# Geotechnical Properties of Problem Soils in Greece

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## Abstract

This is a ten years research programme and it was sponsored by the Geek Ministry of Public Works, in order to prevent damage in public road services. This research program might serve as an information database for geotechnical properties of swelling soils in Greece. The purpose of this laboratory investigation firstly was to examine the engineering properties and secondly to test the geotechnical behavior as many as possible active soils throughout the Greek mainland and islands. For this, grain size analyses, Atterberg limits, x-ray analyses, shrinkage limits tests,, swell pressure in the oedometer, cation exchange capacity and pH in disturbed and undisturbed soil samples have been investigated. Also an attempt has made to correlate swell pressure and shrinkage limit, with the variables which are water dependable (liquid limit, plasticity index, moisture content), in order to determine one swell potential index and the results were very promising.

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***Index terms***— geotechnical properties, swelling soil, shrinkage limit.

## 1 Introduction

xpansive soils are found extensively in tropical areas. The presence of expansive soil affects the construction activities and all civil engineering work. In many parts of S.W. United States, S. America, Africa, Canada, India, and Middle East.

Extensive areas around the world are covered by clay soils of high swelling potential. These clays are now well known as active clays due to their behaviour with volume changes according to their moisture content. In arid and seem-arid regions such as Greece or other Mediterranean countries, the clay material exists in an unsaturated condition due to deep water table. With seasonal climatic changes, the clay tends to change moisture content. The more water they absorb the more their volume increases. Expansive soils also shrink when they dry out. Fissures in the soil can also develop. These fissures help water to penetrate to deeper layers when water is present. This produces a cycle of shrinkage and swelling that causes the soil to undergo great amount of volume changes. Of course no one method of soil analysis can estimate shrink -swell potential accurately for all soils. We can recognize shrink -swell behavior by examining all physical, chemical and mineralogical soil properties.

Soil properties measured were LL, PI, and particle size distribution, clay mineralogy with x-ray diffraction, CEC, swelling pressure, linear shrinkage, and shrinkage limit. Also one expansive soil Index (Is) was developed through the shrinkage limit results in comparison with swell pressure.The existence of specific expansive minerals in the clay soil related to the climatological conditions (drought and heavy rain) in Greece, have resulted to induce unexpected shrinkage and swelling movements with all the unfavourable consequences to light structures, to new road construction and to industry buildings, founded on clay. During the last ten years it became apparent that surface soils in many places are subject to swelling, were structural damages had been appeared in the form of wide cracks in the wall, distortion of floor, heaving of beds in canal, rutting of roads etc. The concern of this laboratory investigation, sponsored by the Ministry of Public Works, first was to examine the engineering properties and the geotechnical behavior as many as possible active soils throughout the Greek mainland and islands. This research work must consider as one inventory that would serve as an information database for geotechnical properties of swelling clay soils in Greece.

# 2 E

From the engineering geology point of view, the question was to identify which swelling clay minerals could cause the most severe damage. Terra Rosa, alluvial clay deposits or the volcanic originated clay.

The second question which had to be answered was, to measure in the lab the swelling pressure of each Quaternary, The Holocene era mainly consists of undivided deposits consisted of red and gray clays, and sand. Deeper we have talus and conglomerates with gravel of serpentinite, ofiolites, basalt or phyllites. The Pleistocene contains talus and conglomerates with gravel, mainly of serpentinite, ignimbrite and rhyolotic tuffs. Also we had one volcanic eruption. The Pliocene contains deposits of marls, soft sandstone, clay and several shell beds. Total thickness more than 60m. **??**IGME,1990). a) Egina Island sampling area No 26 Egina is a small island located in a distance of 20 nautical miles SW of the capital city Athens. The island has one heavy geological past and has suffered two volcanic eruptions. First eruption occurred during Miocene and second eruption in Pliocene era. Most of the island is covered by andesitic rock with pyroxenites and Dacite with biotite, also with pyroclastic fragments (conglomeretes), tuffs and pumice.

In the North part of the island (town of Souvala) damages were reported to the local road network and in many light farmer houses. The first laboratory investigation revealed the presence of smectite as the cause of trouble. The whole area is basin containing Neocene sentiments mix with swelling clay minerals. Smectites produce by degradation of rich in silica glass material and are formed by alteration of basic rocks or other silicates low in K, under alkaline conditions, providing Ca and Mg are present. (IGME, 1990).

# 3 b) Evros. District

Sampling area No 13,14,15 The area is mainly covered by clay, clayey silt, sand mainly from river Evros fluvial deposits a. (age Holocene). A bit deeper there is sand and clayey silt red to yellow in alternating deposits. Continental formations without fossils, mainly terrestrial fluvial terraces, partly deposits of sallow basins. Usually loose, rarely slightly cemented, unbedded or weekly bedded. Pebbles of various size from the Pre-Tertiary basement (schist, serpentinite, quartz, limestone, volcanic), fine grained material from Tertiary sediments. Age Plio-Pleistocene. Thickness over 100m.

Also, clays, grey to yellow, compact, locally imperfectly schistose, with frequent intercalations of fine grained sandstone. They overlie the lower members of Oligocene series (marls and clay alternations), but their contact is covered by alluvial deposits. Additional lower series of clay and marls. grey -yellow or grey clays, thin schistose, in alteration withmarls of green -grey color, they occur in a limited area overlay the Upper-Eocene limestone. **??**IGME, 1980). c) Tripolis Plateau.

# 4 Sampling Area No 25

Quaternary -Holocene age.

The whole plain is covered by alluvial Pleistocene deposits such as clayey silt, clayey sandy material silty-clay and terra-rossa, having thichess approximate 250m.

The surround mountain area consists of Upper Palaocene flysch formation containing alternations of sandstone and sandy siltstone. Also rounded pebbles of serpentinized igneous rocks are locally observed.

Upper Cretaceous limestone. White to reddish, often clayey, compacted with chert, marl and calcitic sandstone. They are multifold and fractured.

Upper Cretaceous dolomitic limestone. Gray to black, thikbeded to massive. In the upper beds have very cohesive breccias with sandy cement.

Upper Jurassic siltstone. Alteration of radiolarites siltstone and limestone. They are mainly green jaspers, thin bedded with siltstone intercalations. The geotechnical problem with this plain is that there is no way to the sea, and the only way to drain the rain water after a strong precipitation is same well known sink-holes in Nestani village. Thus the plain suffers flads every two or three years and by the time where the flady water procceds in a low speed movement underground in a limestone country, houses, farms, roads and all public network are damaged. ( IGME, 1990).

# 5 d) Plain of Viotia.

# 6 Sampling areas 1 to 12

Foundation conditions on the plain north to north-east of Thebes city, about 100 km north west of capital city, Athens, have attracted attention because of the new motorway construction and steady influx of industry. A few years ago it became apparent that the surface soils is the large area are subject to swelling. Light structures are observed to suffer from heaving and in summer the soil surface develops shrinkage cracks. The evidence of swelling is strengthened by the water table lying deeper than 10m and by the regular climatic cycles of dry summers followed by substantial rains in the autumn. The plains are underlain by Holocene terra rossa but there are also lacustrine deposits with intercalations of peat bed, of torrential or river origin at the edges. Deeper, there are Pleistocene deposits of torrential and river origin with variable degree of cohesiveness. The material consists of conglomerates, sandstone, sand, silt, red clay. In the surrounding mountain area there are formations of undivided flysch, (Palaocene-Eocene), consisted of red-cherry clay -marl beds fine and coarse conglomerates, fine sandstone. Also upper Cretaceus limestone is present, microcrystalline, gray to light gray. The upper horizons consist of deep sea (pelagic) hard, white-gray, thin bedded limestone. **??**IGME, 1980).

# 7 e) Sampling

In order to study the physical characteristics, the engineering properties and the mineralogical composition of the swelling soils, a large scale sampling was initiated in 38 deferent regions of 20 Provinces in the Greek territory, collecting 911 disturbed and undisturbed soil samples (Map 1), in different time periods. Sampling included disturbed and undisturbed soil samples collected from 202 shafts and 99 boreholes. In the laboratory the undisturbed samples were wrapped up with paraffin and canvas cloth, in order to prevent them keeping their natural moisture content.

# 8 f) Identification tests

The laboratory based evidence of swelling potential was given by grainsize analyses (table **??**) and Atterberg limits, (histogram 1 and 2).

The material passing the US sieve No 200 varied between 70% and 100%, having a clay fraction between 20-70% average 34,6% and stdev=9,3. For the grain size analysis of the clay fraction smaller than 2 ?m, sodium phosphate solution was used as dispersant. From the Liquid Limit (LL)results (ASTM D4318) the samples yield liquid limit values between25-91% mean value 51,8and stdev=14,76. From the plasticity index test (PI) resultsthe samples revealed PI values varying between 24-70%, stdev=3,66and average 30.1. Such clays belong to the CL and CH groups of the unified classification system.

