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Swell Pressure Predict from Shrinkage Limit

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Abstract: 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. The purpose of this laboratory investigation was to examine the geotechnical behavior as many as possible active soils throughout the Greek mainland and islands. For this, grain size analyses, Atterberg limits, shrinkage limits tests, swell pressure in the oedometer, in disturbed and undisturbed soil samples have been investigated in order to correlate swell pressure and shrinkage limit, two variables which are water dependable, and if it is possible from shrinkage limits tests to estimate swell pressure, and the results were very promising.

Keywords: Swelling Clay, Swelling Pressure, Shrinkage Limit, Geotechnical Properties.

1. INTRODUCTION

The engineering significance of swelling soils in relation to geotechnical problems is now widely recognised. Geotechnical problems arising from expansive unsaturated soils are well demonstrated by many case histories all over the world, especially in geographical zones having arid, semi-arid and tropical climatological conditions. Expansive soils which are rich in montmorillonite or smectite group minerals, absorb water during rain period and undergo swell, but during summer period the water evaporates and causes shrinkage of soil. The alternate swelling and shrinkage cause strain on every structure built on them. From the literature it is reported that light industrial structures and single storey or two storey buildings suffer from heaving, road pavements develop shrinkage cracks, pavements and canal lining, airfields and low embankments resting on swelling soil or embankments constructed with swelling soil, undergo distress and cracking. Each year in the U.S., expansive soils are responsible for more damage to homes than are floods, tornadoes, and hurricanes combined. The reported damages estimated for U.S.A are up to $ 1000 million per year.

2. EXPANSIVE SOILS IN GREECE

The existence of expansive soils in Greece, scattered throughout most of the mainland as well as the islands, accumulated as sediments during the Neocene and Quaternary eras in large drainage basins with some occurrences of terraces up to 10m high. In these plains the sediments are of lacustrine origin but also alluvial, pluvial and alluvial deposits enriched the areas. The material sources are from the weathering of various types of rocks such as basic and ultra-basic igneous rocks, limestone, and mudstone containing silicate minerals. 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.

In the field expansive clay soils can be recognized during the dry season of the year because they exhibit on the ground surface deep cracks in roughly polygon pattern. The zone of seasonal moisture content fluctuation can extend about one meter deep. This creates cyclic shrink-swell behaviour in the soil and cracks can extend to bigger depths than most soil engineers can imagine.

From bibliography it is known that smectite group of minerals (monmorillonite) is formed from basic igneous rocks in poorly drained areas with low rainfall. Kaolinite is formed by leaching of magnesium from previous smectite. Illite is derived by weathering of feldspar or smectite, (Grim, 1968). The arid to semi-arid climate conditions in Greece prevail with substantial rains and floods in the autumn, which follow the regular dry and hot climate cycles of the summer, in combination with the cycles of dry summer - wet autumn or periods of heavy rainfall, have resulted in activating the specific clay minerals, which influence the engineering properties of expansive soils due to physicochemical properties and activate all the unfavourable consequences in construction business. Potentially expansive soils can typically be recognized in the lab by their plastic properties. Inorganic clays of high plasticity, generally those with liquid limits exceeding 50 percent and plasticity index over 30, usually have high inherent swelling capacity.

3. AREAS OF INVESTIGATION.

In the present study, several expansive clay samples were collected from different locations across Greece and swelling properties of these soils were measured by employing a large laboratory investigation. The first laboratory-based evidence of swelling potential was given by grain size analyses and Atterberg limits, (Holtz and Gibbs 1957, Van der Merwe 1957, Seed et all 1962, Terzaghi and Peck 1967, Sridharan 1999). The material passing the US sieve No 200 varied between 70% and 100%. Liquid limit (LL) modified from 30% to 80% and plasticity indices from 20% to 60%. Such clays belong to CL and CH groups of Unified classification system. For the grain size analysis of the clay fraction, sodium phosphate solution was used as dispersant.

From the liquid limit (LL) results (ASTM D4318) of the total number of samples, the majority of samples (34, 5%) yield liquid limit values between 40-50%. From plasticity index (PI) results for the total number of 58 soil samples, the highest portion of 36,2% yield plasticity index values between 30-40%, and one small percent 20,7%, showed plasticity index values between 40-50%, (Table 2).

