academicJournals

Vol. 5(3), pp.58-64, March, 2013
DOI: 10.5897/JGMR11.046
ISSN 2006 – 9766 © 2013 Academic Journals
http://www.academicjournals.org/JGMR

Journal of Geology and Mining Research

Full Length Research Paper

Suitability of soils as bearing media at a freshwater swamp terrain in the Niger Delta

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Accepted 11 February, 2013

This study evaluates the subsurface lithologies as well as examines the properties of the soils at a University location within the fresh water swamp terrain in the Niger Delta. Borings for subsurface exploration in the area were made at five well spaced locations with a hand auger to a maximum depth of 4.00 m in each borehole. Soil samples were retrieved at 0.5 m interval and at positions where changes in lithology were noticed during the boring process. Laboratory tests were carried out on selected and representative soil samples recovered from the borings in accordance with BS 1377 (1975) and ASTM (1979) standards. Moisture content range from 20.6% to a maximum of 26.5% in the silty clay and gravelly, silty clay soils located at 2 m depth and low to medium plasticity range (12 to 18%). The undrained friction angle was determined to be 30 while the undrained cohesion has a value of 58 KN/m^2, the computed coefficient of volume compressibility (Mv) gave 1.24 m^2/MN while the coefficient of consolidation (Cv) resulted in 3.38 m^2/year. Computed total settlements of 69 mm are within design limits for shallow foundation. Borehole 1 (BH1) was dry while BH2 recorded 3.80 m as the ground water level. Observed water table depths in BH3, BH4 and BH5 were 2.00 m, 1.70 and 1.50 m, respectively, at the time of the subsurface investigations. Higher values are expected especially at the peak of the rainy months. Foundation systems in the area must take special precaution to prevent seepage into the structures. This could be by drainage or waterproofing or a combination of both methods.

Key words: Geotechnical properties, subsurface soils, water table conditions, fresh water swamp terrain, Niger Delta.

INTRODUCTION

It has been observed in recent times, that many property developers in the Niger Delta region of Nigeria ignore drastically the role of geotechnical information in the planning, design, construction, operation as well as safety of civil engineering infrastructures. This neglect results to failure of structures.

Frequent structural failure of civil engineering infrastructures in parts of Port Harcourt Metropolis has become a source of worry to so many persons. It is for this reason that a clear understanding of the occurrence, composition, distribution, geologic history as well as the geotechnical properties of subsurface soils in the area is necessary (Startrite Mayton and Company, 2000).

Considering the fact that the Eastern Niger Delta is within the coastal zone, geotechnical investigation /considerations are very desirable. The coastal zone which comprises the beach ridges and mangrove swamps is underlain by an alternating sequence of sand