Further indications of swelling potential came from x-ray analyses, linear shrinkage, shrinkage limits tests using the mercury apparatus suggested by the Transport and Road Research Laboratory (TRRL,1974){32}. Also free swell tests in suspension (Holltz& Gibbs, 1957){16}, were extensively used in order to measure the volume change capacity between air dry and wet conditions. Swell pressure in the oedometer and free swell in the oedometer under an external pressure of 7 kPa (approximately 1 psi) were measured on undisturbed soil samples taken out by Shelby. Finally the cation exchange capacity (C.E.C.) measurement of representative soil samples in comparison with x-ray analyses and the activity charts supported the investigation in order to classify areas having high, medium and low swell potential. The precise definition of cation exchange capacity of the soil samples, was measured with the method of ammonium acetate (Schofield, 1949) and the determination of exchange able ionswas measured with a cornflame photometer. Finally 52 soil samples were tested, collected out of 38 districts For comparison two extra samples were tested, one of pure industrial bentonite as clay material with a high swelling capacity revealing C.E.C. 72 meq/ 100gr and one of pure industrial kaolinite as a material with a low swelling capacity, revealing C.E.C. 6 meq/ 100gr. As it was identified, the cation exchange capacity (CEC) for the Greek swelling soils varies between 20 meq/ 100gr to 70 meq/ 100gr. One soil sample from Viotia province (Area 8) revealed CEC 70 meq/ 100gr, similar to that of industrial bentonite.

Since Schofield (1949), Rich and Thomas (1960, have reported that soils having pH values higher than 7, reveal high C.E.C. values, is was important to measure the pH in the vicinity of each of the above mention soil samples. For these, from thesurrounded soil and in a distance of about 100 cm, different samples were collected and tested with a pH meter. Additionally one samples of pure industrial bentonite revealed pH value 10.5 and one sample of pure industrial kaolinite revealed pH value equal to 5.2. The results of the measurements from 300 soil samples of the Greek territory are reported on Table 2and the recorded values varies between pH = 7.50 and pH = 9.46. 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

# 9 The Mineralogical Analysis of Clay Fraction

The crystalline mineralogical components of a clay soil were identified by the powder method of x ray diffraction analysis. The clay samples were tested with a Philips diffractometer, using copper radiation with nikel filter (CuKa), working with power of 40 KV and 20 mA. Before testing a U.S. No 40 sieve was used to remove the non-clay minerals, the hydrometer method (B.S. 1377) was also used to isolate the silt and clay fraction. The oxygen peroxide method (BS 1377) was used to purify each sample from organic content. In some clay samples was noticed that the three main clay minerals, montmorillonite, Kaolinite, chlorite, were giving not clear peaks. In that case, Wilson's 1987 suggestions was used and the samples were special treated with glycerin and heated up to 120° C, in order to distinguish the montmorillonitic peak.

The mineralogical composition in 57 clay samples (Map. 1), including one sample of each area and one sample of pure industrial bentonite, was determined by x ray diffraction analyses (Table 3), by the method described by Brindley and Brown (1980), and the quantitative analyses was obtained by the method described by Bayliss (1986).

Finally from the quantitative x ray analysis was revealed that: ? Quartz participated in 57 clay samples ? Calcite was revealed in 54 samples ? Plagioclase were present in 29 samples ? Feldspar was identified in 31 samples ? Dolomite was also present in 13 sample ? Montmorillonite participated in 57 samples with high percentages ? Illite was identified in 57 samples ? Kaolinite participated in 39 samples but in small percentages ? Halloysite was also present in 6 samples in well crystallized shape Quartz percentage varies from 10% to 38%, Calcite percent was between 10% and 33%, Plagioclase only in 15 x-ray samples with percent from 5% and 9%, Feldspar in 20 x-ray samples having from 5% to 15% percent, Dolomite only in 6 x-ray samples with one percent between 3% and 6%.The less of 100 percent, is due to organic matter, which was burned during heating.

# 10 Linear Shrinkage Determination

The determination of bar-linear shrinkage was made according to BS1377, in 15x15x140 mm semi spherical moulds, using 406 remoulded clay soil samples from liquid limit test. As it was determined, the samples revealed linear shrinkage larger than 8. The statistics elaboration revealed minimum value 5.9, maximum 31.1, the average value was 15.28 and standard deviation S=3.348. According to Altmeyer's (1956) list, were classified as having critical swelling potential. Several soil samples gave values higher than 20 (Table 4). Also from the correlation graphbetween bar-linear shrinkage and free swelling index it was concluded that there is one good relation having the type of exponential curve oftype Y=ax The shrinkage limit has been used in soil classification as considered in relation to the natural moisture content of soil in the field, indicated whether or not further shrinkage will occur if the soil is allowed to dry out. The method, which has been used for finding the shrinkage limit of the Greek soil samples, was that suggested by TRRL (1974) mercury device test method and involved the measurement of the total volume of each specimen as it was dried out. For correlation purposes three special samples of pure industrial bentonite were prepared and the shrinkage limit was determined in the same manner as the soil samples. The obtained values were 6.8, 6.5 and 7.4 per cent. A total number of 280 disturbed soil samples were tested as was mentioned above and the results are reported on Table 4 with the number of the tested samples per area. In some areas the shrinkage limit results of five samples were similar to those obtained for bentonite. The statistical elaboration revealed minimum value 5.5, maximum value 17, average value 11.4 and standard deviation S=2.37.

# 11 Plasticity Chart and Activity

The heave to be expected under any light structure may be estimated using the plasticity or activity chart, based on the results of Atterberg limits and particle size determination Van der Merve,{33} The simple classification chart using the relationship of plasticity index of the whole sample (weighting plasticity) and the percentage clay fraction, has been used in order to classify the Greek swelling soil into the four categories of potential expansiveness, (Figure 6).From the plotting of 285 soil samples on activity chart, was apparent that Merve"s chart applied for the Greek swelling soils and from the statics was reported that 54% of samples are enlisted invery high activity area. 42% of samples are classified in high activity area. Finally only the rest 14% percent is enlisted to medium activity area. The term consistency index generally refers to the firmness of one cohesive clay that varies from soft to hard, so the determination of consistency index for cohesive clay soils is important for engineering applications due to the strength of clay soil. Since water has a significant effect on it, if the clay has high moisture content, is soft. If the moisture is low, the same clay has high strength.

Since the consistency index depends on the moisture content of the soil and the swelling pressure increases proportional to the reduction of the initial moisture content, became apparent to examine if there is any relation between swelling pressure and consistency index. The consistency index value was calculated according the soil mechanics text books, taking in account from the same soil sample, the liquid limit, the plasticity index and the natural moisture content of the undisturbed soil sample. The graph was plotted having the swelling pressure and the equivalent Ic for each specific pressure. From figure 7 it is apparent that there is a strong relation having the type Y = ax ? of exponential curve and correlation factor R 2 equal to 0.8239 for sampling areas 8, 23 and 34. From this graph we can conclude that the drier the soil sample, which means high consistency index, it is able to absorb more water so, if the mineralogy permits it, will give higher swelling pressure. This property depends on the chemical composition, the physicochemical characteristics and the individual moisture conditions of each area. Swell consolidation test in oedometer were conducted on 224 specimens prepared of equal undisturbed samples collected with Shelby. The majority of samples were tested havingthe initial density and water content as expected in the field. For these, undisturbed soil samples, half inch thick, were placed in the consolidometer ring of the fixed-ring type and the size of container ring was 3.5in. diameter by 3/4in. deep. The initial dial reading was recorded after applying a seating load of 6.25 kPa. The load was increased gradually as required to hold the sample at the original height, up to the maximum load, which represents the maximum swelling pressure. The successive loads were maintained for 48 h to obtain constant values of height. In order to identify the influence of moisture content changes on swelling pressure, samples from the same undisturbed sample (Shelby), were prepared but tested, in the initial moisture content, and after being desiccated for a few days using one silica gel laboratory desiccators. (Figure 9). Additionally, from random shelby 50 extra soil specimens were collected and the values of vertical swell pressure were measured under a seating load of 7 kPa ? Mean value = 5.1 ? Standard deviation = 3.68.

