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Substantial Consolidation and Swelling of Clay Cause Two Interesting Cases of Serious Damage to Hospital Buildings in Egypt

Deux cas de Dégâts Causés par la Consolidation et le Gonflement de l'Argile

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Summary

Great damage occurred during or after the erection and utilization of two hospitals in Egypt. The two hospitals are both three-storey buildings. Considerable swelling of the stiff clay layer due to seepage of water caused serious damage to the foundation of one building, while serious settlement of soft and very soft clay layers which support the footings of the other building was the cause of the damage. In neither case were the soil properties previously investigated by the structural engineer.

Sommaire

De gros dégâts ont été constatés dans deux hôpitaux en Égypte, pendant ou après leur construction et leur mise en service. Ces deux hôpitaux ont chacun trois étages. Le gonflement de l'argile compacte, par suite de l'infiltration de l'eau a gravement endommagé la fondation d'un des bâtiments, Quant à l'autre bâtiment les dégâts ont été provoqués par le tassement excessif de l'argile molle sous les fondations. L'Architecte chargé du calcul de la superstructure n'avait, ni dans un cas, ni dans l'autre, procédé à une étude préalable des propriétés du sol.

CASE OF FAILURE DUE TO SWELLING

Description of the Project

This project consists of two buildings, one of which is three-storeys and the other is just one floor. The walls of the buildings were made of natural sandstone bricks and the roofs were of reinforced concrete. The structural design was based on the wall-bearing system with reinforced concrete columns at points of relative heavy loads. The bearing stress for design was taken as 1·0 kg/cm^2.

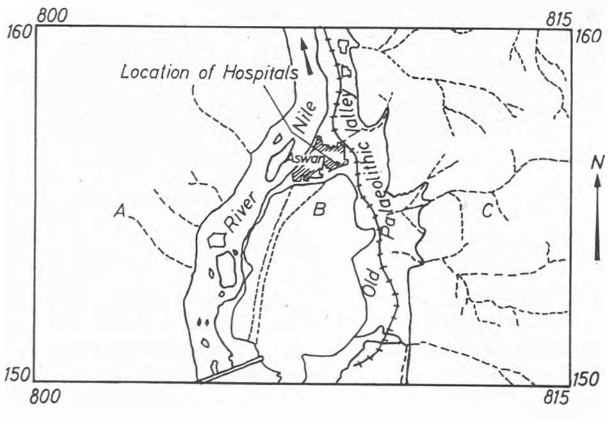

Fig. 1 Sketch map showing the topographical divisions of the Aswan District
Carte montrant les divisions topographiques de la région d'Assouan

Excavation for the foundation of the three-storey building started in August 1949 and construction continued till December the same year when the walls of the ground floor were completed. The progress of construction was running at almost the same rate until the building was completed in October 1951. The building was not used until October 1952, for reasons not known to the writers, but was in use from that date until March 1953 when cracks were first noticed. The cracks were opening fast and the authorities ordered evacuation in June 1953.

To facilitate excavation, which was by hand, the people on the site found it easier to wet the stiff clay, and all the trenches and pits for the foundation were excavated in this way.

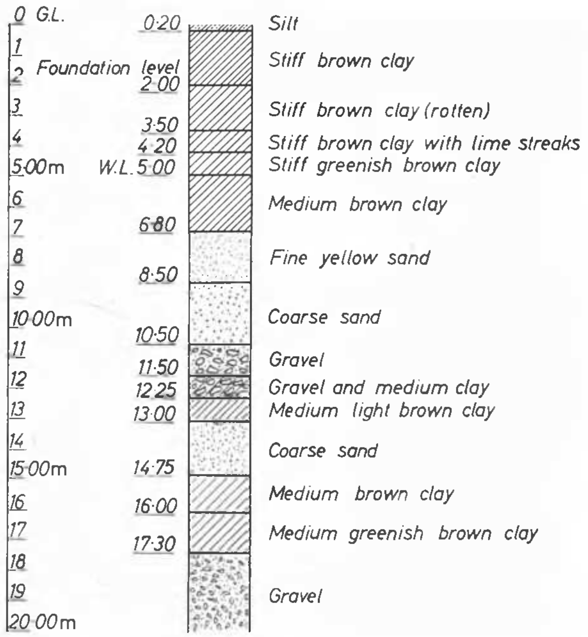

Fig. 2 Boring record from the site of the Aswan hospital
Forage à l'emplacement d'un des hôpitaux

Septic tanks were used for collecting the sewage. The walls of these tanks were made in such a way as to allow the sludge to remain while the water was allowed to drain into the soil.

