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THE BEHAVIOR OF A COMPOSITE MEMBER CONSISTING PARTLY OF AN ELASTIC AND PARTLY OF A SEMI-PLASTIC MATERIAL.

by Inge Lyse*

In dealing with structural problems the engineer often finds that the generally accepted theories of mechanics do not apply for the materials used. This is particularly true for materials which are lacking in homogeneity or elastic behavior. Typical samples of such materials are found in masonry and concrete. When these materials are used in combination with more perfect materials, such as steel, attention should be given to the fact that the stresses in the composite member do not follow any given mechanical law. When the load is first applied the member will not behave much differently from a homogeneous material. The deformation curve for the member is made up of the summation of the curves for the two individual materials. An illustration of a reinforced concrete column subjected to direct compression is shown in Fig. 1. The total load on the column for any deformation is equal to the sum of the loads carried by the steel and the concrete at that deformation. Fig. 2 shows that the same is true for reinforced brick masonry. If, however, the column has to sustain a given load for a long time, the semi-plastic material will deform, or flow. Because of the bond between the two materials, both of the materials must deform the same amount. The elastic material cannot deform without taking more stress and it will carry more and more of the total load

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with the increase in flow of the member. Consequently the stress in the semi-plastic material will decrease with the flow, because the total external load remains constant. The stress distribution will therefore change with time, the elastic material carrying more and more of the total load and the semi-plastic material carrying less. An illustration of the change of stress distribution in a reinforced concrete column subjected to a given load for a long time is shown in Fig. 3. The stress in the steel reinforcement is seen to increase quite regularly with the length of time under load and the stress in the concrete do decrease correspondingly. The change of stress is greatest for the first few weeks under load, gradually decreasing so that after about one-half year, a nearly stable condition has been reached. It is worth noting that the stress in the steel may well reach the yield-point stress and the stress in the concrete become zero due to this effect of plastic flow. With our general accepted theory of working stresses, we would consider a stress equal to the yield-point stress of the steel dangerous for building construction. However, tests have shown that this change in stress distribution has no apparent effect upon the safety of the structure. The elaborate investigation of reinforced concrete columns which was carried out by the American Concrete Institute, partly at Lehigh University and partly at the University of Illinois, has shown that the amount of plastic flow and the accompanying stress variations have no effect on the strength of the columns. The strength is made up of the sum of the strength of the concrete in the column and the yield-point strength of the steel reinforcement, and if spiral reinforcement is used, an additional strength term, due to the spiral. This strength law holds regardless of amount of plastic flow. Fig. 4 shows the effect of the strength of concrete on the strength of the column; Fig. 5 shows the effect of the longitudinal reinforcement; and Fig. 6 the effect of the lateral reinforcement. The strength law for reinforced brick columns had been found to be identical with that for reinforced concrete columns. In dealing with reinforced masonry we must therefore realize that the stress distribution does not signify the safety of the structure. The strength of the member becomes the criterion of design, and since the strength remains the same regardless of plastic flow, the analysis of s stresses has no practical value, neither for reinforced concrete nor for reinforced masonry subjected to direct compression. The reason for this is readily seen from a study of the behavior of ordinary reinforcing bars under long-time loading. In Fig. 7 is shown the deformation diagram of a reinforcing bar subjected to long-time loading. The bar will sustain its yield-point load for an indefinite length of time. The plastic flow will therefore produce no change in the amount of load carried by the steel when the deformation exceeds the yield-point strain, and since the plastic flow has no effect upon the strength of plain concrete, the strength of the column is not affected by the amount of plastic flow.

An illustration of how the reinforcement in a reinforced concrete column may be strained far beyond its yield-point strain without any apparent effect upon the column is given in Fig.8. The column which sustained a load of 70 per cent of its ultimate strength was removed from its loading rig after 115 days of sustained loading and tested to failure. The ultimate strength was 17 per cent greater than that of the companion column which was loaded to failure at the time of applying the sustained load. Other columns showed similar behavior. If high strength steel with no definite yield point is used for reinforcement, its total load contribution may be more than its apparent yield-point strength and the strength of the column increase with the amount of plastic flow. Fig.9 shows that even for first loading the contribution by the high strength steel is as much as 20 per cent in excess of its total yield-point strength.

There seems therefore to be no object in analyzing composite members subjected to direct compression for stresses in the two materials. These stresses do not mean anything anyway. The only important item is the safe load which can be applied and this load should be studied in terms of the ultimate strength of the member. Consequently a given factor of safety should be used as the basis of design. This leads to the conclusion that reinforced concrete and masonry columns should be designed on the basis of a working load equal to a certain percentage of the ultimate strength of the column. This is the only type of design acceptable on the basis of our most recent experimental results.

If, however, the total deformation of the columns becomes important for the design, this can be taken care of by studying the relationship between stress and plastic flow of the concrete when subjected to weather conditions similar to those which will prevail at the structure. The amount of plastic flow as well as that of shrinkage, is very closely related to the humidity of the air in which the concrete is stored. Unfortunately, the time allotted will not permit any further discussion of the interesting problem of plastic deformations and the factors which influence them. I will just point out that the lower the humidity of the air, the greater is the plastic flow and the shrinkage.