? One percentage 17% of samples revealed swelling = 2.5% ? Second percent 12% of samples appeared swelling = 1.5%. ? Also 10% of samples presented swelling between 5.5% and 8% ..( freeswelloedometertestinFigure 10). For some sampling areas there are exceptional swelling percentages. Sampling area 29= swell 11% Sampling area 15= swell 10,5% Sampling area 4= swell 13% Sampling area 2= swell 13.4%

The histogram which was plotted from the obtained values of the 224 soil samples, revealed a mean value of 1.55 kg/cm2 with a standard deviation of S=1.63. Of these values, a percentage 29% of the samples revealed swelling pressure of 0.5kg/cm2. Another percentage of 22% fluctuates to a swell pressure of 1kg/cm2. A third percentage of 13% reached pressure values of 1.5 kg/cm2. A smaller percentage of 7% revealed pressure of 2kg/cm2. 10% of the undisturbed soil samples gave high values of swelling pressure between 2.5kg/cm2 and 4kg/cm2. Higher swell pressure values were also obtained, a small proportion (2.6%) was found having swell pressure between 5kg/cm2 and 6.5kg/cm2. Of course, in some districts the swell pressure (after 72 h desiccation) was exceptionally high: Sampling area25 (town of Tripolis) a swell pressure 11.0 to 12.5kg/cm 2 Sampling area11? (town of Shimatari) a swelling pressure 6kg/cm 2 Sampling area 6? (town of Thiba ) a swelling pressure 6kg/cm 2 c) Swelling pressure and shrinkage limit Chen [11] reported that there was no conclusive evidence of correlation between swelling potential and shrinkage limit, also Sridhar an [6] said that shrinkage limit is not satisfactory used to predict swell potential. Since there is no empirical expression utilizing shrinkage limit and swelling pressure to predict swelling potential, an effort was made to correlate swelling pressure (SP) and shrinkage limit results from the tested locations, but the coefficient of correlation was not acceptable. After a second attempt, the correlation between swelling pressure, liquid limit(LL), moisture content (mc), shrinkage limit (sl), indicated that if we compare the quotient of liquid limit minus moisture content divided by liquid limit minus shrinkage limit ( MC-SL / LL-SL ) and plot it with the swelling pressure, from soil samples from the same Shelby, we have one strong coefficient of correlation. In Figures 12, 13 and 14 from three different sampling areas, we obtain coefficient of correlation R 2 =0.9147 for sampling area 8, R 2 =0.879 for sampling area 29, R 2 =0.8083 for sampling area 15. We have named this fraction, shrinkage limit ratio (Is) and as we can see from the three following graphs between swelling pressure and shrinkage limit ratio there is a strong exponential relation. After obtaining a lot of swelling pressure results from the consolidation test and also having one large number of regression analyses equations, with high regression coefficient for the swell parameters, the first thought was to obtain a plot relating swelling pressure with the brand new shrinkage limit ratio. The idea was strengthened after reading Rao and Rao {24} paper about classification of expansive soils. The plot was obtained from the values of swelling pressure and the values of shrinkage limit ratio (Is). In order to avoid plotting difficulties because soil samples were from different areas (figures 12,13,14), the laboratory obtained values were plotted as groups of soil samples having similar liquid limit. For these three groups of soil were calculated, one group having LL=40-50%, another group of values having LL=50-60% and one third group having LL=60-70%. From figure 15 we can see there is one exponential relation of type x=ab x with moderate coefficient of correlation and each exponential curve represents a group of sampling points, having similar liquid limit percent. Also we can say that when the shrinkage limit ratio (Is) has small value (0.4, 0.5, 0.6), swelling pressure is low. When the value increased, the swell pressure also is moderate or high, and when the shrinkage limit ratio (Is) value is 0.9 or 1.0, then the swelling pressure is very high. The conclusion is, if we have sufficient measurements, from the shrinkage limit ratio (Is) graph we can extract useful values for swell pressure of the tested area. IX.

# 12 Multiple Regression Analyses

The general purpose of Multiple Regression is to learn more about the relationship between several independent variables and a dependent variable. From the literature ( Holtz and Gibbs 1956 {16}, Van der Merwe 1964, Chen 1976 {10}, it is well known that some physical properties of the soil such as liquid limit, clay content, free swell, can predict the swell potential of a clay soil. Regression analysis is widely used for prediction and is also used to understand which among the independent variables are related to the dependent y = 0.004e 7.271x $R^2$ = 0.879 variable, and to explore the forms of these relationships. Since there is not empirical expression from Greek swelling clay soils to predict swelling potential or swelling pressure and we had a large number of samples and laboratory results, an effort was made with regression analyses to correlate swelling pressure (SP), liquid limit (LL), plasticity index (PI), clay content (2?m), free swell in suspension (FS), bar linear shrinkage (LS), water content (MC), (Table 5).The results shows that there is a good linear relation of the type y = ax+b. Multiple linear regression analyses were carried out for every one sampling area, to relate the measured natural and engineering properties, using the statistical computer software program for Excel. For this purpose, an investigation was made into the possible relationship between swelling pressure and the various swell governing factors. The value of correlation coefficient relating with the investigated properties was used to assess the quality of the particular correlation model, higher values being an indicator of a more appropriate model.

In general then, multiple regression procedures will estimate a linear equation of the form:Y = a + b 1 *X 1 + b 2 *X 2 + ... + b p *X p

For each individually investigated Area the multiple regression analysis showed good correlations in all the combinations studied. Table 5shows the resulting equations and all values measured in this study, from undisturbed soil samples, which were collected from eight different Areas for the statistical analysis. Multivariate statistical method was used to identify key model index properties by detecting interactions between variables. For this correlation between free swell, swell pressure and potential indices measured were analysed using Pearson's correlation test chart (Table 6). The Pearson's correlation varies from +1 through zero to -1, where +1 indicates perfect linear relation. The dependant variable was swell pressure and the independent variables were all the measured soil properties. From the results the swell pressure behaviour of the soil depends on a multitude of variables. -0,8343 -0,9706 1 FS 0,70431 0,90879 -0,8579 1 LS 0,87388 0,96687 -0,8911 0,86424 1 2?m 0,66603 0,88698 -0,8277 0,81828 0,89256 1 information to design engineers, because if it is known the ability of soil to shrink or swell before construction, damage can be avoided. 2. The statistical analysis of the relationships between swelling pressure and index properties of the soils such as moisture content, linear shrinkage, free swell, clay content, liquid limit and plasticity index, showed that is satisfactory, with a high linear correlation coefficient to exist between them.

Multiple regression analysis can be used to predict volumetric changes in a swelling soil. From Pearson's correlation chart we can conclude. 3. There is very strong correlation between swell pressure and natural moisture. 4. There is very strong correlation between free swell index and bar linear shrinkage 5. A moderate correlation exists between liquid limit and free swell index. A moderate correlation also exists between plasticity index and colloids percent. 6. A strong correlation exists between plasticity index vs bar linear shrinkage. 7. The correlation between liquid limit and bar linear shrinkage revealed one moderate linear relation.

# 13 XI.

# 14 Implications

The Author feels that the above described research has clearly indicated that index properties of a clay soil, such as liquid limit, plasticity index, natural moisture content, free swell index, shrinkage limit, related with swell pressure, can satisfactory predict that a soil contains expansive clay, even if we don't know the mineralogy of soil, and we highly recommend multi regression analyses for prediction purposes. Also more studies similar to the one presented in this paper will be necessary to strengthen this assessment.

# 15 XII.

# 16 Conclusions

From the above mentioned research, it is difficult for the swelling clay in Greece to detect which type has the stronger swelling potential, because don't exhibit significant differences. s.a.29 (terra rossa) swelling 11%, swell pressure 5.7 Kg/cm 2 , s.a.15 (alluvial) swelling 10,5%, swell pressure 2.7 Kg/cm 2 , s.a. 4 (terra rossa) swelling 13%, swell pressure 6.0 Kg/cm 2 , s.a.2.(terra rossa) swelling 13%, swell pressure 3.0 Kg/cm 2 , s.a.11 (terra rossa) a swelling pressure 6kg/cm 2 s.a6 (terra rossa) a swelling pressure 6kg/cm 2 Of course, in some districts with terra rossa, the swell pressure (after 72 h desiccation) was exceptionally high: sampling area 25 (town of Tripolis) a swell pressure 11.0 kg/cm 2 to 12.5 kg/cm 2 All tested clay types have montmorillonite (smectite group) as major clay mineral, accompanied by illite, chlorite, kaolinite. Also mixed layer clay minerals with quartz, feldspar and calcite, are present. Most substantial parameters for the swelling clay to exhibit high swell pressure are the percentages of active minerals, the value of cation exchange capacity and of course the transaction of moisture content, from the dry to wet condition. [1]

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[1] -55 20-74 20-48 25-56 28-56 22-60 20-58 20-60 20-50 30-50 30-60 42-68 30-55 25-70 20-50 25-45 24-56 20-54 42-76 20-42 20-40 22-50 34-60 14-40 20-48 24-46 15-52 25-78 24-54 22-44 24-64 20-53 20-68 28-44 18-46 20-70 20-60 24-52 Geotechnical Properties of Problem Soils in Greece


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FYROM
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SCALE:1/1000000
SAMPLING AREAS

Figure 1:

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Figure 2: Figure 1 :

