joints; they nearly always are in form of steps (graduated); the brick is seldom cut through.

d) there is no question of regular angles of the breahces. The angle of breaches is solely due to the junction of bricks.

e) traversing vertical breaches (also in zig-zag-lines) point to horizontal dislodging in different places.

f) parallel step-lines cause a loosening of brick-junction (not monolitical as with beton-beams). It would be wrong to speak of the effect of beams and to take under consideration the height of brick-works respectively the momentum of inertia (Traegheitsmoment) of the wall-transversal fracture.

g) Above the space of subsidence there are again and again horizontal breaches to be seen which means exhaution of the tensil strength of mortar (Erschoepfung der Zugfestigkeit des Moertels).

h) Beside of breaches which have the tendency of vault-breaches there are sometimes breaches of entirely opposite direction. This can be explained by the fact that there has been a horizontal- and vertical shifting which caused the loosening of the whole system.

i) Depending on local condition of strength of the mortar there result wedge-like substances. The course of breaches can not be explained by the course of the main tension-trajectories (Hauptspannungstrajektorien).

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VI d 12

A PROBLEM OF FOUNDATION ON LOAMY SOIL IN SUBTROPICAL COUNTRIES

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In this article a special question of foundation on loamy soil will be dealt with, common to all countries (subtropical) where there are separate rain period and a rainless season in course of a year. During the rain period, loamy earth is more and more soaked, while during the rainless period it is dried out to a water content of a few percent only. This change of humidity in the earth is associated with a change of its volume and has a remarkable influence on foundations. The author of this article has had the opportunity of observing these influences on foundations in Palestine in the course of more than 20 years.

Like in other countries there are other foundation problems in Palestine, as for instance the general settling of buildings, although this is not a major problem here. Only a few observations have been made so far in this respect, and this is not the problem to be dealt with in this article. Our question is generally described above, and its significance is the periodical yearly rise and settling of the upper layers of the earth according to the change of its water content, causing cracks in walls of buildings when the earth expands or shrinks. It may be observed that more cracks are caused through expansion than through shrinkage.

As the problem of foundations on loamy earth in countries as represented in this article is strongly influenced by the special features of the subtropical climate, let us start with these.

Diagram (1) shows the quantities of rain during a period of 10 years and the distribution of rain per month. x) It can be seen that the rain season in Palestine lasts only about four months, with a small rainfall during the months preceding and following this period. The other months are not only practically rainless, but the evaporation is relatively higher than in countries with moderate climates. Evaporation varies considerably in different parts of Palestine.

There is a double influence of rainwater on the water-content of the soil. First, the surface of the earth is wetted directly. Lower layers of the earth are subsequently soaked when the rainwater penetrates. Secondly, there is an indirect influence on the water content of the earth through the changing level of the ground water, i.e. the "water-table". Diagrams 2 and 3 show a typical course of the water-table during the same period of years as in diagram 1. They were drawn from observations made on wells in the Haifa Bay area in Palestine. The depth of the water-table was 3-4 metres. One curve gives the ground water level in sandy soil and the other in loamy earth. The relation between the water-table and rainfall is obvious. Specially the ascending branch of the curves is strongly influenced by the rainfall figures, while its descending part is less so.

A periodicity of one year can be stated, and another periodicity can be seen during a number of years. Consequently the water content in the layers above the water-table changes according to the rising or falling ground water.

Foundations are influenced by the change of volume in the loamy earth. Therefore the relation between water content and volume will be shown.

Diagram (4) gives the change of volume of clay as a function of its water content. The diagram is derived from another one by Bourry 1). The linear change is approximately one third of the cubical change i.e. about 7% maximum. With the addition of sand to the clay this percentage decreases. It can be stated that the curve is not a straight line and that the minimum of volume is already reached with a water content of 12%.

The shrinkage of loamy earth during the dry period (summer and autumn) can be observed in the form of cracks in the upper layers of the soil. According to the composition of earth these cracks are smaller or larger and at

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x) Taken from records of observations near Haifa.