The swelling consolidation tests in 50mm diameter and 20mm high oedometer ring were contacted on specimens prepared from undisturbed soil samples, according to ASTM 1993 method D-4546-90, starting with initial vertical pressure of 6.9kpa, all the successive loads were maintained for 48 hours to reach constant values of height. Of these values, a percentage of the samples revealed swelling pressure of 0.5kg/cm². Another percentage of was found to have a swell pressure of 1kg/cm². A third percentage reached pressure values of 1.5 kg/cm². A similar percentage revealed pressure of 2kg/cm². Some of the undisturbed soil samples yielded high values of swelling pressure from 2.0 up to-3.5kg/cm² and one exceptional undisturbed soil sample from Shimatary area revealed swelling pressure 5,80 Kg/m2, with LL = 70 and PI = 54%.

Additionally, using the mercury apparatus suggested by the Transport and Road Research Laboratory (TRRL, 1954), we obtain shrinkage limit tests results only from undisturbed soil samples. The evaluation of Cation-Exchange Capacity (C.E.C.) was succeeded with the acid acetate method and corn flam photometer. For the mineralogical analysis of clay fraction x-ray diffraction method was used.

Table 1: Sieving analysis of soil samples.

Location	**Sample Region**	**Samples**	**Sand %**	**Silt %**	**Clay %**
location 1	**Shimatari**	**25**	**5 - 30**	**30 - 40**	**20 - 55**
location 2	**Yliki**	**28**	**2 - 24**	**24 - 40**	**20 - 74**
location 3	**Anthohori**	**10**	**4 - 18**	**36 - 50**	**20 - 60**
location 4	**Dramesi**	**21**	**2 - 10**	**38 - 54**	**30 - 60**
location 5	**Ormenio**	**27**	**4 - 28**	**22 - 46**	**20 - 50**
location 6	**Exohi**	**27**	**4 - 20**	**42 - 58**	**20 - 54**
location 7	**Serres**	**12**	**8 - 18**	**26 - 32**	**34 - 60**
location 8	**Agia anna**	**33**	**2 – 36**	**21 - 26**	**25 - 78**
location 9	**Patra**	**21**	**2 - 18**	**42 - 50**	**28 - 44**

Table 2: Liquid limit and plasticity index statistics.

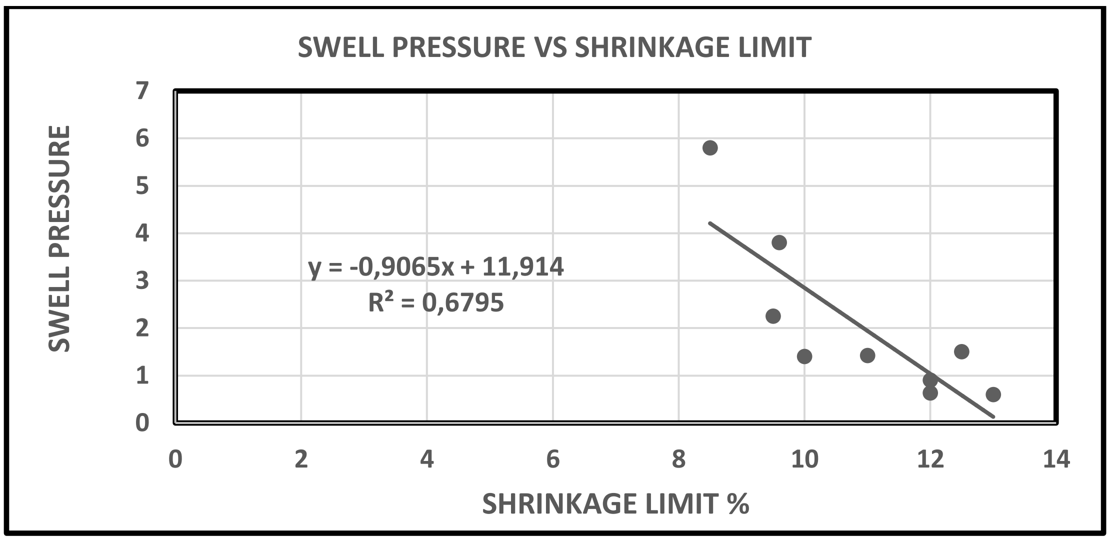
Liquid Limit	**N=58 samples**	**%**	**Plasticity Intex**	**N=58 samples**	**% percent**
30-40	3	5,4%	10-20	1	1,7%
40-50	20	34,5%	20-30	19	32,7%
50-60	18	31%	30-40	21	36,2%
60-70	16	27,5%	40-50	12	20,7%
70-80	1	1,2%	50-60	5	8,6%