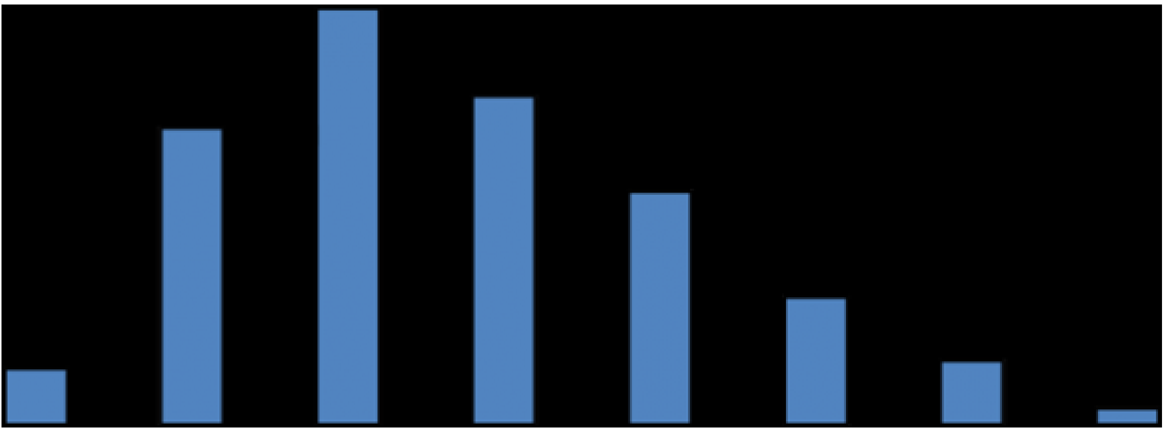

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Figure 3: Figure 2 :

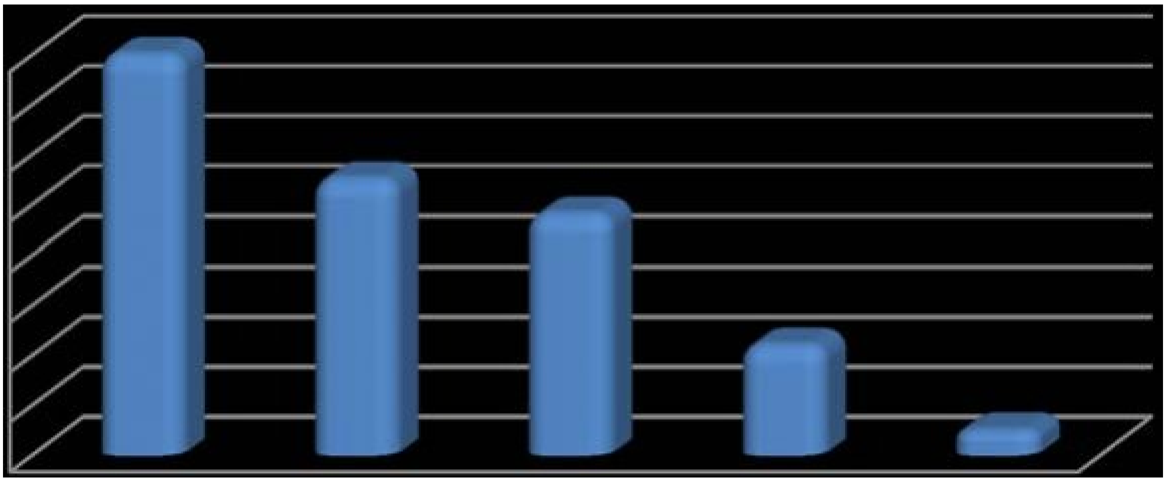

Figure 4:

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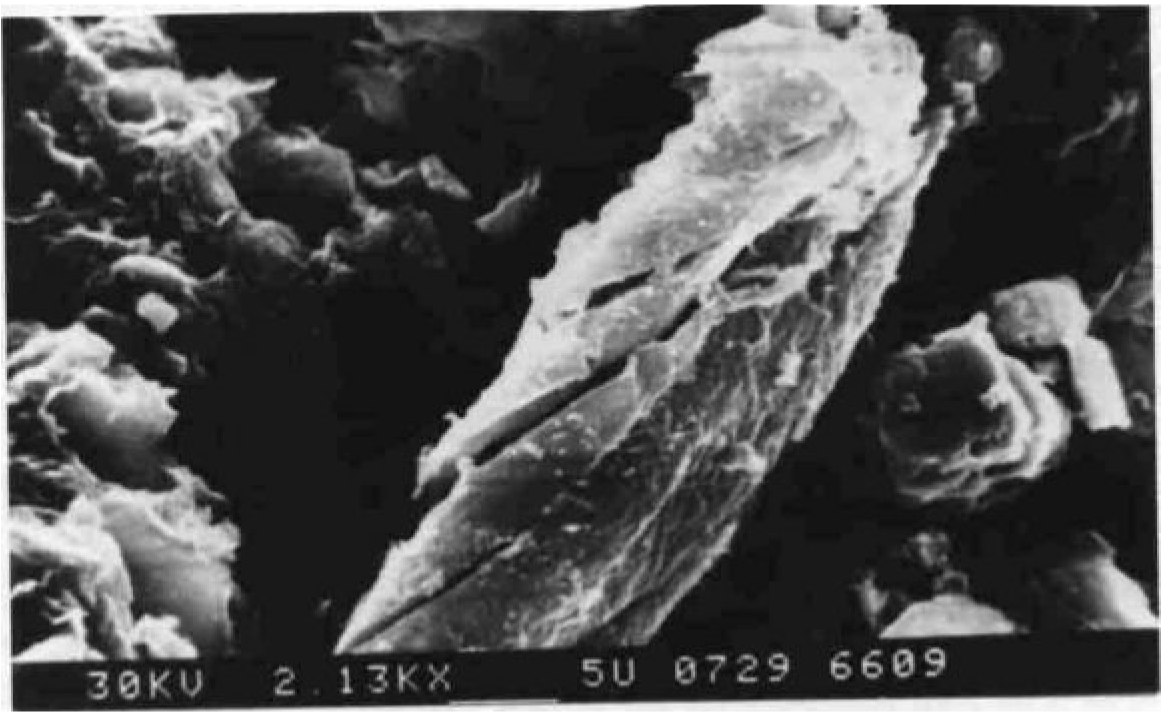

Figure 5: Figure 3 :

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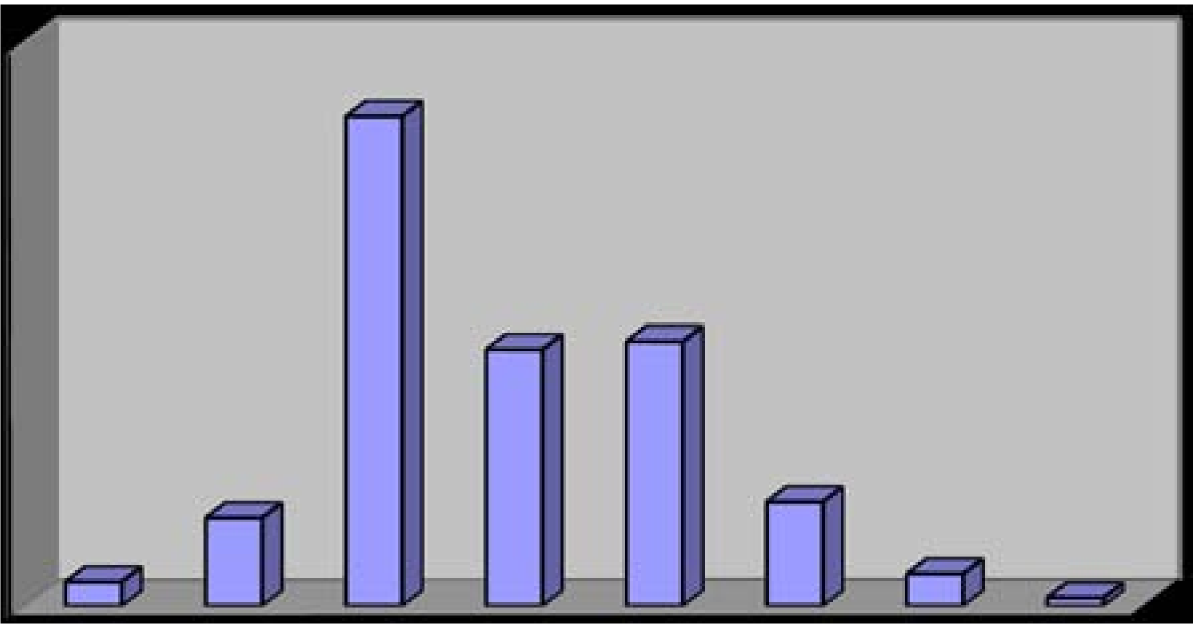

Figure 6: Figure 4 :