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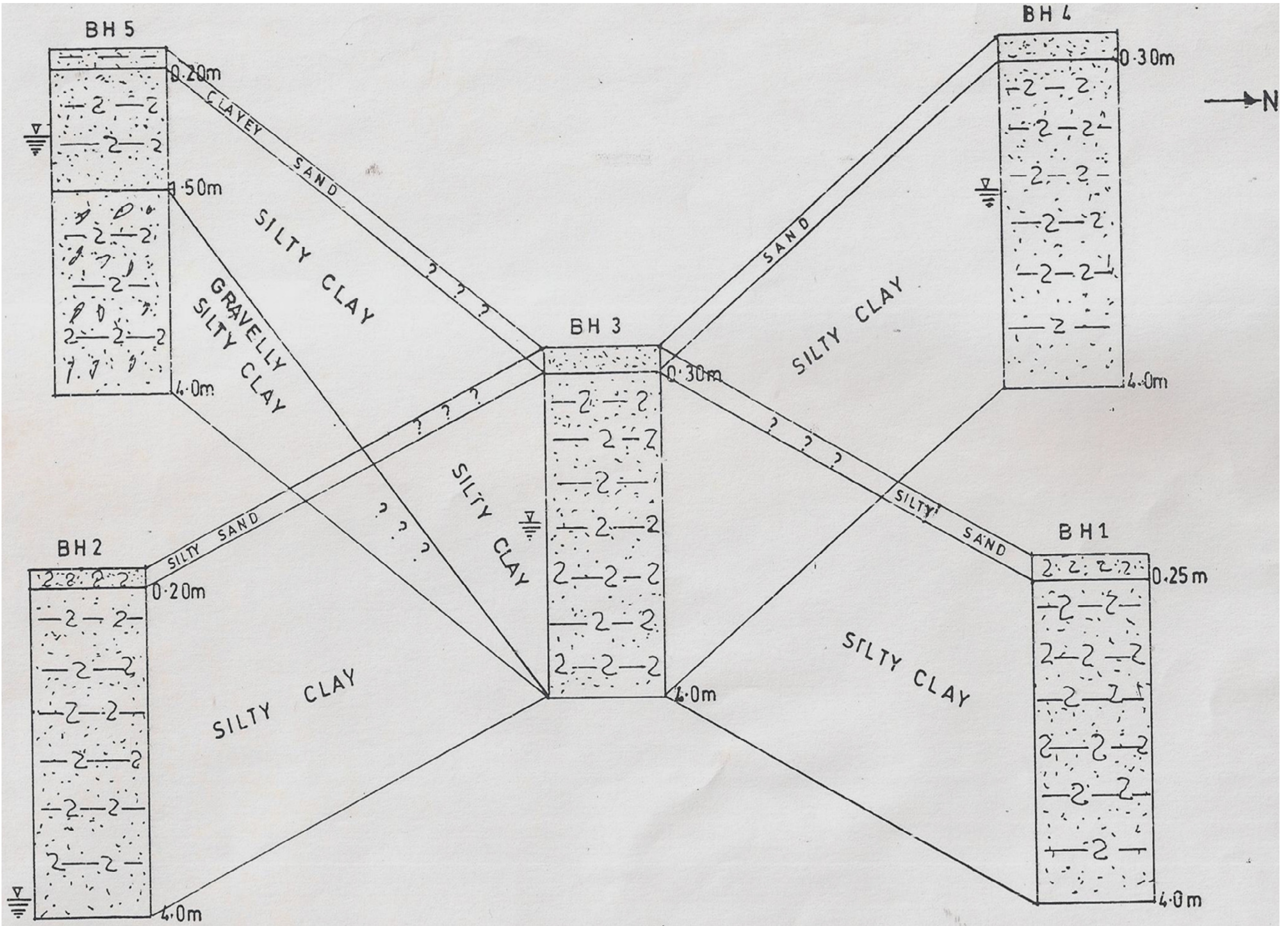

Figure 1. Stratigraphic correlation of boreholes in the study area.

and clay with a high frequency of occurrence of clay within 10 m below the ground surface. Because of the nearness of these compressible clays to the surface, the influence of imposed loads results to consolidation settlement. The impact of the imposed load is exacerbated by the thickness and consistency of the compressible layer. This, in addition to other intrinsic factors (Bowles, 1985) contributes to the failure of civil engineering structures.

This study therefore aims at evaluating the subsurface lithologies and examines the geotechnical engineering characteristics of the sub-soils in the area, including consistency limits, settlement characteristics, particle size distribution (PSD) and their (Youdeowei, 1995) bearing capacities with respect to shallow foundations.

Description of study area

The study area is within the Abuja campus of the University of Port Harcourt, Choba, Rivers State, Nigeria. The area lies within a flat to sub-horizontal geomorphologic setting with a degree of undulations due to differential erosion in the area. The landform elevation ranges between 15 to 30 m above sea level, with a mean annual rainfall which exceeds 2000 mm. The thriving freshwater vegetation is typical of a tropical rain forest.

The local geology of the area is that of the coastal plain sand, which is Pliestocene - Oligocene in age and forms part of the uppermost sections (Krynine and Judd, 1957) of the outcropping Benin Formation. The upper strata of the overburden soils of the area generally comprise mottles of red, brown, and grey lateritic concretions.

METHODOLOGY

Subsurface sampling

Borings were made at five well spaced locations with a hand auger to a maximum depth of 4.00 m in each borehole. The layout of the five boreholes is depicted in Figure 1. Soils samples were retrieved at 0.5 m intervals and at positions where changes in soil lithology were noticed during the boring process.

Stratigraphic profiles and correlation of the five boreholes are presented in Figure 1. All the soil profiles are overlain by dark grey,

Table 1. Summary of geotechnical test results.