Location 1. Shimatari area, (Attica district).

It is located in a distance of 60 km north of Athens and is part of the Athens-Lamia motorway. The investigated area has 10 km length. The surrounding has a thick red clay cover with weak vegetation, is heavily cultivated and clay marl formations appeared deeper than 14 m. The drainage conditions of the area appear to be limited and are done through some dry streams. A total of 10 boreholes in the upper clay horizon supplied 25 undisturbed samples in shelby

Table 3:

LL	**PL**	**PI**	**SL**	**MC%**	**Ic**	**SWELL Kg/m2**	**Shimatari**
72	16	56	9,6	13,6	1,041	3,80	**Km 60**
67	16	51	9,5	16,8	0,984	2,25	**Athina to**
48,5	19	30	10	20	0,950	1,40	**Lamia**
49	20	29	11	21	0,965	1,42	
46	23	23	13	24,8	0,921	0,60	
51,5	20	31	12,5	22,6	0,930	1,50	
63	23	40	12	27	0,901	0,90	
54	23	31	12	25,4	0,922	0.63	
69	15	54	8,5	11,8	1,059	5,80	



Drawing 1: *Swelling pressure versus shrinkage limit, for location 1.*

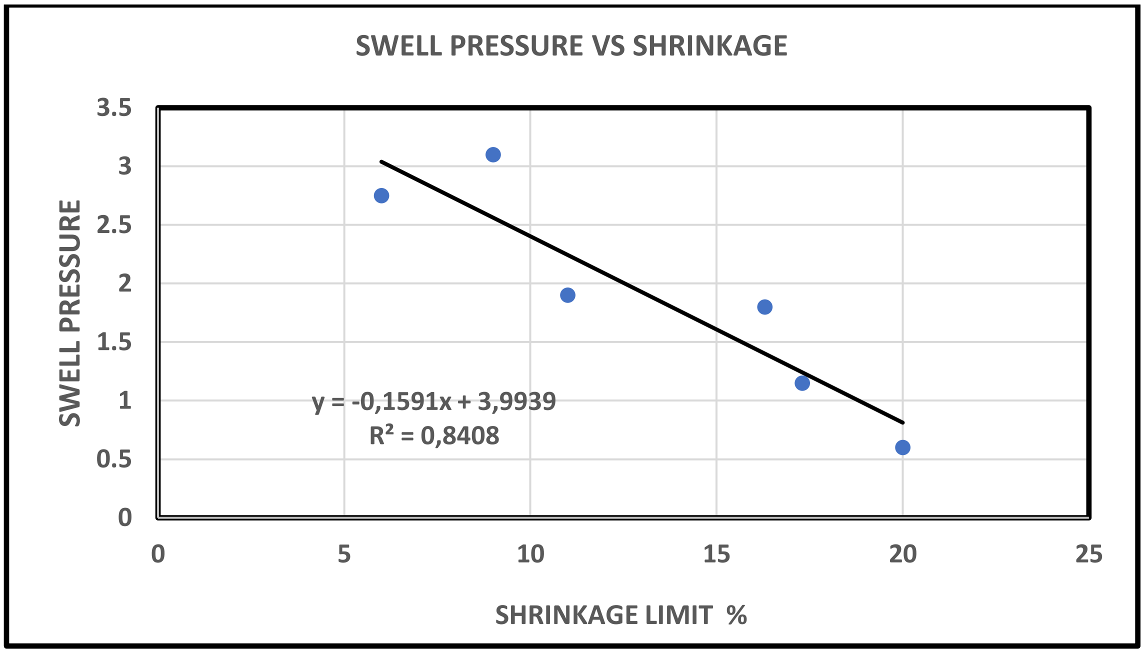
Location 2. Motorway of Yliki lake area.

