concrete.

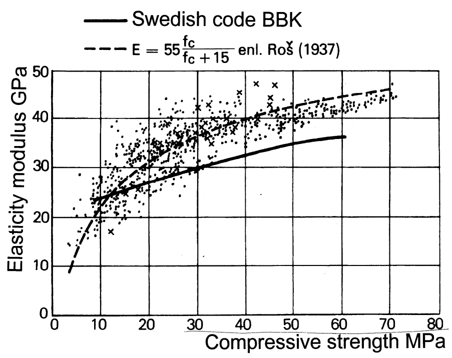

Figure 1. Tests by M. Roš at EMPA in Zürich in 1937, [1] and [2].

In tests with CFRP confined concrete cylinders performed by Rousakis [3] it was concluded that friction between cylinder ends and steel loading platens will deform the cylinders according to figure 2, left cylinder, and influence the results of the studied CFRP confinement effect. Therefore using experience from [4] double teflon platens were used between the concrete and steel platens, which changed the failure picture of the cylinder from cones with shear effects to columnar vertical tensile failure cracks at compressive failure of the concrete cylinder, figure 3 and 4. The distribution of expansion of the compressed concrete cylinder with double Teflon layers was measured with strain gauges in [4]. It was stated that the cylinder expansion under pressure was uniformly distributed, see figure 5, and therefore it could be concluded that the double Teflon plates removed friction between concrete cylinder ends and loading steel platens.

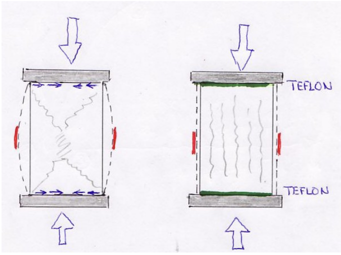

Figure 2. Friction gives bending of the specimens vertical surfaces, where the measuring devices are situated. Bending gives tensile strain, which reduces the compressive strain, left cylinder. Without friction failure cracks becomes vertical, right cylinder.

Figure 3. Cylinder failures, left with friction and right with Teflon layers removing friction.

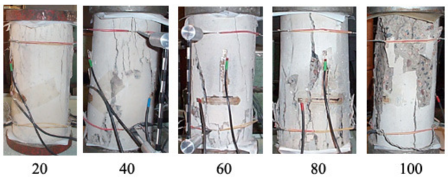

Figure 4. Concrete cylinders outlook after failure with double Teflon layers between cylinder ends and steel platens removing friction. Vertical failure cracks. The numbers under cylinders mark the nominal compressive strength [3].

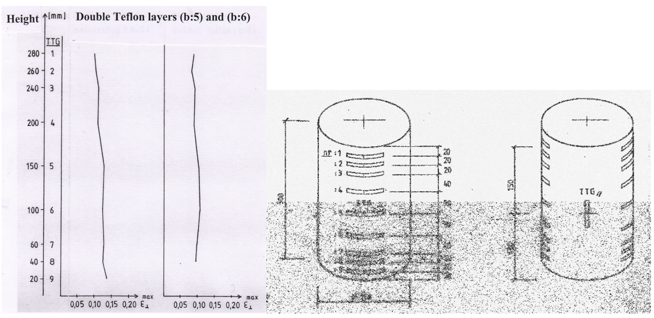

Figure 5. Transverse cylinder expansion under load obtained with two Teflon layers between cylinder and loading platens, [4].

III EFFECT OF TEFLON LAYERS ON CYLINDER STRENGTH

The friction removing effect of the Teflon layers was studied for 5 concrete strengths in [3]. It was concluded that there is a slight strength reducing effect somewhat increasing for increasing concrete strengths.

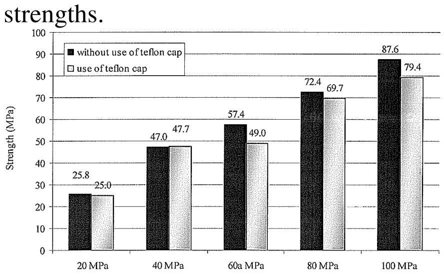

Figure 6. Comparison of concrete compressive cylinder strength with and without double Teflon layers to remove friction, [3].

IV EFFECT OF TEFLON LAYERS ON CYLINDER MODULUS

The modulus of elasticity for five concrete strengths was determined on concrete cylinders with double Teflon friction removing layers on loaded ends in [3]. The obtained measured modulus E_1 is compared with that in CEB-FIP Model Code 1990, [5], E_{1c} for 28 days, in Figure 7.

$E_{1c} = E_{co} [f_{cm} / f_{cmo}]^{1/3}$;

where
$E_{co} = 2.15 \times 10^4$ MPa;
f_{cm} is mean 28 days compressive strength in MPa;
$f_{cmo} = 10$ MPa;

The modulus of elasticity E_{1c} calculated according CEB-FIP Model Code 1990, E_{1c} is based on cylinder strength determined on concrete cylinders without Teflon interlays following the standard procedures. As strain is measured with strain gauges on cylinders without Teflon interlays, the cylinder is prevented to expand at its ends and the middle part thereby bends somewhat outward. This bending gives rise to tensile strains, which are superposed to the compressive strains. Thereby the compressive strain for estimating the modulus is reduced and the modulus becomes too big. As the concrete tensile strength for concrete grade C12 is about 13% of the compressive strength and for C80 about 7%, the friction bending of the cylinder side surface is more evident for lower concrete strengths. The tensile bending strain reduction of the compressive strain will consequently be more for weaker concretes and the measured modulus will become higher as it becomes evident in Figure 7.

Lower modulus than what is obtained by code in calculations may result in too big deformations and can jeopardize column stability.

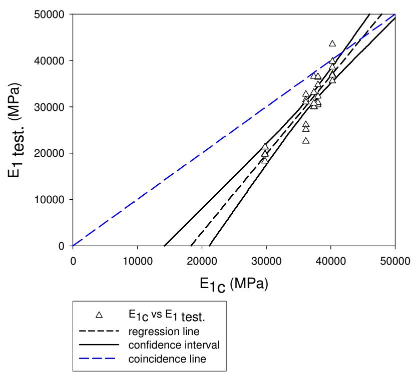

Figure 7. Comparison between $E_{1\ test}$ and $E_{1\ c}$ calculated according to CEB/FIP MC90, [6].

V CONCLUSIONS

The concrete modulus of elasticity obtained with cylinders using Teflon interlays without friction reflects the real situation in columns. As there is very little friction at cylinder ends during loading, the cylinder expands under pressure equally along its length and there is no compressive strain reduction due to bending of cylinder side surfaces. The effect is more pronounced for weaker concretes. The modulus of elasticity in codes especially for weaker concretes is somewhat too big, because its evaluation is done with strains reduced with tensile bending strains obtained with cylinder tests according standard procedures.

In practice concrete strength is normally exceeding the chosen compressive strength for reason to avoid delivered concrete with too low compressive strength. More over, the modulus of elasticity in design is based on concrete 28 day strength, but the concrete, when becomes older, increases its strength and also modulus. This stronger delivered concrete as well the concrete age may give reason for that the modulus of elasticity used in design gives the correct structural deformations. Therefore, most likely, there have not been any complaints about deformations exceeding the obtained in design.

However the code writers should take this observation of bending tensile strains influencing the measured modulus of elasticity in account and formulate an adequate formula for determining the concrete modulus of elasticity for different concrete strengths at 28 days of age. As the concrete becoming older increase its strength the formula could be completed by this modulus of elasticity increase with time. Necessary precautions for safety have to be considered by code writers.

VI REFERENCES

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