Boring number	Sample number and depth	Soil nomenclature	Natural moisture content (%)	Grain size distribution (Percent passing sieves)				Consistency limits			Unit weight (Mg/m^3)	UU triaxial test		Consolidation test		Classification (USC)
				No.4 (4.75 mm)	No. 10 (2.00 mm)	NO.40 (0.42 mm)	No. 200 (0.075 mm)	LL (%)	PL (%)	PI (%)		Q_U (Deg)	C_U (KN/M^2)	Mv (ave) M^2/MN	Cv (ave) $M^2/year$	
BH2	BH2 (2M)	Silty clay	20.6	99.83	97.53	79.00	62.00	46.00	26.75	17.25	2.50	-	-	-	-	CL
BH3	BH3 (2M)	Silty clay	26.5	100	99.00	82.90	57.70	47.00	28.75	12.25	2.43	3.00	58.00	1.24	3.38	CL
BH5	BH5 (2M)	Gravelly silty clay	22.8	91.05	82.80	70.40	57.00	35.50	17.15	18.35	2.81	-	-	-	-	CL

Table 2. Strength characteristic-unconsolidated undrained trixial compression test/bearing capacity.

Borehole number	Depth (m)	Angle of internal friction, $Ø_u$ (Degree)	Undrained Cohesion, C_u (KN/m^2)	Ultimate bearing capacity, Q_{ult} (KN/m^2)	Allowable bearing capacity, Qa (KN/m^2)
BH3	2.0	3.0	58.0	413.4	137.8

humus top soil layers of sand, silty sand and clayey sand that vary between 0.20 to 0.30 m in thickness. These are uniformly underlain in all five boreholes by reddish, mottled brown and grey, fine grained, highly cohesive laterites of silty clay soils. The soil is firm when dry and slightly soft when wet. These concretions of silty clay extend to the maximum bored depth of 4.00 m in Borehole 1 (BH1), BH2, BH3, and BH4. In BH5, there is the presence of gravels in the soil from a depth of about 1.50 m.

Laboratory soil testing

Laboratory tests of natural moisture content determination, grain size distribution analysis, consistency (Atterberg) limits, unit weight determinations, unconsolidated - undrained triaxial compression tests and oedometer consolidation tests were carried out on selected and representative soil samples recovered from the borings in accordance with BS 1377 (1975) and ASTM (1979) standards. These tests were to enable the evaluation of the consistency, gradation, strength and settlement characteristics of the sub-soils in the area that will influence the design considerations and choice of foundation.

RESULTS

Tables 1 to 3 show the summary of the test results and data.

Natural moisture content determination

Results of the moisture content as determined for representative soil samples ranges from 20.6% to a maximum of 26.5% in the silty clay and gravelly, silty clay soils located at 2 m depth. Although these values are moderate, it is noted that the soils possess a good capacity to absorb and retain water, because of their clayey nature. The *in situ* moisture content of the soils is influenced by season, clay and organic contents, and drainage conditions (Akpokodje, 1987).

The water content value of the soils being closer to the plastic limit than the liquid limit is an indication of preconsolidation (Bowles, 1981).

Grain size distribution analysis

It is observed from the results that in all the samples analyzed, more than 50% of the fines passed through the 0.075 mm (No. 200) sieve. These results show that the soils are fine grained, consisting mainly of silts and clays.

Their fine grained nature implies a low permeability potential and this proportion of clay size fractions in the soil will have significant influence on the behavior of the soils, whereby it may display a considerable amount of compressibility.

Table 3. Consolidation test result (One directional).

Borehole number	Depth (m)	Specific gravity	Pressure range (KPA)	Coefficient of consolidation, Cv (m^2/ year)	Coefficient of volume compressibility, Mv (m^2/MN)
BH3	2.0	2.72	0 - 10	2.33	3.56
			10 - 20	1.94	0.82
			20 - 40	7.13	0.35
			40 - 80	2.11	0.24

