

Engineering Geological Characteristics of Soil Materials, East Nile Delta, Egypt

A. I. M. Ismail and N. Ryden

Abstract—This paper is concerned with the study of mineralogy and engineering characteristics of soil materials derived from the eastern part of Nile Delta. The clay minerals of the studied soil by using X-ray diffraction are mainly illite (average 72.6 %) and kaolinite (average 2.6 %), expandable portion in illite-smectite mixed layer (average 7 %). Smectite is more abundant in fluvial clays, whereas kaolinite is more abundant in lagoonal clays. On the other hand, illite and illite-smectite are more abundant in marine clays. The geotechnical results show that the soil under study consists mainly of about 0.3 % gravel, 5 % sand, 51.5 % silt and 42.2 % clay in average. The average shrinkage limit attains 11 % whereas the average value of the plasticity index is 23.4 %. The free swelling ranges from 40 % to 75 % and has a value of 55 % giving an indication about the inadequacy of such soil under foundations.

From a construction point of view, the soil under investigation poses many problems even under light foundations due to the swelling and shrinkage. Such swelling and shrinkage is due to the high content of soil materials in the expandable clay minerals of illite and smectite. Based on the results of the present and earlier studies, trial application of soil stabilisation is recommended.

Keywords—Engineering Geological Investigations, Nile Delta, Swelling, Shrinkage

I. INTRODUCTION

NILE Delta is the largest and most important depositional complex in the Mediterranean basin. Furthermore, it is the unique site in Egypt that is favored for accumulation and preservation of the Quaternary sediments [1]. Clayey to silt clay soils are widely distributed in northern and central parts of Nile Delta.

The thickness of soft clay soils increases with the rising of water table of the quaternary aquifer (sand soils underlain the soft clay soils) as indicated by the increase of thickness of soft clays toward the north. The water table in the studied area was registered at about 20 to 25 m. Such fine grained clay rich soils particularly containing swelling clay minerals have caused numerous problems with great economic losses worldwide if it used as foundation, road base or as construction materials. They have a tendency to swell or shrink when their moisture content changes.

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II. GEOLOGY OF NILE DELTA SEDIMENTS

Nile Valley deposits in Egypt were classified by [1] into five river deposits, namely; Eonile, paleonile, protonile, prenilite and neonile deposits. The younger Quaternary neonile deposits to the north of Cairo (including the Delta sediments) are buried by thick sedimentation of recent Nile. In the Eastern part of the Delta, this sediments layer is thicker than in the western part. The thickness of Nile delta sediments increase from less than 1 m in the southern part to more than 15 m in the northern sector especially around the surface water. However, they nearly diminish towards the Mediterranean coast where the sand deposits are generally predominant.

From structure point of view, the area of the Nile Delta was subjected to tectonic uplift during the late Eocene and Oligocene and has been tectonically controlled since the late Eocene by both ENE-WSW and NW-SE fault systems trending parallel to the Mediterranean Sea and Gulf of Suez-Red Sea respectively [2]. According to [3], the Nile Delta can be subdivided into three zones, namely southern, middle and northern zones. Southern zone characterized by coarse Nile sediments mainly sand deposits. The middle zone is usually characterized by finer sediments when compared to the southern zone, so it assumed to be a transitional zone between the southern and northern Delta zones. The region of the middle Delta generally slopes from east to west [1], making the level of the Damietta branch higher than that the Rosetta branch by two meters. In the northern zone, the finest neonile sediments of the three zones were occurred. The northern part of the Delta is characterized by several brackish lagoons (Maryut, Idku, Burullus and Manzala) connected with the Mediterranean Sea through narrow outlets (Fig. 1).

III. LITHOLOGICAL BACKGROUND

The Quaternary subsurface section of the Nile Delta has been subdivided by many Authors [1], [4]–[8] into two rock units on the basis of their lithologic composition. The section includes from base to top Mit Ghamr and Bilqas Formations [6]. The Mit Ghamr sediments are mainly sands with clay and gravel interbeds with middle Pleistocene age [1]. Bilqas Formation (Holocene) is dominated by sand, silt and clay interbeds; the sediments are more calcareous in the northern part of the Nile Delta. Also peat layers have been encountered within the sediments of the Bilqas Formation. The maximum thickness of this Formation is about 77 m [8]. According to [1], the Bilqas Formation may be included within the Neonile sediments which are late Pleistocene to Holocene. In the eastern part of Nile Delta, the late Quaternary deposits are described by [4] as Nile mud deposits of flood basin deposits to clay, silt and sand.