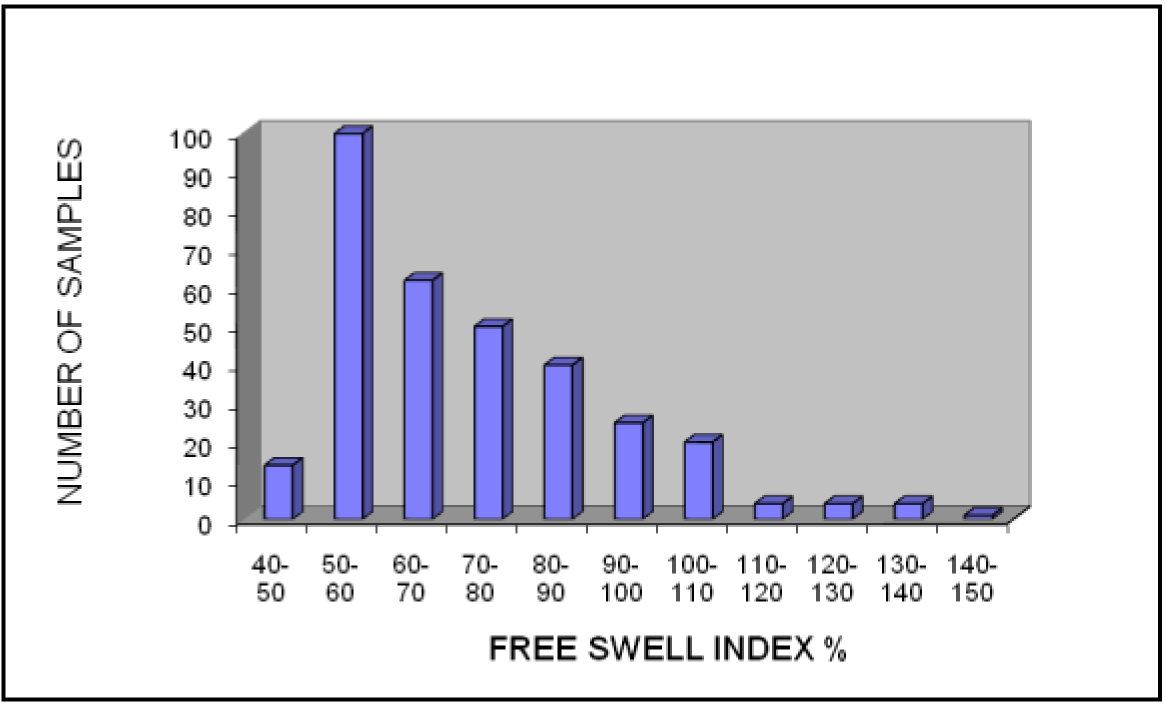

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Figure 7: Figure 5 :

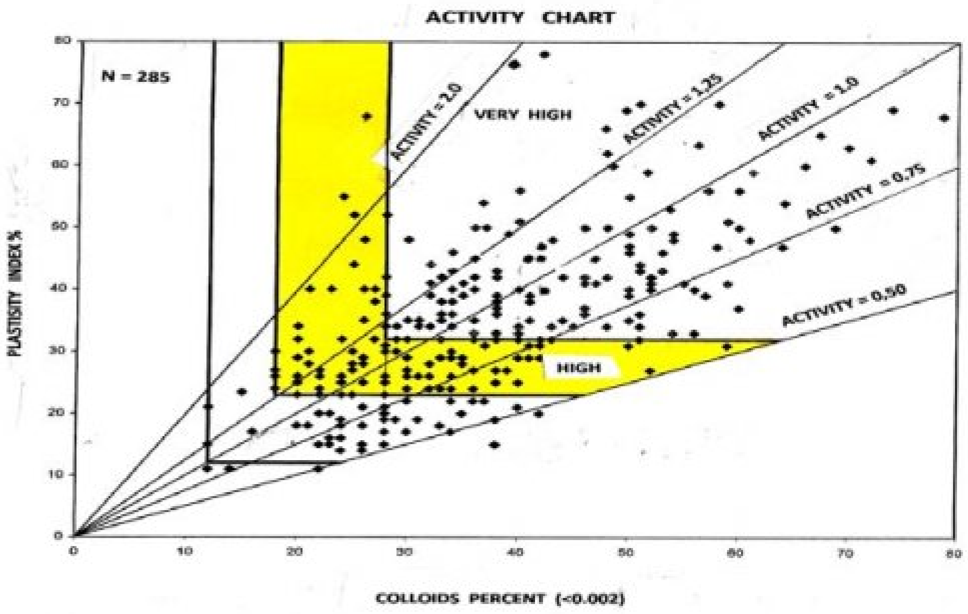

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Figure 8: Figure 6 .

**7**

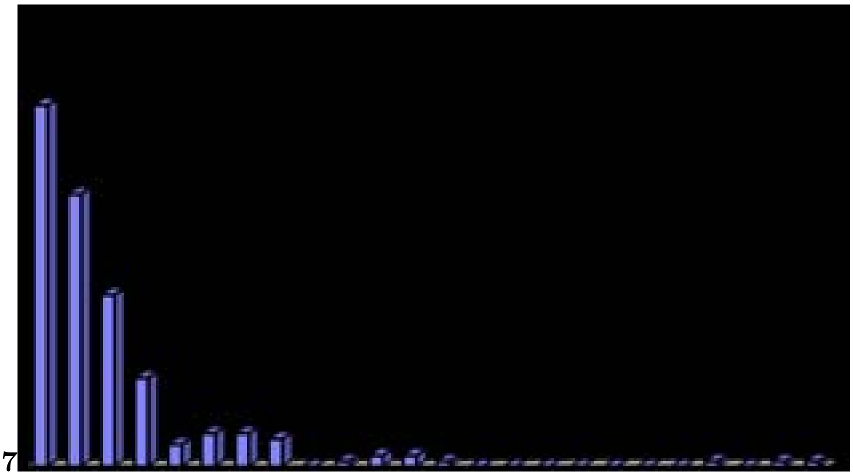

Figure 9: Figure 7 :

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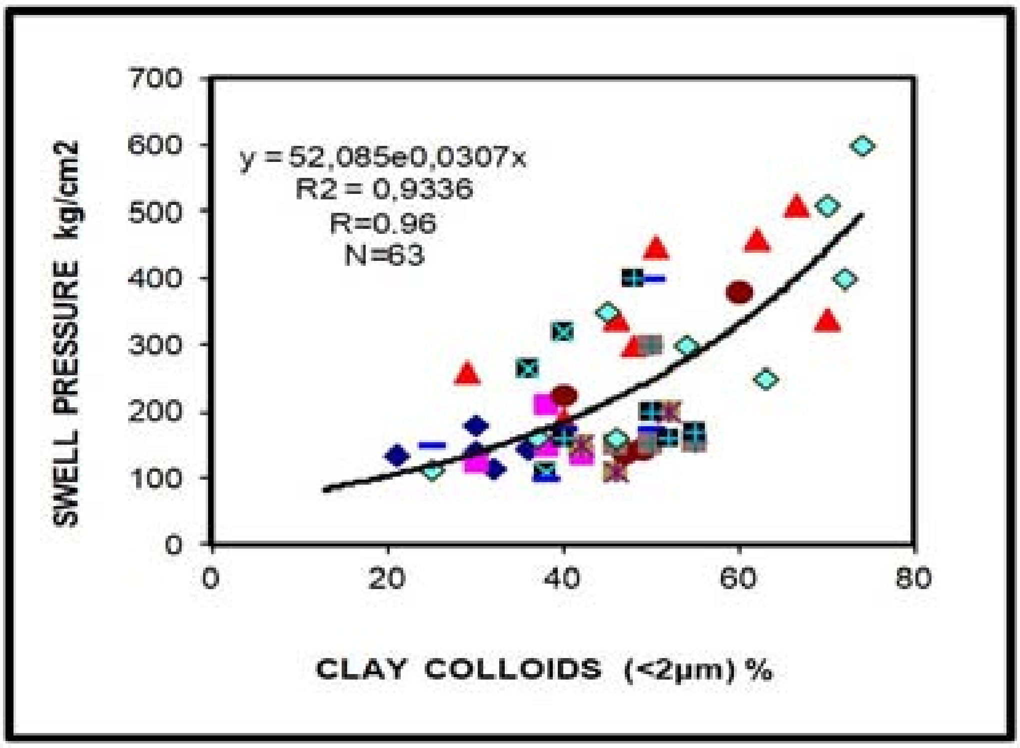

Figure 10: Figure 8 :