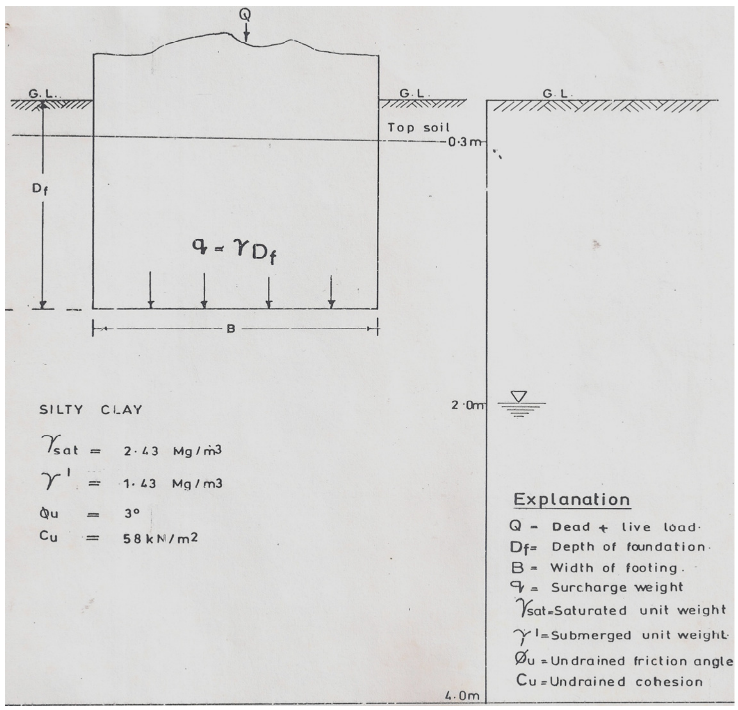

Figure 2. Schematic section of foundation in relation to sub-soil condition in the study area.

Soil consistency

The consistency of the soils in the area was studied by measuring the natural moisture contents, determining both the liquid and plastic limits and the plasticity indices (Atterberg Limits). Results show a low to medium plasticity range (12 to 18%) and corresponding swelling potential (Ola, 1983). These low to moderate plasticity and moisture content means that the soils may require long period to dry after (Terzaghi, 1943) the rains. The soils fall within the soil classification group of CL (that is, low to medium plasticity clays) under the unified soil classification system (U.S.C.).

Soil strength characteristics

The strength properties of the soil sample were evaluated and assessed through a series of triaxial tests to failure. This would assist in the proper design of the shallow foundation system that would bear the weight of the building structure (Figure 2). The foundation system may derive their bearing strength from the silty clay soil which has a stiff consistency, with attention given to the water table conditions in the area (Lambe, 1951).

Shear strength

Values of undrained cohesion and undrained friction angle (ϕ_u) were obtained as indices of the soil strength. The undrained friction angle was determined to be 3°, while the undrained cohesion gave a value of 58 KN/m^2 (Tables 1 and 2). The lack of coarse sand grains in the soil accounts for the very low angle of friction. The bearing capacity basically depends on the shearing