[9] studied the late Quaternary evolution of the northeastern Nile Delta. They stated that these sediments were classified stratigraphically into basal unite (late Pleistocene) and upper unite of Holocene age. The basal unite composed of shallow marine transgressive sands with stiff mud remnant. These remnants suggest river incision and corrosion of unprotected alluvial plain muds during the last Pleistocene. The upper unit belonging to Holocene age and is dominated by mud facies of alluvial plain and lagoonal environments.



Fig. 2 Longitudinal cracking occurs in buildings

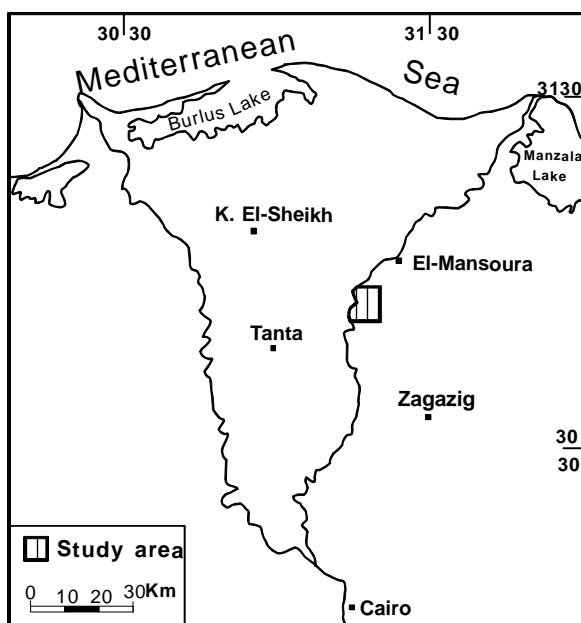


Fig. 1 Location map of the studied area south western part of El-Mansoura

IV. STRUCTURE DAMAGE AND STATE OF PROBLEM

Extensive damage to structures and pavements has been noticed in the newly developed area of the region. The structures that were most affected by heave of expansive soils are relatively light weight structures constructed on shallow footings. Such projects do not usually justify the time and expense of rigorous analyses. The problem was further aggravated by inadequate experience with the ground conditions and associated heave problems. Thus, field study was established in the Eastern Nile Delta (Fig. 1). The area was selected because many residential buildings, sidewalks, and pavements have been severely damaged due to the differential heave of the supporting soil base materials as shown in Fig. 2. Some buildings had been repaired, while others had to be abandoned as the cracking became beyond repair. The damage is primarily in the form of longitudinal cracks in beams and columns as shown in Fig. 2 Extensive hairline cracks and some wider cracks with random orientations can be observed in the pavements due to differential heave (Figs. 3 and 4).



Fig. 3 Differential settlements in the pavement of the studied area



Fig. 4 Mud cracks in the soil materials

V. ENGINEERING PROPERTIES AND SOIL BEHAVIOUR

Engineering and physical properties have been determined on samples from the soil under consideration to give an account about the engineering characteristics of the materials derived from such soil materials. The test methods used in this study are grain size analysis [10], determination of consistency limits (include liquid, plastic and shrinkage limits) and free swell tests. The material studied comes from the area of East Delta soils (Fig. 1). The physical and mechanical properties of the soil under study at various depths are illustrated in Tables 1, 2 and 3. The grain size analysis shows that almost total of the material passes to the sieve 8 mm and more than 90% of

material passes the sieve 63 μm . According to German Standards classification [11], this material belongs to the TM group or middle plastic clay where the materials passing 63 μm > 40% of the total material, plastic limit (I_p) \geq 7%, Liquid limit (W_L) is between 35%-50% ($35\% \leq W_L \leq 50\%$). The relation between the grain size distribution, free swell and the Atterberg limits (liquid limit, plastic limit, plasticity index, shrinkage limit) are illustrated in Fig. 5.