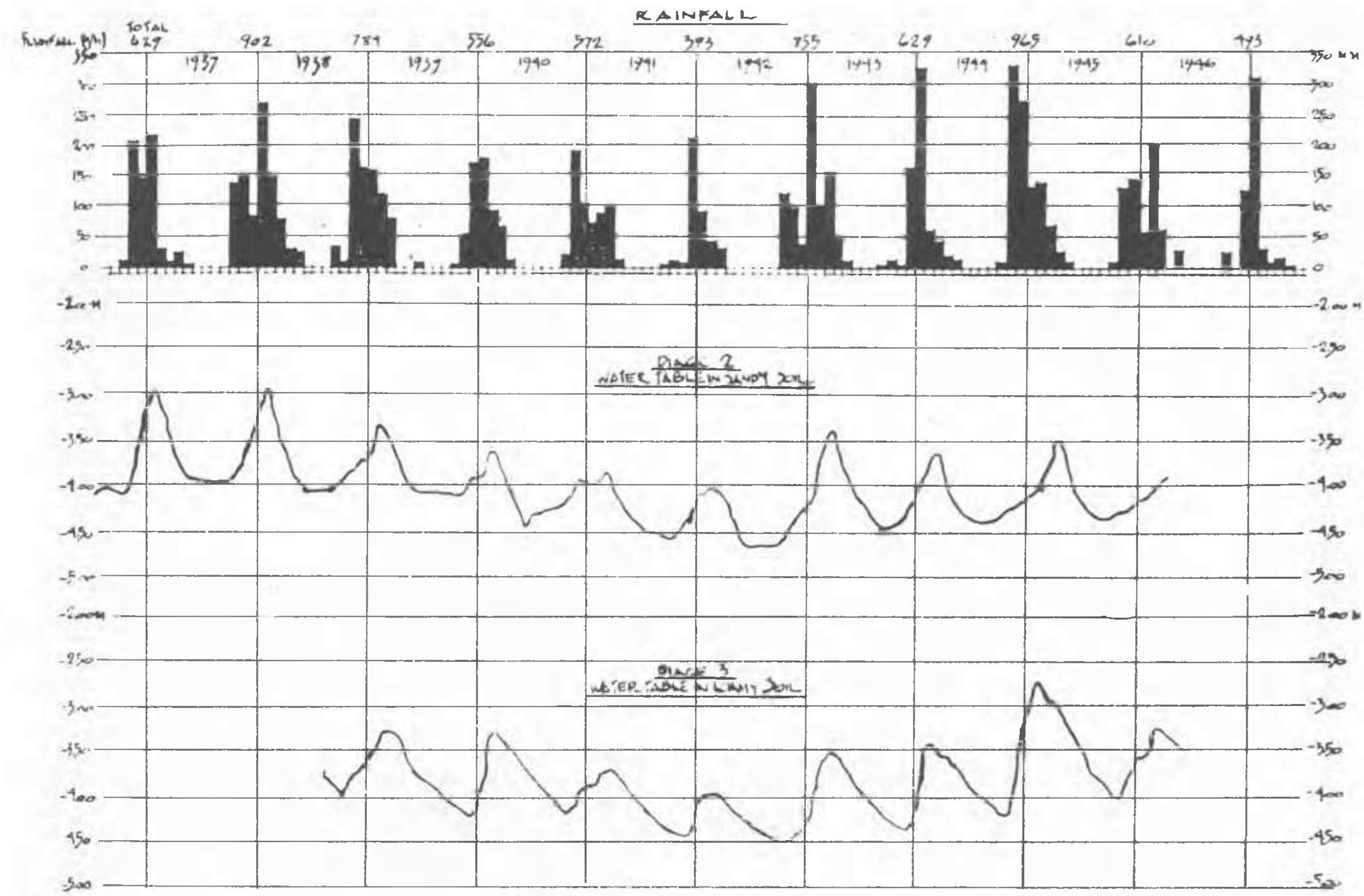
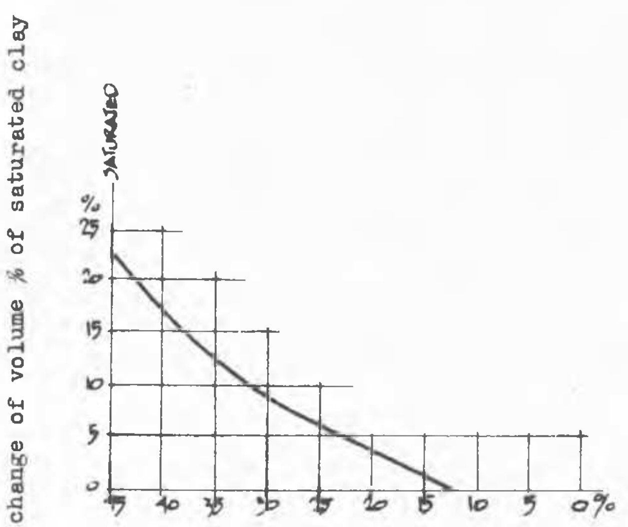


