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Dir. Laurits Bjerrum, Norway

This contribution to the discussion concerns the problem of allowable settlements of structures as seen by the engineer in practice who has the responsibility for the foundation of a building such as a conventional apartment building, an office building or a factory. This engineer has to answer two questions: In the first place he has to evaluate the allowable differential settlements the structure can withstand without experiencing damage, and in the second place to predict the differential settlement which can be expected at a given site.

Concerning the first problem, to evaluate the allowable settlement for a given structure, we are primarily interested in the differential settlements or, more correctly, the distortional settlement which will cause damage to the building. Field observations have clearly shown that the distortional settlement which will cause damage to a building cannot be predicted from a theoretical computation. This is due to the fact that the actual statical behaviour of a building is greatly influenced by a number of factors which are not considered in a theoretical computation, such as interaction between structural and secondary elements, the time factor and the redistribution of the loads (Selbsthilfe des Bauwerkes).

The allowable settlements have therefore to be decided upon on the basis of previous experience derived from observations on similar types of structures. In 1956 Skempton and MacDonald made a review of published records in a paper: "The allowable settlements of buildings" (Inst. Civ. Eng. 1956, pp. 727–768). This review has recently been supplemented and summarized provisionally in the diagram shown on fig. 1. In this diagram are shown the types of damage which can be expected for various values of the angular distortion, being defined as the settlement difference between two points divided with their horizontal distance apart.

It is of interest to observe from fig. 1 that damage to the structural elements will occur at much larger distortions than will cause trouble to mashinery, secondary elements, and so on. In practice the allowable distortion will therefore in almost every case be governed by a consideration of factors which are related to the practical use of the building. This means of course that there is no single damage criterion which can be specified. In each case it must be decided what type of damage can be considered permissible,

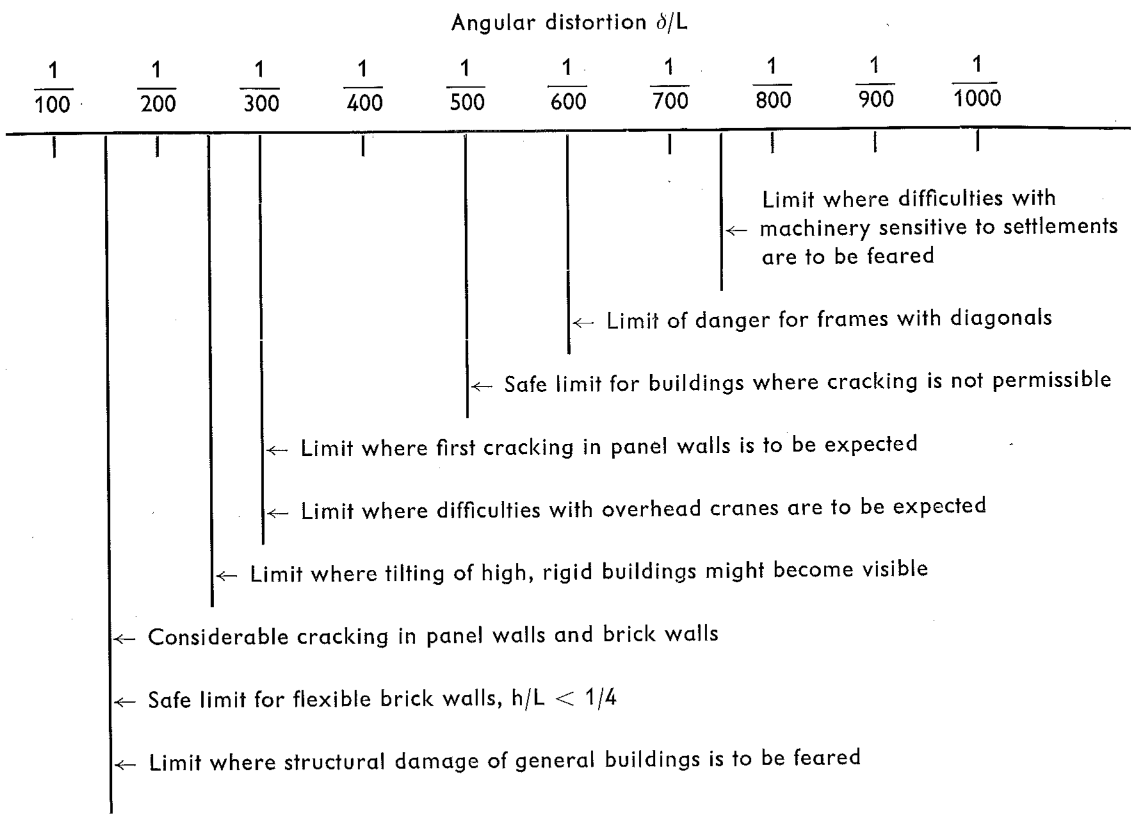


Fig. 1 Damage criteria.

and this will obviously vary from building to building. The allowable settlement will thus be different for a warehouse where the occurrence of minor cracks in partition walls would not justify an expensive pile foundation, and in public buildings such as a hospital where such unsightly cracks should by all means be prevented.