TABLE I
ENGINEERING AND PHYSICAL PARAMETERS OF THE STUDIED SOIL SAMPLES

Depth	Nat. Moist. Cont.	Liquid Limit	Plastic Limit	Plasticity Index
0,3 m	12,5	46,1	29,2	16,9
	11,7	47,0	26,8	20,2
	12,0	44,4	20,5	14,0
	12,7	48,9	24,3	24,6
	13,2	45,9	25,7	20,2
Average	12,6	46,5	27,1	19,4
1,0 m	15,6	51,7	27,2	24,5
	13,2	47,0	25,7	22,3
	15,2	47,6	27,3	20,3
	14,6	47,4	28,1	19,3
	14,0	50,7	25,7	25
Average	14,5	49,1	26,8	22,3
2,0 m	20,8	53,9	24,8	29,1
	21,9	50,1	23,1	27
	23,4	51,1	24,5	26,6
	22,9	53,2	22,8	30,6
	23,5	53,4	23,0	29,8
Average	22,5	52,3	23,7	28,6

Linear Shrinkage	Free Swell	Consistency Index	Liquidity Index	Gravel %	Sand %	Silt %
9,5	40	1,99	-4,99	1,2	5,75	86,76
9,3	45	1,75	-4,75	4,0	6,95	89
9,5	40	2,11	-1,11	4,5	7,55	87,7
8,2	40	1,47	-4,47	4,9	6,5	88,4
9,2	35	1,62	-4,62	4,6	7,5	87,7
9,1	40,0	1,75	-4,75	0,80	6,85	54,90
11,0	45	1,47	-4,47	0	4,33	89,74
10,5	45	1,58	-4,58	0	4,1	89,42
10,0	50	1,60	-4,60	0	3,7	83,8
10,0	55	1,70	-4,70	0	5,7	82,54
11,0	55	1,47	-4,47	0	3,4	84,24
10,5	50,0	1,55	-4,55	0	4,240	83,892
12,2	70	1,14	-4,14	0	2,0	86,44
14,5	75	1,04	-4,04	0	2,00	86,11
13,0	75	1,04	-4,04	0	4,71	89,87
14,1	80	0,99	-4,01	0	4	86,16
12,4	75	1,00	-4,00	0	4,84	87,55
13,4	75,0	1,04	-4,04	0	4,00	88,42

TABLE II

AVERAGE GRAIN SIZE DISTRIBUTION OF THE STUDIED SOIL MATERIALS

Depth (m)	Gravel %	Sand %	Silt %	Clay %
0,3 m	0,80	6,85	54,90	37,45
1,0 m	0,00	4,25	53,89	41,86
2,0 m	0,00	4,00	48,42	47,58

TABLE III

AVERAGE ATTERBERG LIMITS OF THE SOIL UNDER INVESTIGATION

Depth (m)	Nat. Moist. Cont. (W)	Liquid Limit (W_L)	Plastic Limit (P_L)	Plasticity Index (PI)	Linear Shrinkage (LS)	Free Swell (FS)	Consistency Index (I_c)	Liquidity Index (I_L)
0,3 m	12,6	46,5	27,1	19,4	9,1	40	1,75	-0,75
1,0 m	14,5	49,1	26,8	22,3	10,5	50	1,55	-0,55
2,0 m	22,5	52,3	23,7	28,6	13,4	75	1,04	-0,04

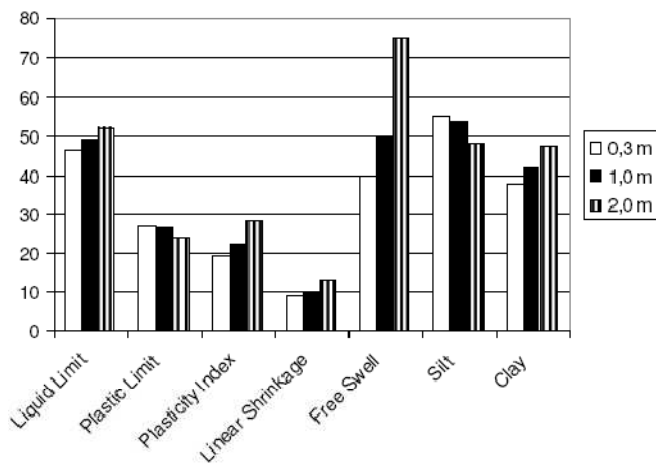


Fig. 5 Relation between the grain size distribution (%) and the consistency limits (water content %) as well as free swell (%)