It is located in a distance of 90 km north of Athens, near the lake Ylikii.

It includes a zone of 20 km long on both sides of the new motorway from Athens to Thessaloniki and is founded on an old drained lake of Neocene Geological period. The wider area consists of heavily cultivated black and gray clay. The drainage conditions are limited, as a result of which water stagnates in the winter months since it is part of the Thebian plain. A total of 30 undisturbed shelby samples were taken with drilling from the clay horizon. In the deeper horizons, argillaceous formations were found.

Table 4:

LL	PL	PI	SL	Ic	MC%	SWELL Kg/m2	YLIKI
62	11	51	9	1,25	10,6	3,10	
59	13,2	44	6	1,26	12	2,75	
56	19	37	11	1,09	17,5	1,90	
45	19	26	16,3	1,16	15	1,80	
64	22	42	17,3	0,95	24	1,15	
50	22	28	20	0,98	23,6	0,6	



Drawing 2: *Swelling pressure versus shrinkage limit, for location 2.*

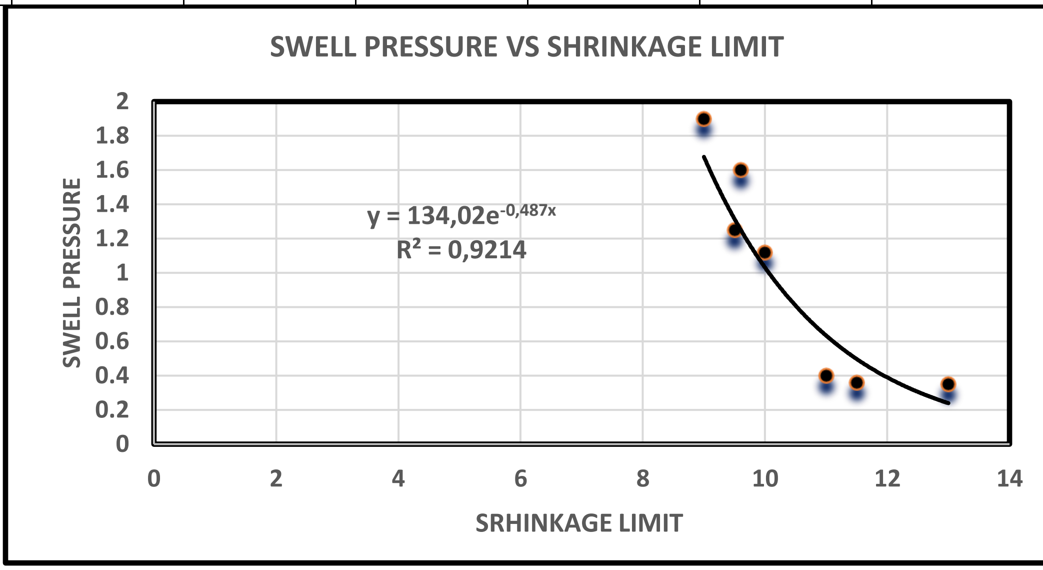
Location 3. Anthohori village, (near city of Thives.)

Geotechnical investigation was contacted for the needs to build a new community center, containing several offices and one nursery school in semi-detached construction. The area is located within the area of the former drained lake, contains thick black clay material, having very high Atterberg limits. Also has poor drainage and is heavily cultivated because black clay is very fertile. From boreholes, 10 disturbed and 5 undisturbed shelby samples were taken from the black gray clay layer.