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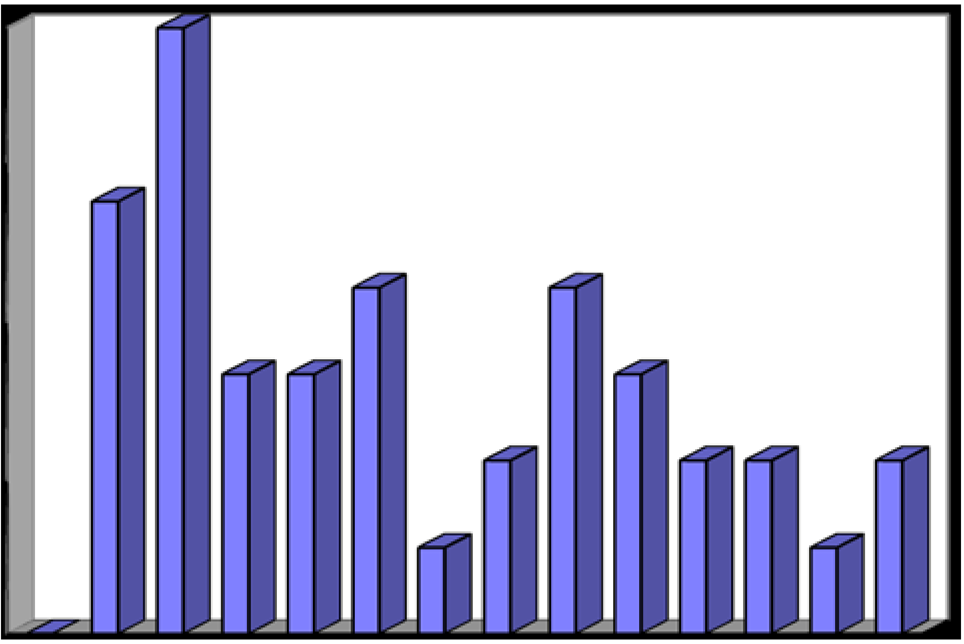

Figure 11: Figure 9 :

**1011**

Figure 12: Figure 10 :Figure 11 :

**1213**

Figure 13: Figure 12 :Figure 13 :

**14**

Figure 14: Figure 14 :

.

| Sampling area | n | Sand % | Silt % | Clay % |
|---|---|---|---|---|
| Area 1 | | 5-30 | 30-40 | |
| Area 2 | | 2-24 | 24-40 | |
| Area 3 | | 2-20 | 48-50 | |
| Area 4 | | 10-23 | 34-45 | |
| Area 5 | | 16-26 | 20-30 | |
| Area 6 | | 2-20 | 30-44 | |
| Area 7 | | 2-22 | 40-50 | |
| Area 8 | | 4-18 | 36-50 | |
| Area 9 | | 4-28 | 28-46 | |
| Area 10 | | 10-15 | 40-45 | |
| Area 11 | | 2-10 | 38-54 | |
| Area 12 | | 2-16 | 20-30 | |
| Area 13 | | 2-26 | 30-43 | |
| Area 14 | | 4-42 | 26-41 | |
| Area 15 | | 4-28 | 22-46 | |
| Area 16 | | 10-40 | 15-45 | |
| Area 17 | | 4-26 | 40-46 | |
| Area 18 | | 4-20 | 42-58 | |
| Area 19 | | 2-10 | 22-48 | |
| Area 20 | | 18-34 | 26-40 | |
| Area 21 | | 14-36 | 28-45 | |
| Area 22 | | 18-30 | 26-31 | |
| Area 23 | | 8-18 | 26-32 | |
| Area 24 | | 26-40 | 18-34 | |
| Area 25 | | 14-30 | 10-18 | |
| Area 26 | | 4-40 | 11-51 | |
| Area 27 | | 2-46 | 25-44 | |
| Area 28 | | 2-36 | 21-26 | |
| Area 29 | | 2-26 | 34-38 | |
| Area 30 | | 8-32 | 28-48 | |
| Area 31 | | 6-24 | 31-38 | |
| Area 32 | | 2-36 | 22-38 | |
| Area 33 | | 8-15 | 22-33 | |
| Area 34 | | 2-18 | 42-50 | |
| Area 35 | | 8-30 | 34-44 | |
| Area 36 | | 2-14 | 28-60 | |
| Area 37 | | 2-22 | 36-48 | |
| Area 38 | | 10-36 | 22-32 | |

Figure 15: Table . 1

**2**

| Sampling Area | C.E.C. meq/100 gr | N PHN |
|---|---|---|
| Area.1 | 55.3 | |
| Area.2 | 58.9 | |
| Area.2 | 55.1 | |
| Area.2 | 57.6 | |
| Area.2 | 56.2 | |
| Area.3 | 35.1 | |
| Area.4 | 49.8 | |
| Area.5 | 36.0 | |
| Area.5 | 27.8 | |
| Area.6 | 17.2 | |
| Area.7 | 36.7 | |
| Area.8 | 70.0 | |
| Area.9 | 48.6 | |
| Area.10 | 51.3 | |
| Area.11 | 50.1 | |
| Area.12 | 37.6 | |
| Area.13 | 37.4 | |
| Area.13 | 41.2 | |
| Area.13 | 43.4 | |
| Area.14 | 37.0 | |
| Area.15 | 35.6 | |
| Area.15 | 26.0 | |
| Area.15 | 15.6 | |
| Area15 | 22.7 | |
| Area.16 | 50.2 | |
| Area.17 | 39.6 | |
| Area.18 | 34.0 | |
| Area.19 | 36.4 | |
| Area.20 | 23.3 | |
| Area.21 | 25.3 | |
| Area.22 | 18.2 | |
| Area.23 | 42.4 | |
| Area.23 | 25.1 | |
| Area.24 | 17.4 | |
| Area.25 | 16.8 | |
| Area.25 | 18.1 | |
| Area.25 | 53.7 | |
| Area.26 | 57.2 | |
| Area.27 | 32.4 | |
| Area.28 | 27.4 | |
| Area.28 | 56.9 | |
| Area.28 | 24.4 | |
| Area.29 | 50.4 | |
| Area.30 | 34.0 | |
| Area.31 | 17.9 | |
| Area.32 | 14.4 | |
| Area.33 | 23.6 | |
| Area.34 | 30.5 | |
| Area.35 | 26.0 | |
| Area.36 | 56.1 | |
| Area.37 | 17.6 | |
| Area.38 | 25.2 | |

**3**

| Area Area.1 Area.2<br>Area.3 Area.4 Area.5<br>Area.6 | ??nt? llite 06<br>Mo- 05 11 10<br>ril 18 –<br>lonite | Clorite<br>04 10 20<br>08 04 – | Kaolinite 03<br>–05 –04<br>– |
|---|---|---|---|
| Area.7 Area.8 Area.9 | 28 20 – | 02 04 – | –06 – |
| Area.10 Area.11 | 08 08 | 06 08 | 13 04 |
| Area.12 | 12 | 08 | 04 |
| Area.13 | 04 | 12 | 04 |
| Area.14 | 05 | 05 | – |
| Area.15 | 17 | 08 | 06 |
| Area.16 | 05 | 10 | – |
| Area.17 | 07 | – | 06 |
| Area.18 | 06 | 04 | 04 |
| Area.19 | 05 | 05 | – |
| Area.20 | 12 | 04 | – |
| Area.21 | 08 | 06 | – |
| Area.22 | 13 | 12 | 10 |
| Area.23 | 17 | – | – |
| Area.24 | 05 | 05 | – |
| Area.25 | 12 | 07 | 10 |
| Area.26 | 07 | 07 | 07 |
| Area.27 | 21 | 06 | 06 |
| Area.28 | 28 | 06 | 06 |

| | | | | |
|---|---|---|---|---|
| Area.29 | 53 | 08 | 04 | 04 |
| Area.30 | 15 | 06 | 05 | 05 |
| Area.31 | 50 | 09 | 07 | 07 |
| Area.32 | 28 | 27 | 05 | 05 |
| Area.33 | 34 | 05 | 04 | 04 |
| Area.34 | 21 | 12 | — | — |
| Area.35 | 26 | 07 | 04 | 04 |
| Area.36 | 25 | 10 | — | — |
| Area.37 | 26 | 10 | 05 | 05 |
| Area.38 | 10 | 08 | 07 | 07 |
| | 40 | 12 | — | — |
| Industrial Bentonite V. | 72 | 08 | 05 | — |

Figure 17: Table 3 :