Diagram 1,2,3.



water content in clay (by volume) acc. to Bourry
Change of volume as function of water content.

Diagram 4.

smaller or greater distances (40-50 cms.).The cracks sometimes reach a depth of 2.0 m. and even more. The vertical cracks represent the horizontal effect of earth shrinkage. For our theme the vertical effect is of striking importance; together with the changing water content the loamy earth shrinks and expands periodically within one year. That means that the upper layers of the soil go up and down accordingly. If the foundations or other parts of a building are placed on a layer of shrinking or expanding earth they will settle or be lifted accordingly.

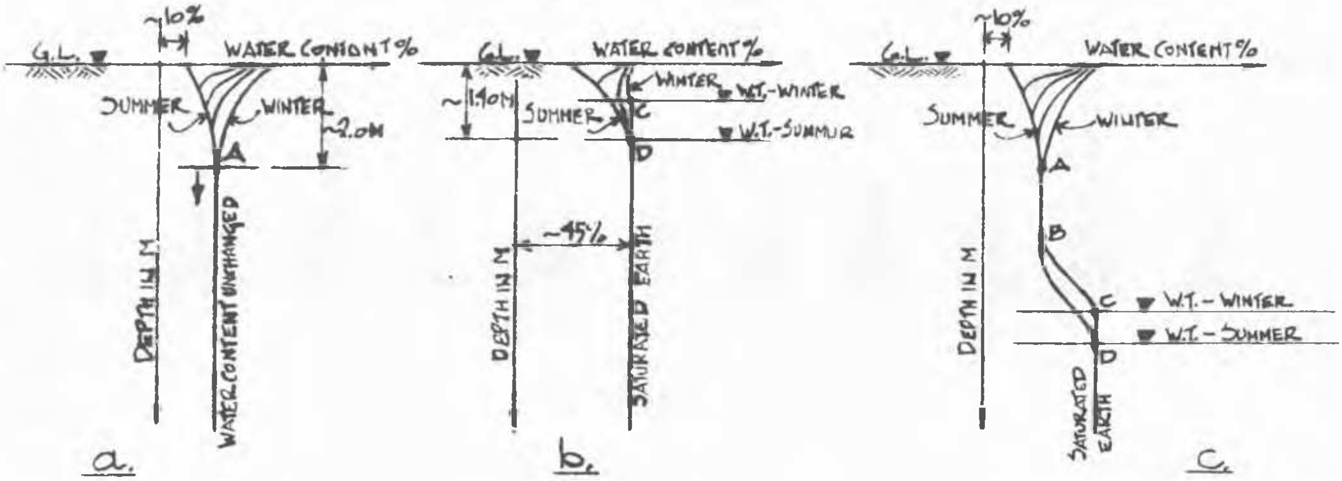
It should be a principle that foundations of buildings should not be placed on layers, the volume of which is subject to change through change of water content.

The change of water content in the earth, whether caused by the rainfall directly on the surface of the ground, or indirectly through the change of the water table and the consequent change of the volume of soil is of decisive influence on the depth of foundation. Three different cases may be distinguished:

a. Water table is deep (i.e. for question of foundations it is sufficient to speak of a depth of 10 metres or more.)
b. Water table is shallow (say at a depth of 2.0 m. or less)
c. The water table is medium (at a depth of 2.0 m. to 6.0 m.).

a) Water Table is deep.