Values of relative consistency and liquidity indices throughout the moisture content are summarized in Table 3 [12]. The values of consistency index (I_c) for the soil under investigation ranges from 1.04 to 1.76, whereas the liquidity index (I_L) ranges from -0.04 to -0.76 suggesting that the moisture content of soil materials is below the plastic limit (Table 3). Linear shrinkage has been calculated using British Standards [13]. It ranges between 9.1 % and 13.4 % and increases with depth. The free swell test procedure is defined by British Standards [14]. Loose dry sieved materials passing a 0.4 mm sieve are poured in water. The increase in volume of soil is referred as free swelling. The calculation of the free swell index by using 10 ml of dry loose powder is given in the equation: Free swell = $(V - 10) / 10 * 100\%$, whereas V represents the recorded volume of settled solids in ml. By increasing the depth, free swell values increase.

The clay mineral contents were investigated by using X-ray diffraction (XRD). This method is particularly useful for identifying fine grained minerals and mixtures or intergrowth of minerals that may not lend themselves to analysis by other technique so it is the primary method for identifying clay minerals as well as other minerals. It is therefore used to identify the various types of clay minerals. This method is based on the principles of diffraction of X-rays by planes of atoms in the crystal structure producing a so called diffractogram. An X-ray chart is produced by plotting the diffraction angle against the intensity of the diffracted radiation. Clay and non clay minerals were identified using the peak position of the X-ray chart according to [15]–[16]. The identification of clay minerals depends on the examination of the oriented mounts of studied soil under three separate conditions [16] namely: air dried, ethylene glycol treated and after heating to 550 °C for one hour. The determination of quartz, calcite and dolomite was carried out by mixing the samples with a Calcium Fluoride (CaF_2) standard. The expandable smectite in mixed layer clay minerals was calculated according to [17] as shown in the diagram (Fig. 6) by determining the peak intensity of the mixed layer in ethylene glycol treated state.

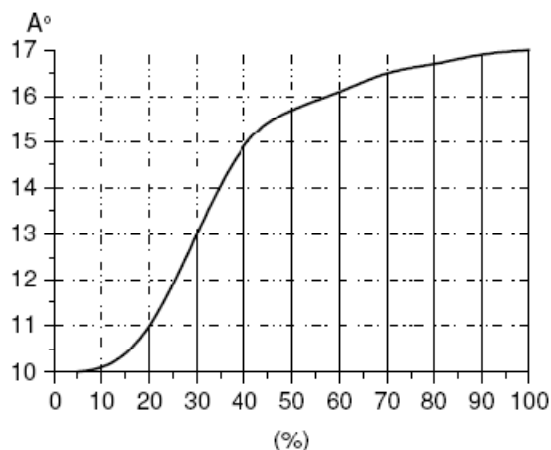


Fig. 6 Determination of expandable portion of mixed layer clay minerals (%) from the peak intensity of mixed layer (A°)

X-Ray diffraction (XRD) analyses of the soil under investigation (Fig. 7) showed the presence of varying amounts of several minerals: Quartz, Calcite and clay minerals with small amount of Chlorite and Hematite (Fig. 7). The clay fraction were examined under three separate conditions; air dry state, ethylene glycol treatment and heating to 550°C (Figs. 8, 9 and 10). A semi quantitative XRD analysis was conducted using Automated Powder Diffraction Computer Program and the percentage of each of the minerals was calculated and is given in Tables 4 and 5. By this program, we could calculate the major diffraction peak heights followed by calculation of the net area of the peak which are converted to mineral percentages.

The percentage of smectite in mixed layer is calculated according to the diagram [17] (Fig. 6) by determining the peak intensity of the mixed layer in ethylene glycol state. Sometimes smectite bearing mixed layer is transformed to illite [17], [18]–[21]. [22] studied the subsurface sediments at Rosetta promontories. They stated that such sediments have been deposited in Holocene time. X- ray diffraction of clay fractions in these sediments are mainly montmorillonite and kaolinite with lesser amounts of illite. These minerals indicate that the mud deposits were carried by the river Nile to the Mediterranean Sea and deposited under fluviomarine conditions. Montmorillonite rich soils make great problems in the pavement design and this type of soils must be improved by additives to meet the requirements of construction engineer was studied by [23]–[25].