Table 5:

LL	PL	PI	SL	MC	Ic	SWELL Kg/m2	Anthoxori Biotia
66	18	48	13	27,9	0,793	0,35	
64	17	47	9,5	16	1,021	1,25	
68	16	52	9,6	13,2	1,053	1,60	

64	18	46	11,5	27,1	0,802	0,36	
57	17	40	11	19,7	0,932	0,4	
64	16	48	9	12,5	1,027	1,90	
62	17	45	10	16	1,022	1,12	



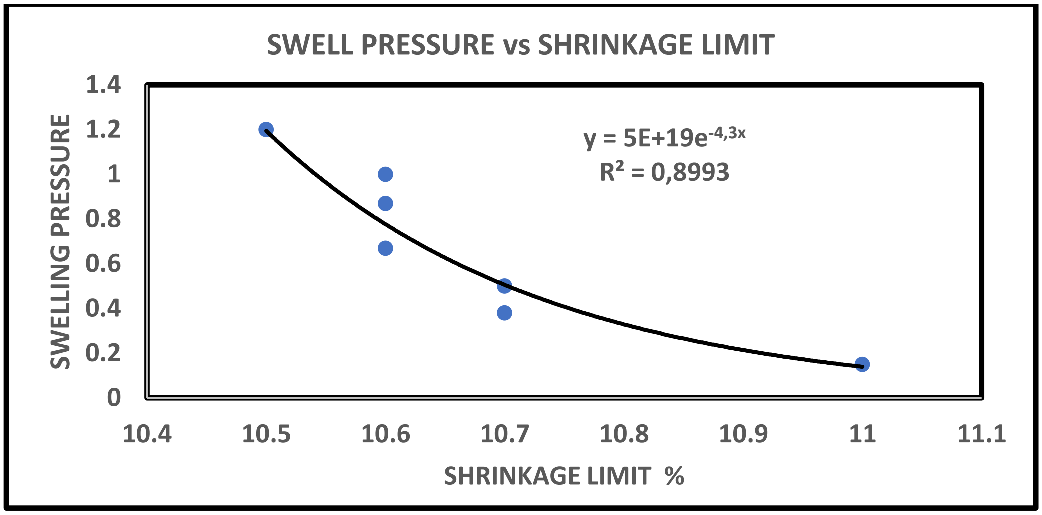
Drawing 3: *Swelling pressure versus shrinkage limit, for location 3.*

Location 4. Dramesi area (in Attica district).

Dramesi area is located north of Athens in about 50 km distance. Is a hilly land consisted of red clay having moderate plasticity index. The requirement was to improve and enlarge the existing road connecting the motorway from Athens to Lamia and finally to Thessaloniki with the city and port of Chalkida. The area belongs to the Neocene era, has poor drainage, and most farmers cultivate olive trees and wheat. From the red clay layer, 21 disturbed and 8 undisturbed shelby samples were taken. In the deeper horizon, red clay marl was found.

Table 6:

LL	**PL**	**PI**	**SL**	**Ic**	**MC**	**SWELL Kg/m2**	**DRAMESI**
48.5	18.5	30	10	0.95	20	1.40	
49	20	29	9.5	0.965	21	1.42	
46	23	23	10.6	0.921	24.8	0.60	
63	23	40	10.2	0.901	27	0.90	
54	23	31	11.2	0.922	25.4	0.63	



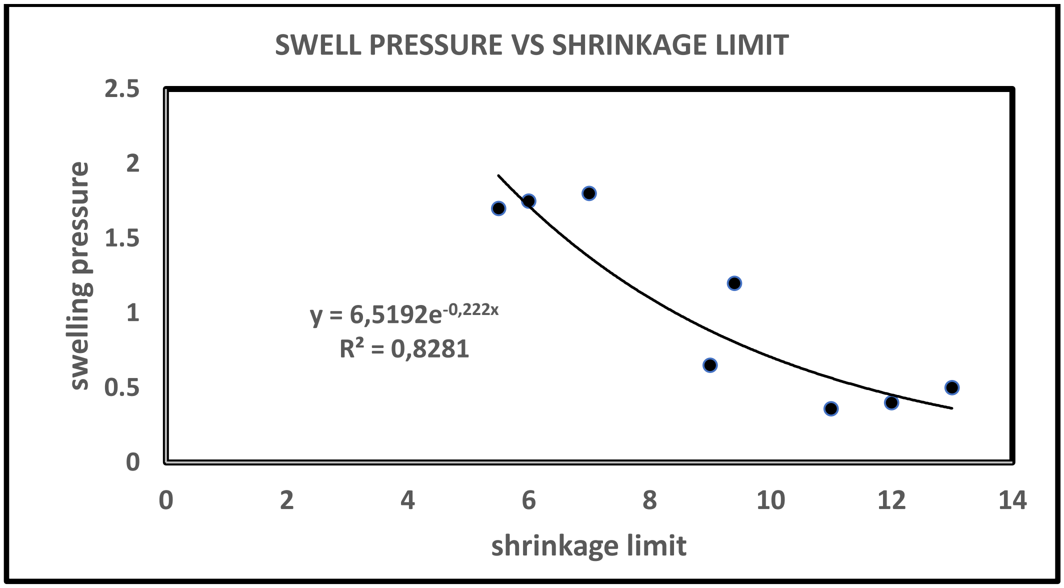
Drawing 4: *Swelling pressure versus shrinkage limit, for location 4.*

