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The Behaviour of Concrete and Reinforced Concrete under Sustained Loading.

Das Verhalten von Beton und Eisenbeton unter dauernder Belastung.

Comportement du béton et du béton armé sous l'action des charges permanentes.

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This short contribution will deal only with the effect of sustained loading on reinforced concrete constructions, on the basis of numerous data obtained experimentally in the laboratory regarding the behaviour of concrete and reinforced concrete under compressive, tensile and bending loads maintained in action over a period of two to three years. The slow changes of shape which result from shrinkage and expansion will be considered together with those attributable to sustained loading.

Special emphasis will be laid on the importance of the conditions under which the concrete is stored, for if the deformations and other properties of the concrete are to be recorded numerically account must be taken of whether the structure is immersed or buried, or is exposed to the weather and seasonal changes, or whether it is under cover or heated during a great part of the year.

The strength R_b, the modulus of elasticity E_b, the plastic strain under sustained loading, and the amount of shrinkage, all vary considerably according to these conditions of exposure. The following are relative average values for concrete stored under permanent conditions for three years.

	under water	in air: relative humidity 70 %	in air: relative humidity 45 to 50 %
R_b	1.00	0.75	0.60
E_b	1.00	0.80 to 0.85	0.65 to 0.70
Plastic strain	1.00	2.00 to 2.25	3.00 to 4.00
Shrinkage	+ 1.00	—3.50 to —4.50	—5.00 to —6.00

It must be understood that numerical values for the properties of concrete also vary a great deal in accordance with such well-known factors as the proportions of the mix, the granulation and the age of the concrete.

Once plastic deformation has taken place under the action of the dead load and permanent live load, everything proceeds as if the value of the modulus of elasticity were reduced, and (as is well known) one of the results of this condition is a corresponding change in the distribution of stress between the concrete and the reinforcement. This change takes place slowly, and, as is true of the strain, it tends in the course of time towards a limiting value.

In reinforced concrete *compression members,* stored in dry air and loaded to between 22 and 24 % of the cube strength of the concrete, the compressive stress in the reinforcing bars may reach 15 to 20 kg per sq. mm, or 19 to 27 kg per sq. mm if the compression due to shrinkage is added. When the stress in the concrete amounts to between 30 and 32 % of the cube strength, stresses of 20 to 30 kg per sq. mm may arise in the reinforcing bars under certain conditions of testing in dry air, and when augmented by the compression due to shrinkage they may considerably exceed the elastic limit of mild steel.

In *members subject to bending* the compression zone may behave in a similar way to the above, and in dry air the compressive stresses in the reinforcement, including those due to shrinkage, may in exceptional cases approach the elastic limit of mild steel. In the tensile zone, however, the increase in stress of the reinforcing bars is relatively small, and consequently the lever arm of the resisting couple is not greatly reduced despite the plastic strain undergone by the concrete.

It is of interest to note that the compression in tensile reinforcement due to initial shrinkage was found to have disappeared during the long period that the bending load was maintained in being, and a similar observation has been made on bars embedded in specimens of reinforced concrete exposed permanently to simple tensile and compressive loads.

In all the beams subjected to bending (concrete at 60 kg per sq. cm, steel at 12 kg per sq. mm, $m = 15$) while permanently exposed to dry air, the cracks in the concrete under tension appeared as a result of the shrinkage stresses of the concrete while the load was being applied, and the cracking continued to increase while the load was maintained, though the cracks did not open at all conspicuously.

After long periods under load, neither the compressive nor the tensile strength of plain concrete, nor the compressive nor the bending strength of reinforced concrete, was found to be less than the strength of the corresponding members stored under the same conditions without having been subjected to the loads. Once the permanent strains had taken place the elastic character of the reinforced members continued to be manifested after repeated loading and unloading which followed upon two or three years of maintenance under permanent load.

The conclusion may be drawn that the strength of reinforced concrete is not reduced by its being kept under heavy permanent loads during a very long period. It does not appear that a lower breaking stress in the concrete need be assumed to meet such conditions, nor does the usual coefficient of 28/100 need to be diminished. Less importance attaches to the elastic limit of the steel being exceeded in the case of compressive reinforcement than in that of tensile reinforcement, but it would, nevertheless, appear desirable to make use of high elastic limit steels in the compression zone of the concrete under special conditions, where the magnitude of the permanent load and the conditions to which the structure is exposed are liable to cause large plastic strains in the concrete with the passage of time, and where, consequently, there is a risk of excessive stresses in the reinforcing bars. In such a case special attention should be paid to the effectivences and the spacing of the cross stirrups, and the danger of cracking should be the object of special care.