**4**

| Sampling area | n | Free Swell% | n | Linear. Shrinkage% | n | Shrinkage. Limit%. |
|---|---|---|---|---|---|---|
| Area.1 | 14 | 52 -90 | 23 | 9.6 -27.0 | | |
| Area.2 | 20 | 50 -106 | 20 | 9.6-23.0 | | |
| Area.3 | 9 | 50 -78 | 14 | 8.6-18.0- | | |
| Area.4 | 9 | 85 -130 | 28 | 10.7 -21.8 | | |
| Area.5 | 10 | 54 -67 | 10 | 13.2-18.2 | | |
| Area.6 | 6 | 50 -72 | 5 | 11.4-17.7 | | |
| Area.7 | 4 | 51 -72 | 6 | 10.3-19.5 | | |
| Area.8 | 10 | 70 -115 | 10 | 16.9-17. | | |
| Area.9 | 3 | 63 -85 | 3 | | | |
| Area.10 | 9 | 50 -133 | 9 | | | |
| Area.11 | 5 | 55 -66 | 5 | | | |
| Area.12 | 12 | 51 -73 | 12 | | | |
| Area.13 | 21 | 70 -130 | 18 | | | |
| Area.14 | 9 | 50 -75 | 9 | | | |
| Area.15 | 9 | 52 -88 | 24 | | | |
| Area.16 | 26 | 50 -87 | 4 | | | |
| Area.17 | 7 | 55 -70 | 7 | | | |
| Area.18 | 6 | 55 -80 | 6 | | | |
| Area.19 | 6 | 56 -83 | 7 | | | |
| Area.20 | 13 | 50 -76 | 11 | | | |
| Area.21 | 4 | 53 -66 | 4 | | | |
| Area.22 | 4 | 50 -68 | 6 | | | |
| Area.23 | 8 | 55 -75 | 11 | | | |
| Area.24 | 7 | 50 -65 | 10 | | | |
| Area.25 | 16 | 50 -93 | 25 | | | |
| Area.26 | 11 | 60 -140 | 5 | | | |
| Area.27 | 5 | 50 -65 | 6 | | | |
| Area.28 | 11 | 54 -85 | 15 | | | |
| Area.29 | 9 | 65 -130 | 10 | | | |
| Area.30 | 22 | 51 -110 | 22 | | | |
| Area.31 | 4 | 58 -70 | 10 | | | |
| Area.32 | 11 | 50 -87 | 7 | | | |
| Area.33 | 12 | 50 -142 | 10 | | | |
| Area.34 | 5 | 50 -65 | 4 | | | |
| Area.35 | 9 | 50 -72 | 5 | | | |
| Area.36 | 4 | 87 -108 | 4 | | | |
| Area.37 | 14 | 52 -81 | 13 | | | |
| Area.38 | 8 | 52 -65 | 8 | | | |

Figure 18: Table 4 :

**5**

| Sampling Area | Equations | Parameters | Coefficient R 2 |
|---|---|---|---|
| Area 1 | SP = -0.6024 w + 1.1341 Ic LL = -4.482 + 1.3225 PI -0.1268 FS + | | 0.90 |
| | 3.0279 LS -0.735 2?m | | 0.97 |
| | FS = -35.85 -1.68 LL+ 2.67 PI + 11.51 LS -2.167 2?m | | 0.94 |
| | SP = -0.14 -0.09 LL + O.16 PI + 0.02 FS + 0.14 LS -0.11 2?m | | 0.92 |
| Area 7 | SP = 4.7397 -0.2186 w + 4.1179 Ic LL = 2.869 + 0.7291 PI+ 0.2847FS | | 0.95 |
| | + 0.8077LS -0.268 2?m FS = 14.142 + 2.45 LL -2.34 PI -0.008 LS + | | 0.91 |
| | 0.185 2?m SP = 0.94 -0.22 LL -0.15 PI -0.04 FS + 0.56 LS + 0.39 2?m | | 0.96 |
| | SP = 0.2754 -0.0577 w + 1.7367 Ic | | 0.92 |
| Area 30 | LL = -44.67 -0.5375 PI + 0.6815 FS + 4.6416 LS + 0.409 2?m FS = | | 0.90 |
| | 58.54 + 1.08 LL + 1.00 PI -5.38 LS -0.542 2?m SP = 9.10 + 0.17 LL | | 0.92 |
| | +0.18 PI -0.09 FS -1.17 LS -0.08 2?m | | 0.95 |
| | LL = 117.308 + 2.7893 PI + 0.7222 FS -5.3889 LS -2.594 2?m SP = | | 0.87 |
| | 3.8121 -0.1062 w + 0.0066 Ic | | |
| Area 12 | FS = -198.33 + 0.465 LL -3.081 PI + 11.597 LS + 4.058 2?m | | 0.96 |
| | SP = -31.47 + 0.05 LL -0.54 PI + 1.20 LS -0.04 FS + 0.82 2?m | | O.92 |
| | SP = -0.9740 + 0.0059 w + 1.3953 Ic LL = 16.105 + 1.2059 PI -0.2788 | | 0.93 |
| | FS + 1.2902 LS -0.029 2?m | | 0.91 |
| Area 25 | FS = 14.191 + 0.224 LL -0.016 PI + 0.799 LS + 0.715 2?m SP = -0.33 | | 0.92 |
| | + 0.07 LL + 0.04 PI -0.25 FS + 0.79 LS + 0.029 2?m | | 0.96 |
| | | | 0.96 |
| | SP = -0.5667 -0.0097 w + 1.7352 Ic | | 0.82 |
| Area 28 | LL = 40.49 + 0.4795 PI + 0.3665 FS -0.7701 LS -0.317 2?m FS = -3.47 | | 0.94 |
| | -0.146 LL -0.460 PI + 3.11 LS + 1.35 2?m SP = 0.14 -0.01 LL + 0.03 | | 0.97 |
| | PI + 0.01 FS -0.17 LS + 0.04 2?m | | 0.92 |
| Area 29 | SP = 0.1492 -0.0284 w + 1.3943 Ic LL = -117.497 + 0.1516 + 0.3236 | | 0.86 |
| | FS + 7.6588 LS + 0.663 2?m FS = -16.426 + 2.731 LL -0.953 PI + | | 0.95 |
| | 3.598 LS -1.736 2?m SP = -30.88 -0.15 LL -0.09 PI -0.01 FS + 2.23 LS | | 0.98 |
| | + 0.27 2?m | | 0.94 |
| | SP = -1.0166 + 0.0003 w + 2.2391 Ic | | 0.94 |
| Area 15 | LL = 3.9328 + 0.9234 PI + 0.2035 FS + 0.1213 LS -0.070 2?m FS = | | 0.94 |
| | 28.06 + 0.341 LL -0.544 PI + 0.128 LS + 0.769 2?m SP = -3.19 -0.04 | | 0.95 |
| | LL + 0.01 PI + 0.02 FS + 0.27 LS -0.04 2?m | | 0.99 |
| | | | 0.92 |

Figure 19: Table 5 :

**6**

| | SP | LL | PI | MC | FS | LS | 2?m |
|---|---|---|---|---|---|---|---|
| SP | 1 | | | | | | |
| LL | 0,499 | 1 | | | | | |
| PI | 0,732529 | 0,923733 | 1 | | | | |
| MC | -0,95932 | -0,41148 | -0,68126 | 1 | | | |
| FS | 0,968208 | 0,515936 | 0,712314 | -0,89149 | 1 | | |
| LS | 0,925799 | 0,449577 | 0,662551 | -0,90055 | 0,875296 | 1 | |
| 2?m | 0,929392 | 0,588749 | 0,77714 | -0,88073 | 0,857321 | 0,8 | 1 |

Figure 20: Table 6 :

**7**

| | SP | PI | MC | FS | LS | 2?m |
|---|---|---|---|---|---|---|
| SP | 1 | | | | | |
| PI | 0,84211 1 | | | | | |
| W | | | | | | |

Figure 21: Table 7 :

## .1 Acknowledgment

The Author wishes to thank all the staff from the soil mechanics laboratory (KEDE -Ministry of Public Works) in Athens, for their assistance to fulfill this paper.

From all tested sampling areas with Multivariate statistical method it was concluded: ? There is a strong correlation between swell pressure and natural moisture content. This relation has the type Y = ax b with correlation coefficient $R^2$ =0.80 to R 2 = 0.98, which indicates a perfect linear relation in the 100 percent of tested samples. ? Also there is a strong correlation between free swell and bar linear shrinkage results having the type of Y = ax b where b>0 and correlation coefficient $R^2$ =0.80 to R 2 = 0.96, which indicates a perfect linear relation for the 60% of soil samples. For the rest 40 percent of the results there is one moderate relation having $R^2$ =0.791 to R 2 = 0.522. , ? The correlation between liquid limit and free swell index revealed a good linear relation, having the type Y = ax-b and for the 64%of samples one correlation coefficient between $R^2$ =0.80 and R 2 = 0.96 . For the rest 34% of samples the coefficient varies between $R^2$ =0.780 and R 2 = 0.635 (moderate). ? The correlation between plasticity index and colloids percent revealed a that there is a strong relation of type Y = ax-b, For the 32% of samples the correlation coefficient varies from $R^2$ =0.922 to R 2 = 0.888. The rest 68% of tested soil have one correlation coefficient between R 2 = 798 and R 2 = 0.687, (moderate). ? The correlation between liquid limit and bar linear shrinkage revealed one linear relation having the type Y = ax-b, but with respect to correlation coefficient is a moderate one, because only 50% of samples has $R^2$ =0.80 and R 2 = 0.96. The rest 50% has one not acceptable coefficient R.

## .2 ? The plasticity index vs bar linear shrinkage graph

indicates that in all the samples the coefficient of correlation is strong, r=0.815. Also bar linear shrinkage values start from 8% and goes on up to 23.3%. ? In the bar linear shrinkage -clay content graph there is a tendency for linear relation, but since the points were scattered, it is better to consider the envelope of the points.