Location 5: Ormenio vilage, (Evros River)

Ormenio is the last village of the Greek territory with the Bulgarian boundaries in Evros District, having a distance 1000km North – East from Athens. The project was a road under construction having length 150 km, connecting Bulgarian border with Alexandropoulis harbor, for the needs of USA Navy and Army. The area belongs to the Evros river valley, has very low altitude, poor drainage, floods easily, is heavily cultivated because the soil is very rich and consists of black and gray clay, up to a depth of 6 m, with high LL moderate PI. In the deeper layer, lacustrine soil was found. Along the first 20 Km length, 40 boreholes were drilled. From the boreholes, 30 disturbed and 40 undisturbed samples in shelby were collected for laboratory testing.

Table 7:

LL	PL	PI	SL	MC%	Ic	SWELL Kg/m2	ORMENIO EVROS
49	18	31	9	20,6	0,916	0,65	
42	14	28	7	13,6	1,014	1,80	
44	**22**	24	12	21,9	0,921	0,4	
41	20	21	11	21,9	0,909	0,36	
39,5	13	26	5,5	14	0,981	1,70	
49	15	35	6	14,8	0,977	1,75	
43	13	30	9,4	14,5	0,95	1,20	
51	18	33	13	20,2	0,933	0,5	



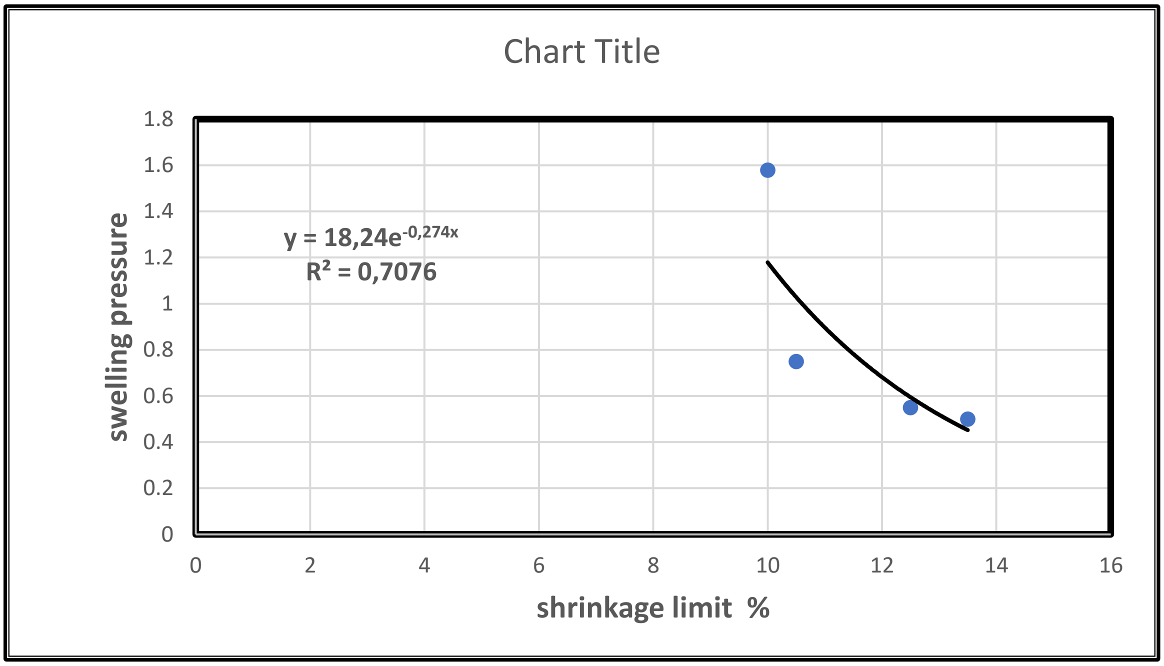
Drawing 5: *Swelling pressure versus shrinkage limit, for location 5.*

Location 6. Exohi village, (Pieria district).