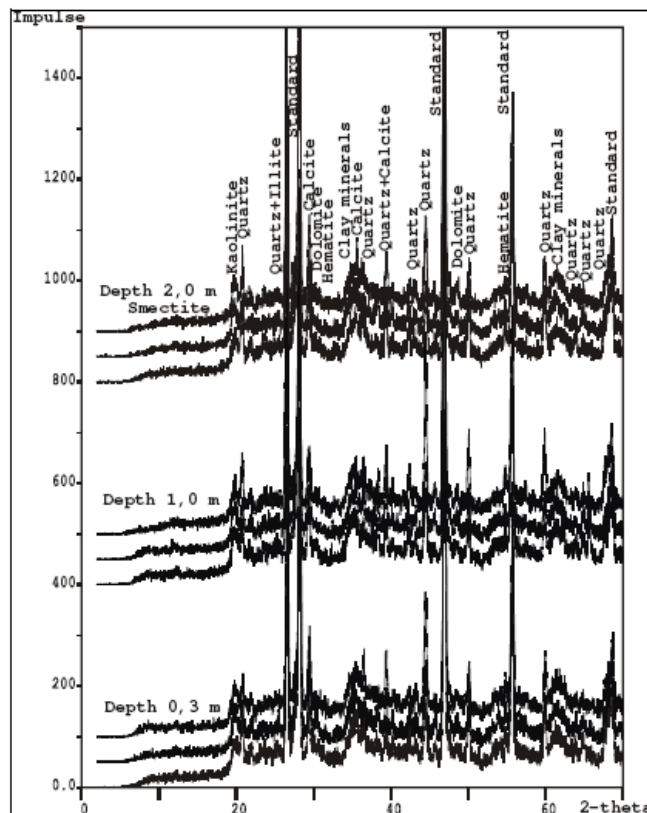


Fig. 7 X-ray diffraction curve with CaF_2 standard for the examined soil materials

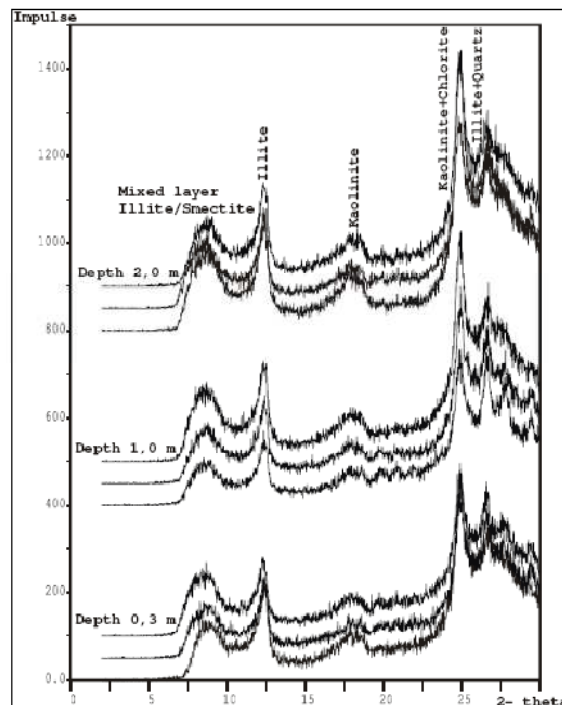


Fig. 8 Clay minerals in the air-dried state for the studied soil materials, East Nile Delta

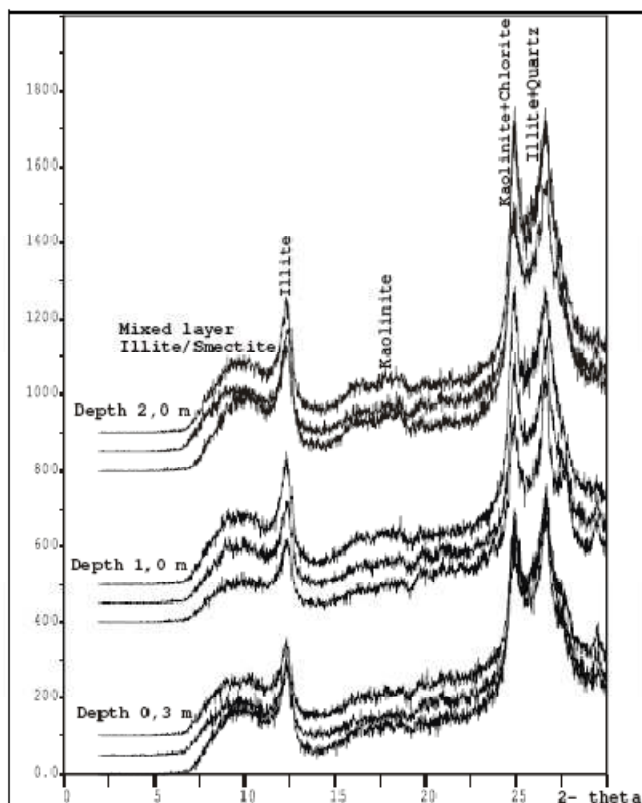


Fig. 9 Clay minerals in the ethylene glycol state for the studied soil materials, East Nile Delta