X.

## .3 Summary

1. Expansive soils cause billions of dollars of damage to homes and property each year. If the propensity of a soil to shrink and swell is known before construction, shrinkage limit results can give

[Sept ()] , Sept . 1989. London Univ. U.K.

[Rao and Rao ()] '12 th Swell-shrink behaviour of expansive soils'. A S Rao , M Rao , R . *Int.Conf. in Geomechanics-IACMAG, October*, (Goa, India) 2008.

[Rao and Rao ()] *A case study of cracked building with design Guidelinesonexpansive soils*, R Rao , K Rao . 1998.

[Al-Rawas] *A Goosen -2006 -Expansive soils: recent advances in characterization and treatment books. google*, M F Al-Rawas . Taylor Frances, London, U.K.

[Khreasat ()] 'A mineralogical and morfological characterization of shrink-swell soils of the North plains of Jordan'. S A Khreasat . *J.Agr.&Envirm. Sci. V* 2007. 2 (5) p. .

[Sridharan et al. (1989)] 'Classification procedures of expansive soils'. A Sridharan , K Prakash , A Stamatopoulos , E Gassios , J Christodoulias , H Giannaros . *Recent experiances with Swelling soils. 12th Intrn. Conf. on S.M.F.E*, 2000. 1989. August 1989. 143 p. 655. (Proc.Inst. Rio de Janeiro)

[Grim ()] *Clay Mineralogy*, R E Grim . 1968. New York, USA: McGraw-Hill Publ. Book Co.

[Brindley and Brown ()] *Crystal structures of clay minerals and x-ray identification*, G W Brindley , G Brown . 1980. London, UK: Mineralogical Society.

[Schollenberger and Simon ()] 'Determin-ation of exchange capacity and exchangeable bases in soil-ammonium acetate method'. C J Schollenberger , R Simon . *Soil Science* 1945. p. 13.

[Shi et al. ()] 'Engineering geological characteristics of expansive soils in China'. Bin Shi , Hongtao Jiang , Zhibin Liu , H Y Fang . *Eng Geol* 2002. 67 p. .

[Christodoulias ()] 'Engineering Properties and Shrinkage Limit of Swelling soils 16'. J Christodoulias . *Journal of Earth Science and Climatic Change* 2015. 6 p. 5.

[Holtz and Gibbs ()] 'Engineering properties of expansive clays'. W Holtz , G Gibbs , HJ . *Transactions* 1957. ASCE. 121.

[Bell ()] *Engineering treatment of soils*, F C Bell . 1993. London, UK: Chapman and Hall.

[Thomas and Baker ()] *Expansive soil index for predicting shrink-swell potential. Soil science of america*, Thomas , Zelanzy Baker . 2000. U.S.A.

[Christodoulias and Giannaros (1988)] 'Failure of a Railway Embankment'. J Christodoulias , H Giannaros . *2nd Intrn. Conf. on Case histories in Geotechnical Engineering*, (Rolla, USA) 1988. June 1-5,1988. Univ.Missouri-

[Chen ()] *Foundations on Expansive Soils*, F H Chen . 1976. New York, USA: Elsevier.

[Briaudj-Louis et al. ()] *Foundations on shrinking and swelling soils. (Prediction of Movement, Construction Issues)*, Sangho Briaudj-Louis , Xiong Moon , Zhang . 2002. Texas, USA March. Department of Civil Engineering, Texas A&M University

[Mitchell ()] *Fundamentals of Soil Behavior, 2 nd edn*, J K Mitchell . 1993. New York: Wiley.

[Charles ()] *Geotechnical Aspects of Buildings on Expansive Soils in Kibaha, Tanzania: Preliminary Study - Licentiate Thesis Division of Soil and Rock Mechanics Department of Civil and Architectural Engineering*, Lucian Charles . 2006. Stockholm, Sweden. yal Institute of Technology

[Greece] Greece . *6th Intrn. Conference on expansive soils*, (New Delhi-INDIA)

[Institute of geological and minining exploration ()] *Institute of geological and minining exploration*, Geologicalmap1:50.000. 1980. EVROS DISTRICT. IGME

[Institute of geological and minining exploration TRIPOLIS PLATAEU ()] 'Institute of geological and minining exploration'. Geologicalmap1:50.000. *TRIPOLIS PLATAEU* 1980. IGME

[Institute of geological and minining exploration ()] *Institute of geological and minining exploration*, Geologicalmap1:50.000. 1980. IGME ; PLANE OF VIOTIA

[Institute of geological and minining exploration ()] *Institute of geological and minining exploration*, Geologicalmap1:25.000. 1990. IGME ; Island of LESVOS

[Institute of geological and minining exploration. Geologicalmap1:25.000, Island of EGINA ()] *Institute of geological and minining exploration. Geologicalmap1:25.000, Island of EGINA*, 1990. IGME

[Christodoulias and Gassios ()] *Investigation on Motorway damage due to expansive soils in*, J Christodoulias , E Gassios . 1987.

[Astm ()] 'Method D4546-90, Standard Test method for one dimensional swell or settlement potential of cohesive soils'. Astm . *Annual book of ASTM Standards*, 1993.

[Christodoulias and Giannaros ()] 'Methods of design earthworks on Expansive'. J Christodoulias , H Giannaros . *Greece. Intrn. Conf. On Foundations and Tunnels*, 1989. p. .

[Rao et al. ()] *Prediction of swelling characteristics of remoulded and compacted expansive soils using free swell index. QJEngGeo& Hydro*, A Rao , S &phanikumar , A S Sharma , RS . 2004. London, U.K \. 37 p. .

[Komornick and David ()] 'Prediction of swelling pressure of clays'. A Komornick , D David . *Proc ASCE J SMFD* 1969. 1 p. .

[Seed et al. ()] 'Predictions of swelling potential or compacted clays'. H B Seed , R J WoodwardJr , R Lundgren . *JASCE SMFD* 1962. 88 p. .

[Sridharan ()] *Problematic Soils. Volume change behaviour of expansive soils*, A Sridharan . 1999. Yanagisawa, Moroto, Mitachi. Balkema, Rotterdam. p. .

[Bayliss ()] 'Quantitative analysis of sedimentary minerals by power diffraction'. P Bayliss . *Powder Diffraction* 1986. 1 p. .

[Cerato and Lutenegger ()] *Shrinkage of clays. Unsaturated soils*, A B Cerato , A Lutenegger , J . 2006. USA: ASCE publications. p. .

[Soil Mechanics for Road Engineers. Determination of the Shrinkage limit of soil ()] *Soil Mechanics for Road Engineers. Determination of the Shrinkage limit of soil*, 1974. UK. TRRL. Transport and Road Research Laboratory

[Wilson ()] 'Soil smectite and related inter stratified minerals'. M L Wilson . *Proc. Int. clay conference* 1987. p. .

[Astm ()] *Standard Test Method for Expansion Index of soils*, Astm . 2000. p. . Geotechnical Engineering Standards, USA.

[Zangalis (1998)] 'Standarless quantitative mineralogical analysis of rocks'. K Zangalis . *Powder Diffraction* 1998. June. 13 (2) p. .

[Arefnia ()] 'Studying the correlation between shrinkage index and other characteristics of clay soils for Tehran region. 1-10 April'. Ali Arefnia . *Methods of testing Soils for civil engineering purposes*, (London, UK) 2011. 1990. 1990. 1377. (BS)

[Masoumeh Mokhtari Masoud Dehghani ()] 'Swell-Shrink Behavior of Expansive Soils'. *Damage and Control. EJ* Masoumeh Mokhtari & Masoud Dehghani (ed.) 2012. 17 (2012) . RoBund. REJGE, University of Hormozgan

[Delwar et al. ()] 'Swelling characteristics of Madinah clays'. H Delwar , M I Matsah , Sadaqahb . *Geological Society* Q.J.E.G. (ed.) 1997. 30 p. .

[ QJ E G ()] *Testing and sampling of tropical residual soils*, QJ E G . 1990. 23 p. . (Engineering Working Party Report)

[Izdebska-Mucha ? Emilia and Wo´jcik ()] ‘Testing shrinkage factors: comparison of methods and correlation with index properties of soils’. Dorota Izdebska-Mucha ? Emilia , Wo´jcik . 10.1007/s10064-012-0449-0. *Bull Eng Geol Environ* 2013. 2013. 72 p. .

[Van Der ()] ‘The prediction of heave from plasticity index and the percentage clay fraction of soils. The Civil Engineering’. Merwe Van Der . *South African Institution of Civil Engineers* 1984. 6 p. .

[Stamatopoulos et al. ()] ‘Treatment of expansive soils for reducing swell potential and increasing strength’. A Stamatopoulos , J Christodoulias , H Giannaros . *Quar J EngGeol* 1992. 25 p. .