In order to determine the change of water content in the soil, samples must be taken from different depths at different seasons of the year. One significant date is autumn when the soil has practically its lowest water content. Another important date is near to the end of the rain period when the earth shows its maximum water content. Between these extreme figures others may be obtained by determining the water content during the rain period. The attached diagram (5a) shows typical curves with a change of water content at different depths. It is of importance to say that from a certain depth marked "A" in diagram (5)- the water content practically does not change during the



Change in depth of water content
Diagram 5.

whole year, and thus also the volume remains unchanged in these layers. As the water table is supposed to be at a great depth, it does not influence the volume of the earth in this layers from beneath. It is therefore advisable to put footings at a depth of point "A" or lower. This depth was often found in Palestine to be 2.0 m. under surface.

It may be of interest to discuss the question what happens to the building if the engineer puts the foundations on layers of less depth than marked by "A".

Two phenomena may appear: During the dry period the footings may sink together with the shrinkage of the earth; and during the rain period the footings may be lifted together with the expanding soil. This fact would not be of importance if the magnitude of the rise or the settling were equal under all footings. But such a case is impossible, because the change of water content in the earth differs under various parts of the building. The soil under foundations situated at the circumference of the building is subject to a greater loss of water in summer and to a larger gain of water in winter than the soil under inner footings of the building. Even the water content under the outer foundations varies with the influence of rain sun and wind from different quarters of the heavens. If so, the rise or sinking of various parts of the building is different, and thus cracks are caused in the building, as an example, cracks observed in a building in the Esdraelon-Valley are shown in fig. 6.

b) <u>Water Table is shallow</u>.

Diagram No.(5b) shows the water content in various depths at different seasons. This diagram differs from that of (a) in two respects:

Firstly, there are two points marked in the diagram by C and D - from which downwards the water content is constant: C is significant for water-table in summer and autumn, and D in winter near the end of the rain period. The water-table changes between C and D during the year, C-D varying between 0.6 and 0.9 m. according to observations.

Secondly, the water content at C or D is equal to saturation. As the water content and consequently the volume of the earth changes above the lowest water-table, it is advisable to place the footings of the building into the ground water, although the permissible stress must then be kept low. It is of importance to ascertain the lowest water table, which depends not only on the yearly periodicity but upon the periodicity of a number of years, as can be recognized from diagram No.1. The range of changes of the lowest water table according to this diagram was found to be about 0.60 m.

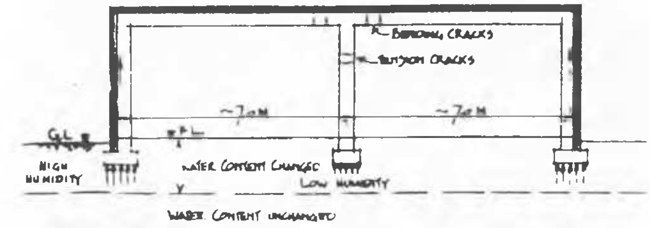
Case (b) is more complicated for ensuring the building against cracks than (a), because the building is under the influence of both direct rain water and ground water. Even if the foundation is put into the ground water, but parts of the building such as foundation beams and flooring are in contact with layers above point A, they will be lifted simultaneously with the increase of volume of the soil and cracks will consequently occur. There are many grave cracks of this kind in building in Palestine.

c) <u>Water table is at a medium depth</u>.

This case comprises (a) and (b). Diagram No. 5c shows the change of water content in the soil at various depths in different seasons. The zones of influence of rainwater and ground water are separated. There is a zone between points A and B which is not influenced at all. If this zone is large enough it is suitable for bearing the footings of the building, because the expanding effect of zone B D is hampered by the weight of the upper layers. Nevertheless it will be advisable to put the footings near point A, and then this case is similar to case (a).

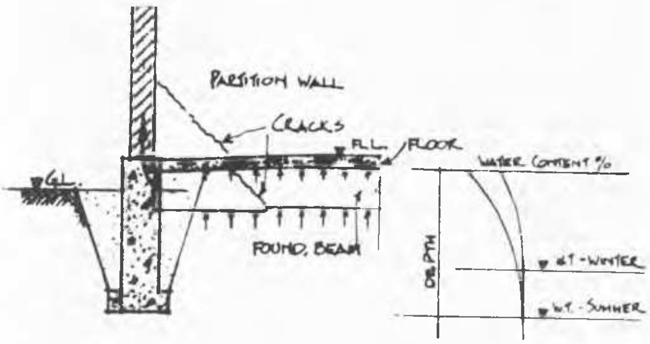
If Zone A B is small, or point B coincides with point A, or if Zone B D protrudes into the layers higher than A, it is advisable to lower the footings into the ground water as in (b).