Geological History of Aswan Area

The River Nile runs north from Aswan; its alluvial plains, deposited by the river between the cliffs of older sedimentary rocks, increase in width northwards. The sedimentary rocks are replaced by large areas of igneous and metamorphic rocks going south from Aswan. These rocks belong to the pre-Cambrian group of rocks. From the sketch map, Fig. 1, the topographical divisions of the Aswan district are evident as the city takes the form of a triangle. On the south side lie the old pre-Cambrian rocks; on the east side lies the Palaeolithic valley

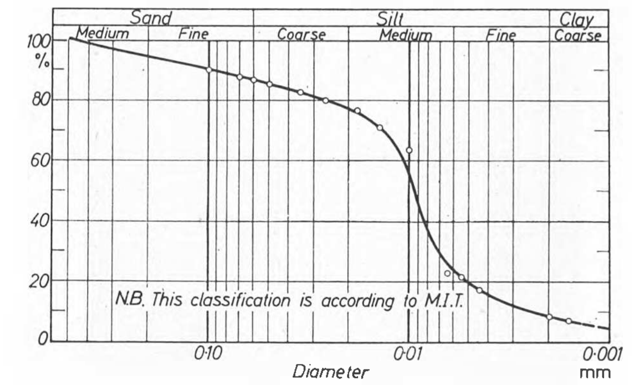

Fig. 3 Grain size distribution for Aswan clay
Granulométrie (région d'Assouan)

where the river ran in ancient times; and the west side is bounded by the Nile.

The site of the hospitals is composed of recent and Pleistocene deposits. It was mentioned by Ball (1908) that the origin of these deposits was traced back to the time when the Nile forsook its eastern channel, a backwater and lagoons being formed in which fine sedimentation could take place in the still water.

Fig. 2 gives the boring log for the soil under consideration.

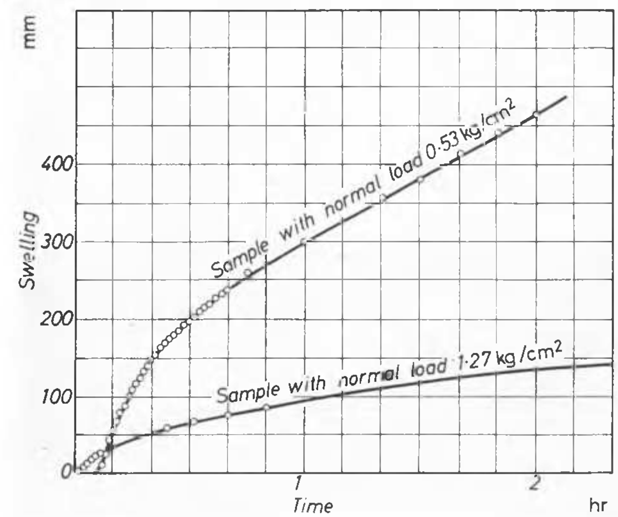

Fig. 4 Swelling-time curves from Aswan clay
Courbes montrant le gonflement dans le temps

Laboratory Tests

(1) Atterberg limits, natural water content and specific gravity of solids are given below:

LL = 70·8 per cent, PL = 32·8 per cent,

W = 6·5 per cent, $\gamma_s = 2{\cdot}65$

The shrinkage limit test failed as the clay cake became brittle after being put in the oven for drying it.