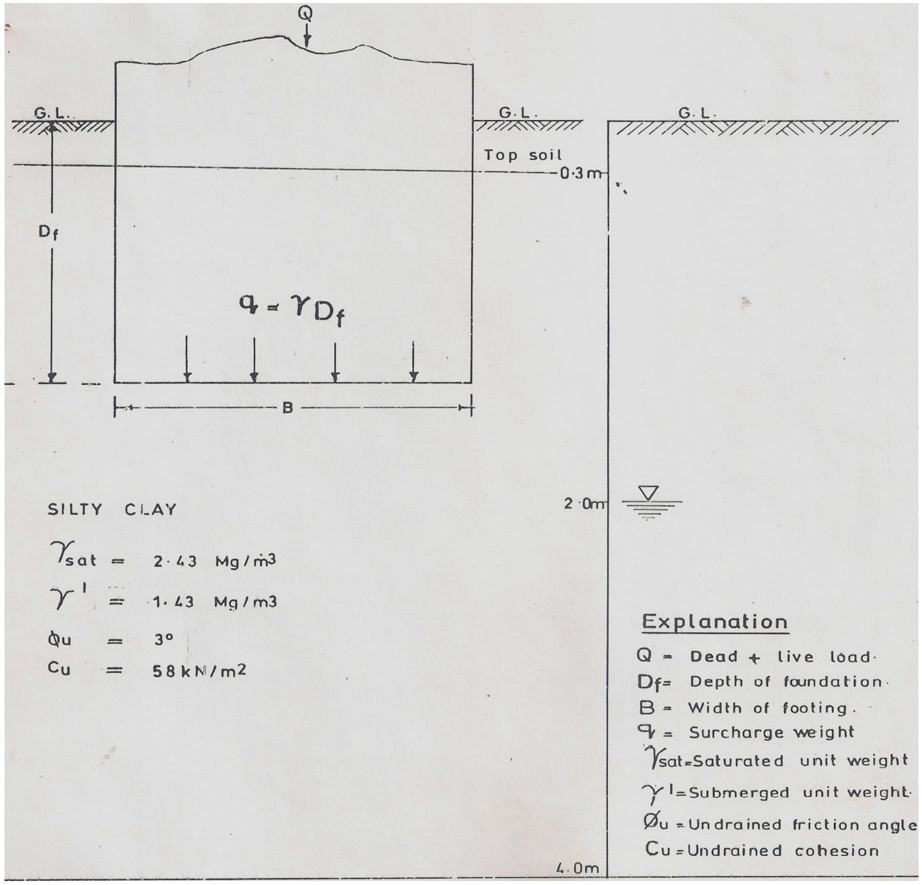

Figure 2. Schematic section of foundation in relation to sub-soil condition in the study area.

resistance of the soil. There is also a sharp increase in bearing capacity as the friction angle increases. However, the combination of relatively high frictional resistance and cohesion enhances high shear strength in soils. Plots of Mohr circles depicting shear strength values are shown in Figure 3.

DISCUSSION

Soil bearing capacity

The ultimate bearing capacity of soil beneath a foundation load depends primarily on the shear strength. The allowable value for design takes into consideration both strength and deformation characteristics. The foundation must be designed so that the actual bearing stress is less than the bearing capacity, with an appropriate margin of safety to cover uncertainties in the estimate of both the bearing stress and the bearing capacity.

The choice of shallow in the area will rely heavily on the consistency of the silty clay soil [which is observed to be stiff (indurated) when dry] and the position of the water table. If the depth of the footings or excavation will be below the water table, drainage will be required. The result of decreases in water content is increased in the shear strength of the soil. The allowable soil pressure (q_a) to control shear failure with a suitable factor of safety (3) was determined as 137.82 KN/m^2. An allowable bearing pressure of 75 to 125 KN/m^2 can be borne with relative ease by this clayey soil (Tomlinson, 1980).

Consolidation properties

The consolidation characteristics of the soil is influenced by a combination of the particle size, the type and quantity of clay/organic matter, the *in situ* bulk density and the permeability. One dimensional oedometer consolidation test was carried out on the representative soil sample of silty clay which may bear the foundation. Two parameters were determined and obtained from the laboratory consolidation testing. These are: (i) the coefficient of volume compressibility (Mv) which determines the area that is likely to be compressible under a given among of load and (ii) coefficient of consolidation (Cv), which is an indication of the likely rate

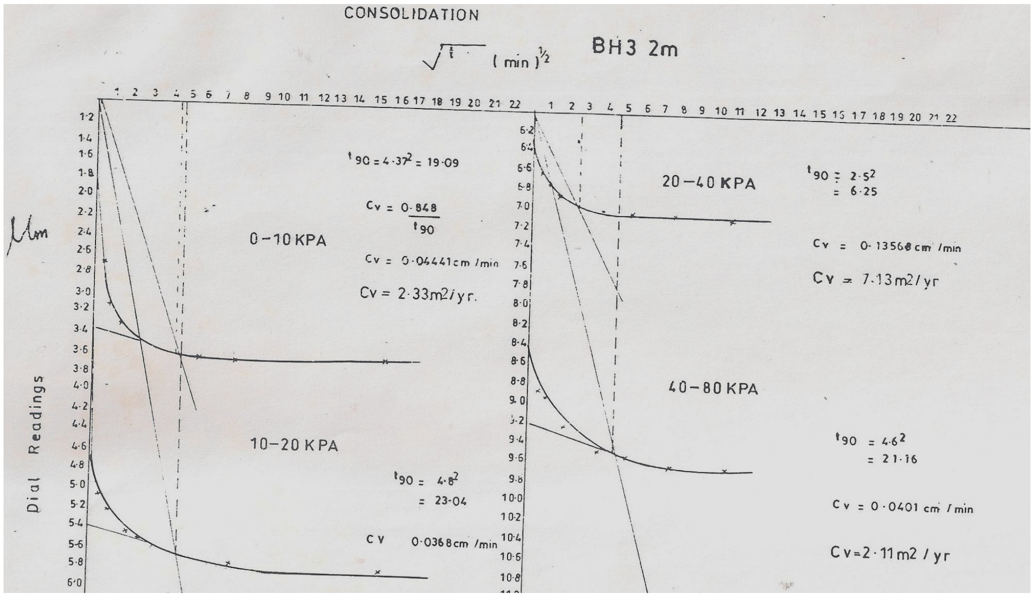

Figure 4. Determination of coefficient of consolidation (Cv) using Taylor's (1948) "Square root of time" method.