So far we have made clear what conditions should be given to footings of a building in order to obtain a sound foundation in the three different cases described. It must, however, be remarked that, even if these conditions are given, nevertheless many cracks may occur in walls, and they occur owing to the action of expanding earth (only in a few cases through shrinkage), if parts of the building are in contact with loamy earth with changing water content. If the rise of the settling of the earth layers were equal under all parts of the building, cracks could not occur in the walls and a change of the position of the building in height would be of minor importance. Such a case is impossible because the magnitude of this rise or settling depends upon factors varying for different parts of a building which are in contact with earth changing its volume, even if the stresses are adapted to the size



Cracks caused by rise of outer footings

Diagram 6.



Cracks caused by rise of found. beam.
Rise of floor.

Diagram 7.

of the footings in order to ascertain an equal settlement.

1) The water content in the earth is not the same at different places under the building: at the circumference the earth is more exposed to atmospheric influence than the earth under the inner parts. Consequently it will be more soaked by rain during winter and more dried out by sun and wind during the summer period.

Differences in water content may even be caused around the building owing to the different orientation of its facades, according to direction of sun wind and rain. If, therefore, reinforced concrete beams supporting walls have been cast by error directly on the earth, the force of expansion acting upwards will be greater on beams near the outside of the building than on beams in its interior parts.

2) The thicker the expanding earth layer is, the greater is the magnitude of the rise at its top, or, if there is resistance to the rise, the force of expansion will be greater.

Two important consequences result in building from (1) and (2). One is the occurence of cracks in walls, beams and foundations, if the expanding earth pushes certain parts of the building more upwards than others. The cracks are quite characteristic and there are many forms of them. It can be observed at what places they occur and it can be distinguished whether they were caused by compression or tension. Their course and the direction of the acting forces can be stated. Thus the reason for cracking can easily be recognized. As an example, cracks observed in a building near Haifa are shown in fig. 7. Often the lateral expansion of the loamy earth inside the socle or the running foundations causes cracks. The other consequence is the typical rise of flooring in rooms forming a curved domelike surface, which can often be observed. The greatest rise, of course, is in the middle of the room and could be stated to reach 6 cms. and even more.

In the following lines means will be suggested for preventing cracks in building, caused by factors described above. These means have been applied successfully by the author in buildings in Palestine.

(I) Contact between parts of the building, excluding of course footings, on one hand, and the earth, subjected to change of volume, on the other hand, has to be avoided. From this point of view flooring should not be laid directly on earth but on supporting slabs built at a certain distance above the surface of the earth, thus avoiding any contact with it. Foundation beams also must not be in contact with earth at their bottom, and it would be the best to raise them completely above the surface of the earth.

It is advisable to keep the whole space under the building area free of earth, thus preventing also the horizontal action of expanding earth.

(II) If a layer with constant volume is found to be not too deep, another method may be applied; the whole loamy earth in the building area may be excavated to the depth of the footings and filled again with other material which is not subject to volume change if the water content changes.

(III) It must be borne in mind that the settling of different foundations of a building may differ from each other in the course of years, even if they have been placed according to considerations made in the three typical cases above. Therefore, strengthening reinforced concrete members should be used connecting the top of the footings. The purpose of these strengthening members is to equalize the settling of a row of footings. They must be strong enough in order to transfer part of the force acting in one footing to the neighbouring one. Any beam or wall or socle can be used as such a structural member, if it is reinforced accordingly.

(IV) A way of preventing superfluous expansion or shrinkage of the earth is to keep the water content in the earth artificially equal as much as possible during the whole year. During the winter period with its concentrated rains the surplus water should be removed from the building as much as this can be done, while during the whole dry summer period, the earth should be kept wet by constant watering around the house. This method has been succesfully applied and is preferable to other methods in cases where existing buildings suffer from cracks as discussed here. It must be admitted that this method is the same as the Almighty applies in countries of a moderate climate.

<u>REFERENCE.</u>

1) Salamang. Die Physikalischen und Chemischen Grundlagen der Keramik. Berlin, I. Springer, 1933.

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