This area is located 400km north of Athens. For the investigation purposes, 14 boreholes were drilled having 30 m depth, in order to determine the geological background, because creeping movements occurred in the village. From the drilling, 15 undisturbed and 27 disturbed samples were kept in shelby. Up to 6 m brown, gray clay was found with high liquid limit percent, while in the deeper layers, up to 30 m clay, marl, silt and sandy horizons alternated.

Table 8.

LL	**PL**	**PI**	**SL**	**MC**	**Ic**	**SWELL Kg/m2**	**EXOHI PIERIA**
48	18	30	10	11.7	1.2	1.58	
56	21	35	10.5	18	1.18	0.75	
52	25	27	13.5	21	1.14	0.5	
51	25	26	12.5	23	1.07	0.55	



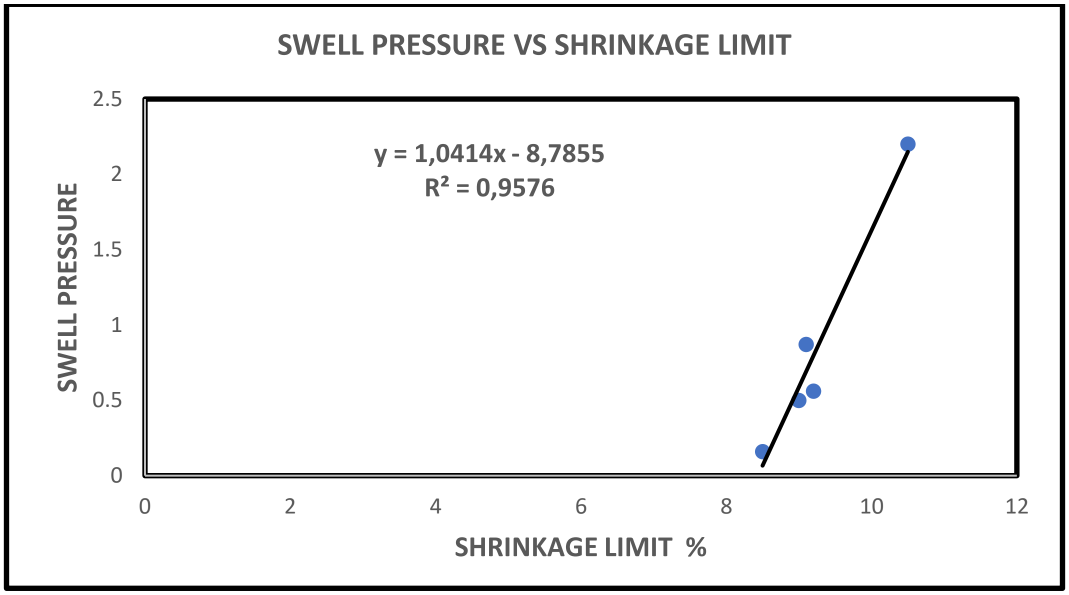
Drawing 6: *Swelling pressure versus shrinkage limit, for location 6.*

Location 7. Serres motorway towards Alexandroupoli.