(2) *Mechanical analysis test*—Fig. 3 represents the gradation curve for the soil on which the foundation of the two hospitals rests and which was responsible for their damage. The soil

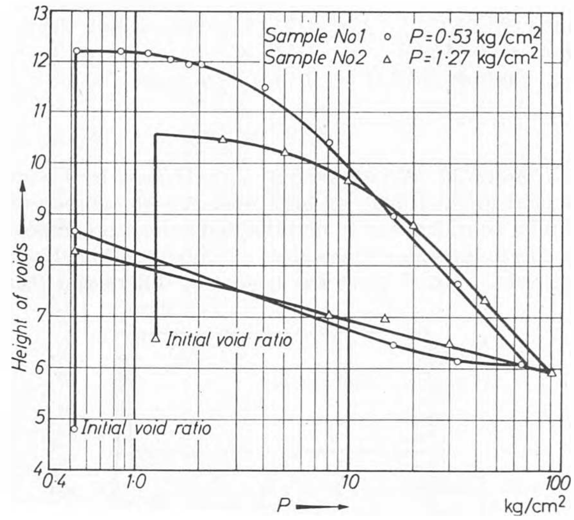

Fig. 5 Swelling-consolidation tests on Aswan clay
Essai de gonflement-consolidation

contains about 9 per cent clay, 78 per cent silt and 13 per cent sand.

(3) *Swelling consolidation tests*—Cylinders of diameter 3·4 cm and height 2·1 cm and 2·3 cm were carved from natural blocks of the clay under consideration. The clay cylinders were fitted in metallic cylinders of diameter 3·5 cm and height

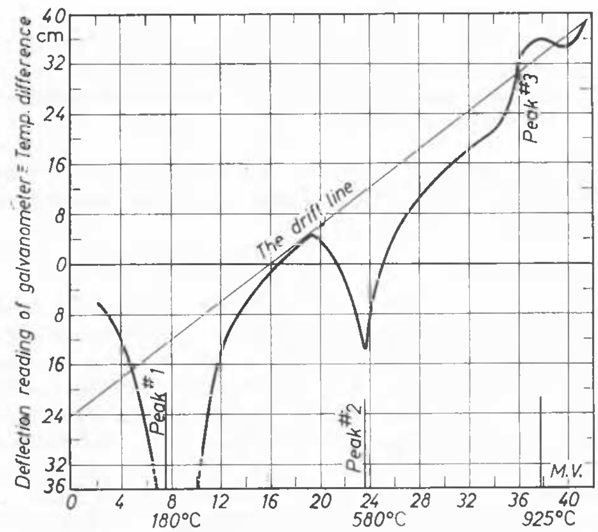

Fig. 6 Differential thermal analysis curve for Aswan clay
Courbe obtenue au moyen de l'analyse thermique différentielle

7·0 cm. Normal loads of 0·53 kg/cm² and 1·27 kg/cm² were applied to the circular side of the samples, wetting was then started and the swelling measured. Fig. 4 gives the time-swelling curves. Fig. 5 gives the e-log *P* curves for the two tests.

(4) *Chemical analysis test*—A chemical analysis test was carried out on a sample of the clay considered:

		per cent
Moisture (free water)	=	6·50
Loss due to ignition	=	9·73 (including H_2O of pure clay)
Silica (SiO_2)	=	54·54 (including SiO_2 of clay)
Alumina (Al_2O_3)	=	11·77 (Alumina of pure clay)
Calcium oxide (CaO)	=	3·14
Sodium chloride (NaCl)	=	0·18 (Cl ion = 0)
		99·87 per cent

(5) *Differential thermal analysis test* (D.T.A. *test*)—Several differential thermal analyses tests were run on samples of the clay under consideration to find the mineralogical composition of the clay in the soil. Fig. 6 gives the curve resulting from one of the tests. Fig. 7 gives the curves of differential thermal

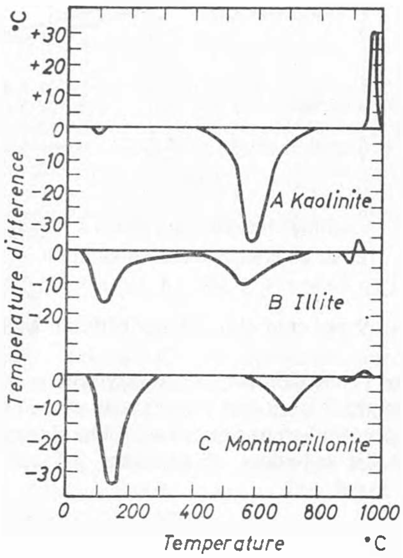

Fig. 7 Typical thermal analysis curves of clay minerals
Courbes typiques de l'analyse thermique différentielle de minéraux argileux

analyses of the three main clay minerals, namely: kaolinite, illite and montmorillonite. These curves are included for comparison.