It should be emphasized that in practice the use of the review of observations presented in fig. 1 requires detailed consideration of a number of relevant factors. One of the most important is probably the time factor. The slower the settlements occur, the larger distortional settlements is a building able to withstand without experiencing damage. The settlement criterion will therefore be different for buildings on sand and on clay. Another factor of importance is the sequence and method of construction. If for example the secondary elements are placed after the main structure is completed and a part of the settlements have occurred they will of course only be subjected to the distortion connected with the remaining part of the settlements. Finally, it is necessary to take into consideration that other types of cracks inevitably appear in all buildings due to other reasons than differential settlements, requiring maintenance expenses independent of whether or not cracks result from settlements.

The second problem which the responsible engineer faces concerns the estimate of the differential settlement which he can expect at a given site.

Limiting the problem to structures on clay, differential settlements will result as a consequence of one or more of the following factors:

1. Variation of thickness of compressible strata.
2. Variation of load of different parts of the building.
3. Distribution of stresses in the soil beneath the foundation.
4. Inhomogeneity of the compressible strata.

It is in general possible to estimate with adequate accuracy the differential settlements due to the two first mentioned factors. The third factor will, in the following, be considered together with the fourth factor, the effect of which cannot be estimated on the basis of conventional soil exploration and testing, and therefore has to be evaluated on the basis of field observations.

To help evaluate the differential settlements due to the factors 3 and 4, fig. 2 has been prepared showing the maximum settlement differences observed at various buildings plotted against the maximum settlements. In the preparation of this diagram all cases have been excluded where the thickness of the compressible strata varied or where different parts of the building showed a different load intensity. The plotted points should thus indicate the maximum settlement difference which can be expected due to two factors only, the inhomogeneity of the ground and the stress distribution in the ground.

A detailed study of the points plotted in fig. 2 will show that there are two additional factors which exert influence on the behaviour of a given building. In the first place it will depend on the depth of the seat of

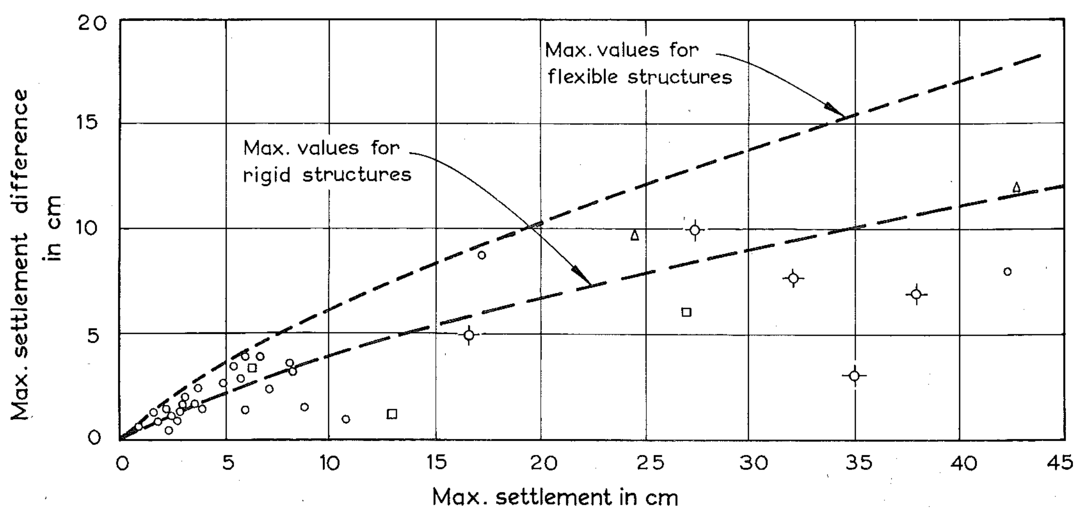
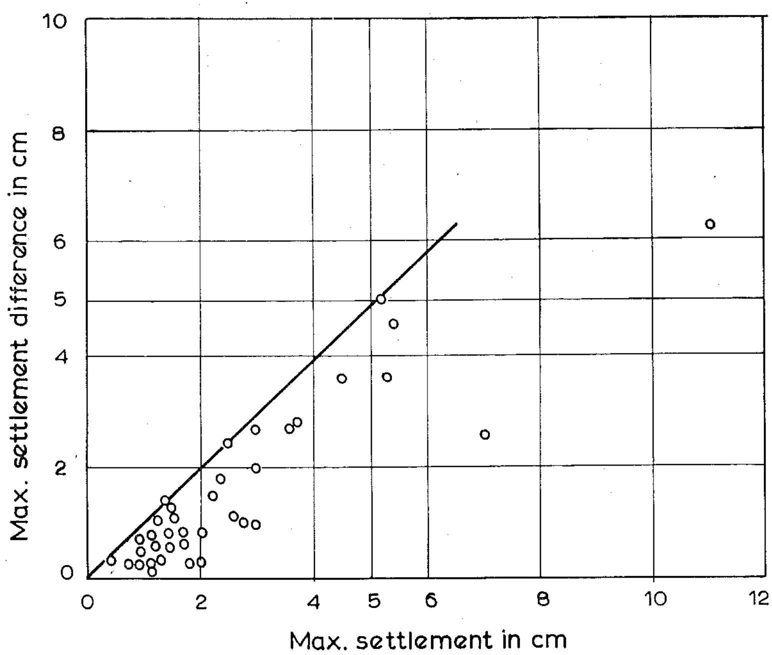