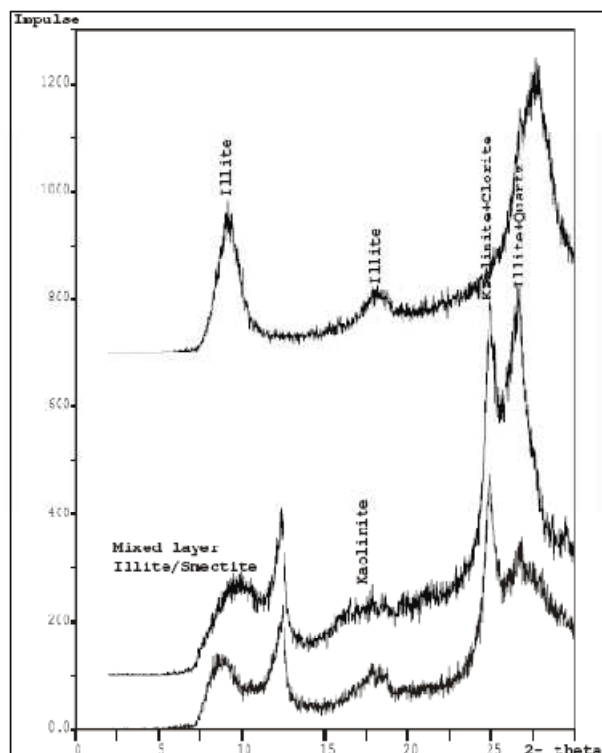


Fig. 10 Clay minerals in the air dried, ethylene glycol and heating states for the studied soil materials, East Nile Delta

TABLE IV
 AVERAGE MINERAL CONTENT FOR THE SOIL UNDER INVESTIGATION

Depth (m)	Quartz %	Calcite %	Dolomite %	Smectite %	Illite %	Kaolinite %
0,3 m	16	2	1	4	73	4
1,0 m	13	2	2	8	73	2
2,0 m	13	2	2	9	72	2

TABLE V
 AVERAGE CLAY MINERALS CONTENT OF THE STUDIED SOIL MATERIALS

Depth (m)	Illite	Kaolinite	Mixed Layer		Total Illite
			Smectite	Illite	
0,3 m	71	5	4	20	91
1,0 m	71	3	9	17	88
2,0 m	73	2	11	14	87

VI. SUMMARY AND CONCLUSIONS

Silty clay soils of the East Nile Delta show well developed unfavourable materials underneath the infrastructure and may be insufficient to meet certain civil engineering requirements. Hence this investigation was carried out to determine the behaviour of the silty clay soils and its influence on the engineering properties. Mineralogically, illite is the dominant clay minerals, quartz, mixed layer illite-smectite, kaolinite, calcite and dolomite are present in variable amounts. Furthermore, the character of the clay minerals changes, for example, illite-smectite mixed layer frequently was being degraded upward. Index properties including grain size distribution, Atterberg limits, free swelling and linear shrinkage were determined. The relation between the index properties and mineralogical characteristics reveal the influence of the clay mineral content on the engineering parameters. With increasing the illite and illite-smectite mixed layer as well as the percentage of clay fraction, the plasticity index, swelling and shrinkage increase.

Buildings, engineering installations and infrastructures constructed above the soil of the studied area of the East Nile Delta suffer damage a result of swelling or shrinkage that can take place. A survey of buildings in this area indicated that buildings were frequently fractured as a result of the differential settlement that was occurring due to the change of water content under the construction. Changes in moisture content of the soils beneath structure would result in this type of damage. It is necessary to reduce the soil moisture changes below the foundation making a good drainage to prevent the accumulation of water or modification and/or stabilization of the base layer soil materials by one method of soil improvement.

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