Site Investigation

The swelling of the soil, upon which the foundation of the three-storey building was established, resulted in the raising of some parts of the building while the rest remained in place. These differential movements seriously damaged the building and it is hard to say that one wall was left intact. Some of the cracks were about 2 cm wide. In parts, where the toilets and wash rooms were located, the reinforced concrete ceiling crept horizontally on the walls for a distance of about 3 cm. In these places the glass windows were crushed. The floor of the wash room on the ground floor was raised for a height of about 50 cm above its levelled horizontal surface. The pavement around the building took a wavy shape due to the swelling of some parts of the soil close to the places where water percolated. Figs. 8, 9 and 10 are photographs taken of the buildings.

Discussion of Test Results and Field Investigations

From the boring log in Fig. 2, the succession of the soil layers from coarse gravel and sand to clay is a good example of the alluvial deposits forming the river terraces during its course along the Palaeolithic valley. The soil layer upon which the building stands is of such compactness that it could be cut and shaved with a knife. From the gradation curve this soil can be considered to be clayey silt. This clayey silt, when in its

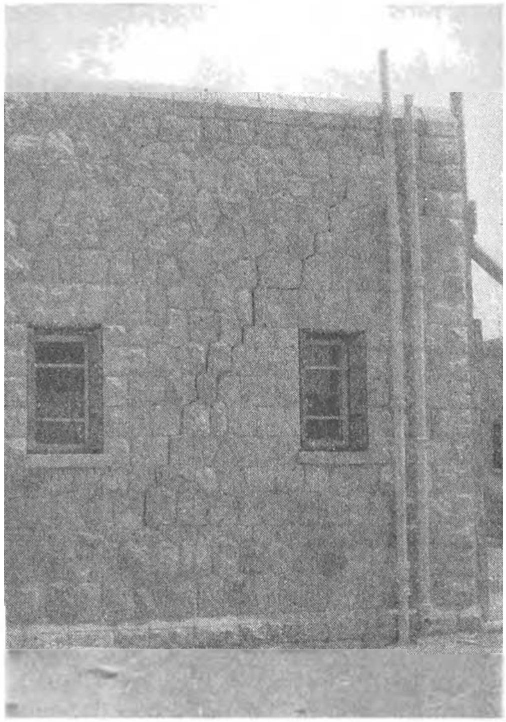

Fig. 8 Wall of toilet rooms in the one-floor building showing serious cracking
Fissures dans le mur du bâtiment sans étage

solid natural state, has a pattern of macroscopic fissures. It breaks along these hair cracks and the resulting surface is shiny and has a soapy feeling. The gradation curve shows about 9 per cent clay in this soil. As it was not possible to determine the mineralogical composition of the clay by x-ray or

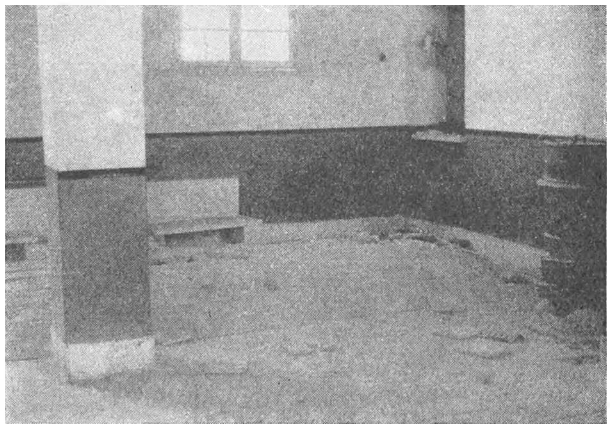

Fig. 9 Upward movement of floor of the wash room in the three-storey building
Soulèvèment du plancher de la salle d'eau dans le bâtiment à trois étages

electronic microscope, the D.T.A. test was used. The chemical analyses and D.T.A. tests both helped in the determination of the mineralogical composition of the clay. From the D.T.A. curve, three peaks were noticed. Peak 1 at temperature about 180° C. took place at the stage of the loss of hygroscopic water.