Fig. 2 Maximum settlement difference plotted against maximum settlements for buildings on clay.

Fig. 3 Maximum settlement difference plotted against maximum settlements for buildings on sand.



the settlement, i.e. the depth below the footing where the compressible layer is located. If the seat of the settlements is at great depth, for instance below a top crust or an upper layer of sand or gravel, the point will fall in the lower part of the graph. In the second place, the rigidity of the structure is a factor which has an influence on the relative magnitude of the differential settlements. This factor is difficult to evaluate, but following Skempton and MacDonald's terminology, it has been attempted in fig. 2 to differentiate between "flexible" and "box type" structures, and two upper limiting curves are drawn.

In fig. 3 is shown a similar diagram for buildings on sand. For sand the conditions are less complicated as the seat of the settlements is in general just beneath the footings. As pointed out by Skempton and MacDonald, the differential settlements of buildings on sand are of the same order of magnitude as the maximum settlements.

It should finally be emphasized that the presented diagrams are based on a limited survey and supplementary studies are required before final conclusions can be drawn. The purpose of this contribution is thus primarily to indicate some of the factors of importance for the evaluation of the allowable settlements.

Prof. Dr.-Ing. E. Schultze, Deutschland

In Abschnitt 4 seines Beitrages erwähnt Kany, daß bei der Berechnung von starren – aber natürlich auch von biegsamen – Balken und Platten auf dem elastischen Untergrund häufig die geologische Vorbelastung des Bodens berücksichtigt werden muß. Da die Tafeln von Kany aber für eine Belastung auf der Oberfläche des Halbraums entworfen worden sind, ergibt sich die Frage, wie dies zweckmäßig geschieht.

Für das Berechnungsverfahren maßgebend ist der Ansatz, daß die Setzungen gleich den Durchbiegungen des Balkens oder der Platte sein müssen. Dabei müssen die Setzungen für einen Sohldruck berechnet werden, von dem die geologische Vorbelastung abzuziehen ist (Fig. 1), während die Durchbiegung für die gesamte Sohldruckbelastung, also ohne Abzug der Vorbelastung, berechnet werden muß. Bei einfach verdichteten Böden ist die Vorbelastung gleich dem Aushubgewicht γt, sonst gleich σ_v. Wenn man in die entsprechenden Gleichungen einmal p_s und das andere Mal $p_s - \gamma \cdot t$ bzw. $p_s - \sigma_v$ einsetzt, ergeben sich recht umständliche Berechnungen. Man kann dann auch die aufgestellten Tafeln nicht mehr benutzen. Dies läßt sich aber ohne weiteres dadurch erreichen, daß man die geologische Vorbelastung als negative äußere Belastung des Balkens auffaßt. Man erhält dann die Sohldruckverteilung $p_s - \gamma \cdot t$ bzw. $p_s - \sigma_v$, die sich mit Hilfe der vorhandenen Ansätze und Tafeln ohne weiteres berechnen läßt.