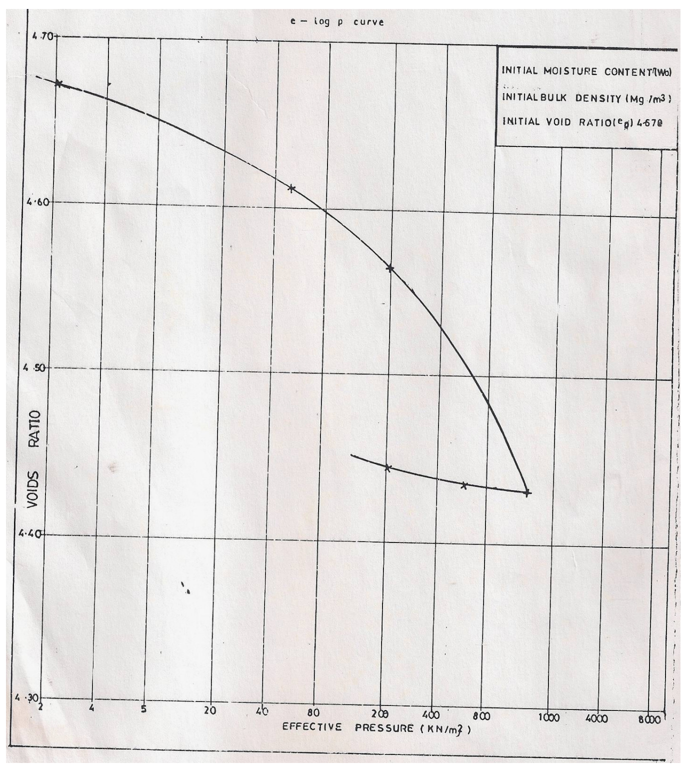

Figure 5. Consolidation test: eLOGp curve.

of settlement per annum under the given loading conditions. Tables 1 and 3 show the results of Mv and Cv values (average and at varying pressure ranges). In computing Cv, the "square root of time fitting method" (Taylor, 1948) was adopted. The plots are given in Figures 4 and 5. Average Mv values gave 1.24 m^2/MN, while average Cv values resulted in 3.38 m^2/year. These values are indicative of moderate compressibility and low rates of consolidation for the silty clay soil.

Settlements

It is settlement that usually determines the allowable soil pressure beneath a foundation load (Bowles, 1982). Settlement depends primarily on the compressibility of the clay soil, which is intimately related to its history of loading (Peck et al., 1974). Clay usually show progressively decreasing compressibility and decrease in deformation modulus with increasing depth. At the study site, where the soil type is essentially clayey, long-term consolidation settlements will prevail. In the area of BH5, where the clay deposit contains continuous measures of gravels below 1.50 m, they may form drainage outlets, giving an increased rate of settlement. Estimated total settlement around the centre of the study area (BH3) was determined as 69 mm. For foundations on clay, Skempton and MacDonald (1956) prescribed design limits for total settlement of 65 mm for isolated foundations and 65 to 100 mm for rafts.

CONCLUSIONS AND RECOMMENDATIONS

Sub-soil stratigraphy and laboratory tests show that the materials that may bear the foundation system in the study area are essentially reddish, mottled brown and grey, fine grained, highly cohesive, stiff, silty clay, and lateritic concretions. The soils are preconsolidated and Atterberg limits show a low to medium plasticity range. Computed safe bearing pressure is within acceptable limit for the soil type. Consolidation characteristics were determined to be indicative of moderate compressibility and low consolidation rates. Computed total settlements are within design limits for shallow foundations. However, if groundwater is within the area, it must be removed by pumping down the water table. The use of grout (cement mix with/or without sand and water) or concrete curtain walls or other appropriate means to support the foundation is also recommended. It may also be necessary to waterproof the entire surface of the structure below the water table if drainage would be excessive.

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