This peak is considered relatively deep. Peak 2 belongs to the crystal breakdown at which the temperature is about 580° C. Peak 3 gives the stage of recrystallization effects and it took place at a temperature about 925° C. This last peak is relatively small. Comparing this result with those of Fig. 7 it will be noticed that the curve of kaolinite is very different from that of the clay under consideration. (Notice peaks 1 and 3.) The clay can be considered either illite or montmorillonite. The difference between these two clay minerals is distinct. Illite is a fixed lattice clay mineral; fixation is due to the presence of the potassium ion holding the sheets tightly. Montmorillonite is an expanding lattice clay mineral. In the chemical analyses, however, no trace of potassium was found, which gives good reason for considering the clay mineral to be montmorillonite.

The solidification and compactness of the soil considered is due to the cementing action of the clay present. Upon hydration the water molecules enter between the clay sheets, increasing the distance between them, and swelling of the soil results.

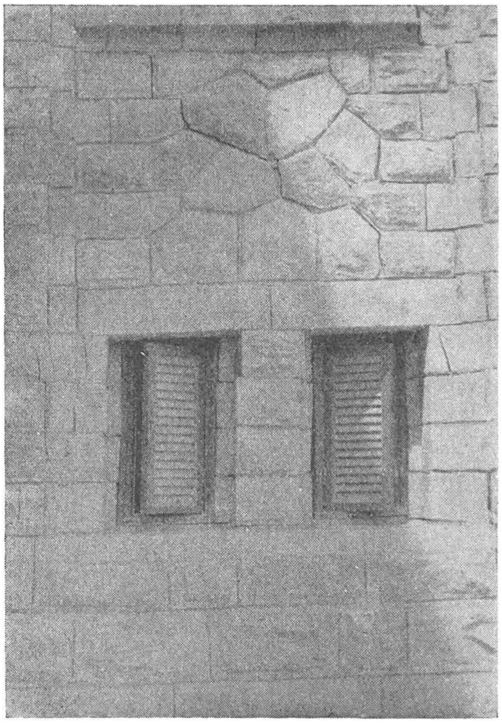

Fig. 10 Distortion of windows of the toilet rooms in the three-storey building
Déformation des fenêtres dans le bâtiment à trois étages

From site investigations, it was found that swelling of the soil was due to percolation of the sewage water from the septic tanks into the soil under the foundation. As the hydrated soil was confined in the horizontal direction, swelling took place in the vertical direction which was least resistant. This resulted in lifting the building upwards. The downward pressure from the weight of the building is only a fraction of the swelling pressure. To stop the clay from swelling, or to reconsolidate it after swelling back to its initial void ratio, tremendous pressures will be required of the order of 100 kg/cm^2 and more, as can be seen from the e-log P curves in Fig. 5.

CASE OF FAILURE DUE TO SETTLEMENT

The second case is completely different both in soil conditions and in behaviour of foundation, the only similarity being that the building is a hospital. This hospital is 53 × 9 m and is built in the North Delta of Egypt.

The hospital is a three-storey building. Borings at the site showed that the formation is mainly marine clay deposits that differ in consistency from soft to very soft and extend to a depth of about 20 m. Sand deposits were found under the clay layers.

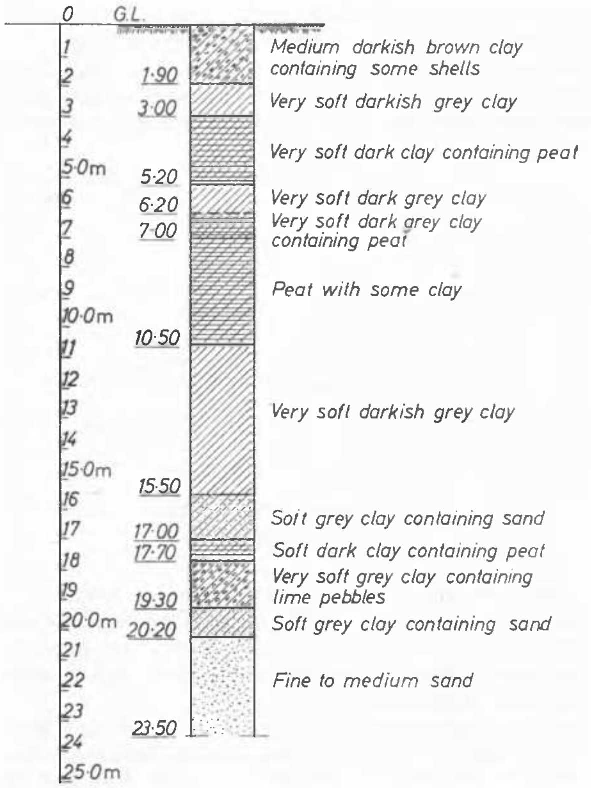

Fig. 11 Boring record from the Nile delta site
Forage sur chantier

Thin layers of peat were found at different depths within the clay deposits. Fig. 11 shows the soil formation at the site.

Laboratory tests were made on undisturbed samples of the clay. Results of such tests show that the natural water content varies between 60 and 320 and its variation with depth is erratic. Cohesion of such clays varies between 0·5 kg/cm^2 at the surface to 0·12 kg/cm^2 as an average for the whole depth.

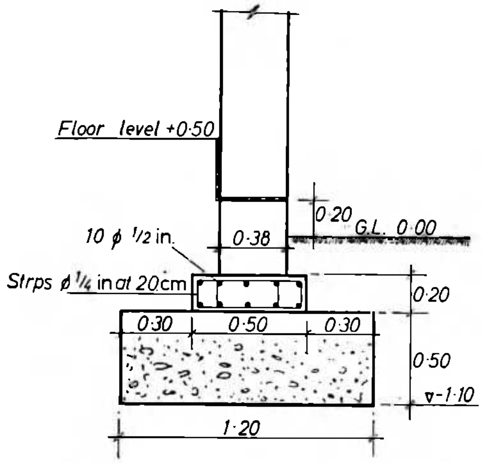

Fig. 12 Section through wall-footing
Coupe d'une semelle

No relationship could be found between the strength of the soil and the natural water content.

It was considered satisfactory to design the foundation as wall-footings, with maximum allowable stress from both dead and live loads not exceeding 0·8 kg/cm². The depth of the footings is almost 1·00 m from the ground surface as shown in Fig. 12. The writers find no basis for such choice and no calculations were made to compute the ultimate bearing stress and the settlements caused by the loads of the building.

However, during construction of the third floor, cracks showed in the building, and distinct variations in the floor and ground levels were observed. Construction was stopped and settlement observations were made on twenty points on the buildings, from which it was found that the settlement varied from 40 to 54 cm. The time when the cracks were observed—one year after the start of construction—showed that the stresses did not exceed 0·4 kg/cm².

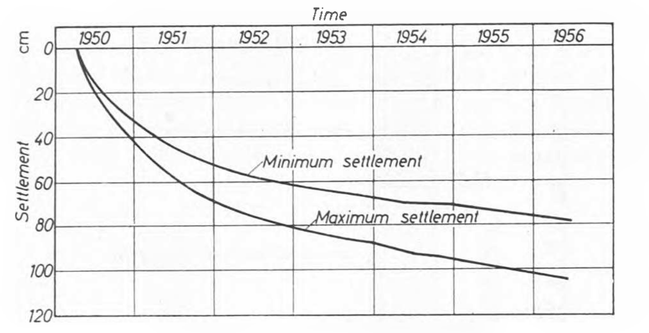

Fig. 13 Observed settlements
Tassement observé

There was a discussion as to whether it could be a bearing capacity failure or whether it was excessive settlement due to consolidation of the soft and the very soft clays and peat. Computations show that the ultimate bearing capacity of such soil strata is about 0·35 kg/cm². Settlement computations show that a subsidence of 50 cm could be reached in a relatively short period of time under stress 0·4 kg/cm².

The writers advised loading the building by sand bags in a uniform way to reach a stress of 0·8 kg/cm² at the base of the wall-footing foundations. Recorded settlements during the period 1951–56 showed that the settlements at the end of this time reached a minimum value of 78 cm and maximum of 104 cm with a maximum differential settlement of about 26 cm. Fig. 13 shows the maximum and minimum settlements during the lifetime of the hospital.

Observations on the fixed points in the building are to be continued for the next two years before a final decision is reached as to whether the hospital can be used or will have to be demolished.

Conclusion

The two cases show how serious can be the neglect of the study of the soil properties before construction. Soil tests in both cases would not have cost more than a hundred pounds and would definitely have saved the two buildings from such serious damage.

The writers are indebted to Dr F. Selim of the Chemical Department, Faculty of Engineering, Cairo University, for his great help in doing the chemical analyses and the D.T.A. tests.

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