The city of Serres is located in the middle of Macedonian region of Greece in a distance of 700km North to N-East from Athens. The project was to rehabilitate the motorway driving towards Turkey, because due to swelling clay the pavement was severely damaged in different sections. For the laboratory investigation 16 boreholes 15m deep were drilled, along the road at a total distance of 10 Km. The area is lowland, has moderate drainage, is heavily cultivated with wheat and consists of red clay in considerable depth. 12 disturbed and 16 undisturbed shelby samples were taken from this layer

Table 9:

LL	**PL**	**PI**	**SL**	**MC**	**Ic**	**SWELL Kg/m2**		**SERRES**
48	18	30	9	23.3	0.823	0.5		
52	16	36	8.5	28.1	0.663	0.16		
60	18	42	10.5	15	1.071	2.2		
55	22	33	9.2	24.4	0.927	0.56		
53	19	34	9.1	23	0.882	0.87		



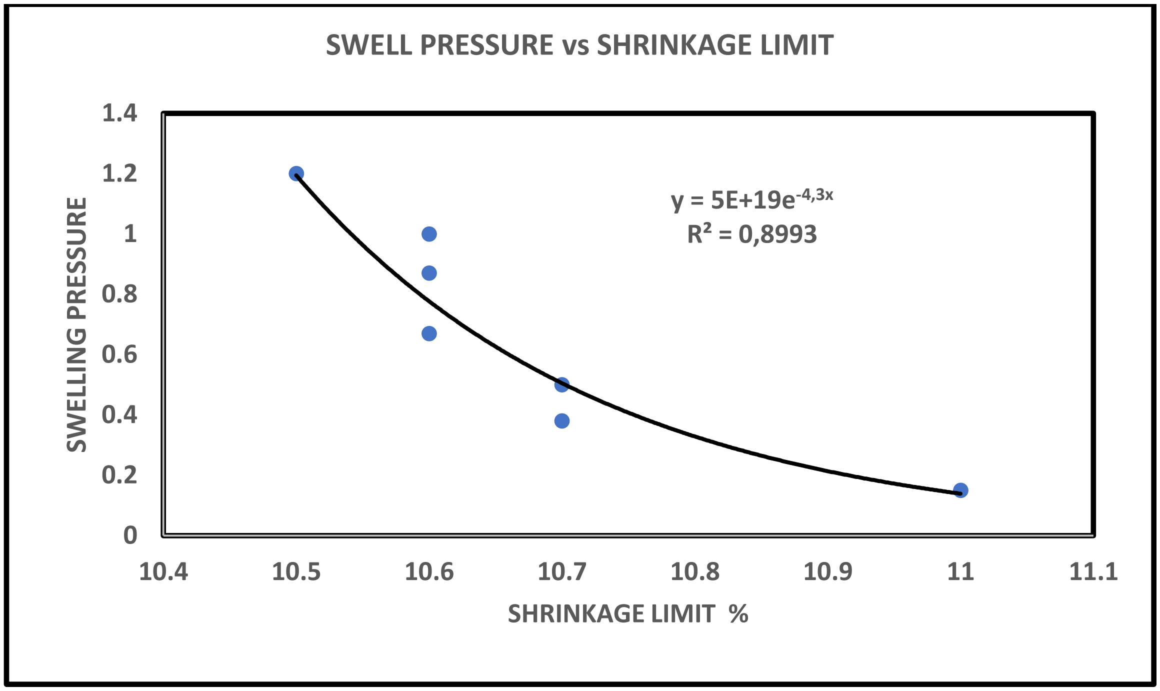
Drawing 7: *Swelling pressure versus shrinkage limit, for location 7.*

Location 8. Agia Anna village -Health center building, (Evia Island).

The reason for this investigation was the total wall cracking and the floor uplift of the one-story Health center building. The only solution was to demolish the old building and construct a new one with framework of reinforced concrete. The area is hilly with good drainage, plenty of vegetation and having one pinaceae tree forest in the mountain above the village. From the drilling it was found that the soil consists of a thick layer of red clay, up to 8 m and at the deepest, up to 22 m, alternating layers of clay and clayey marl. From 15 boreholes 33 disturbed and 10 undisturbed shelby samples were collected withing the clay horizon.

Table 10.

LL	PL	PI	SL	MC%	Ic	SWELL Kg/m2	AG.ANNA *EVIA*
65	19	46	10,6	18,6	1,008	1.0	
47	26	21	11	32,8	0,676	0,15	
60	22	38	10,6	23	0,973	0,87	
60	25	35	10,7	34,5	0,728	0,38	
54	22	32	10,7	26,4	0,862	0,5	
51	16	35	10,5	15,8	1,005	1,20	
51	22	29	10,6	27,6	0,806	0,67	



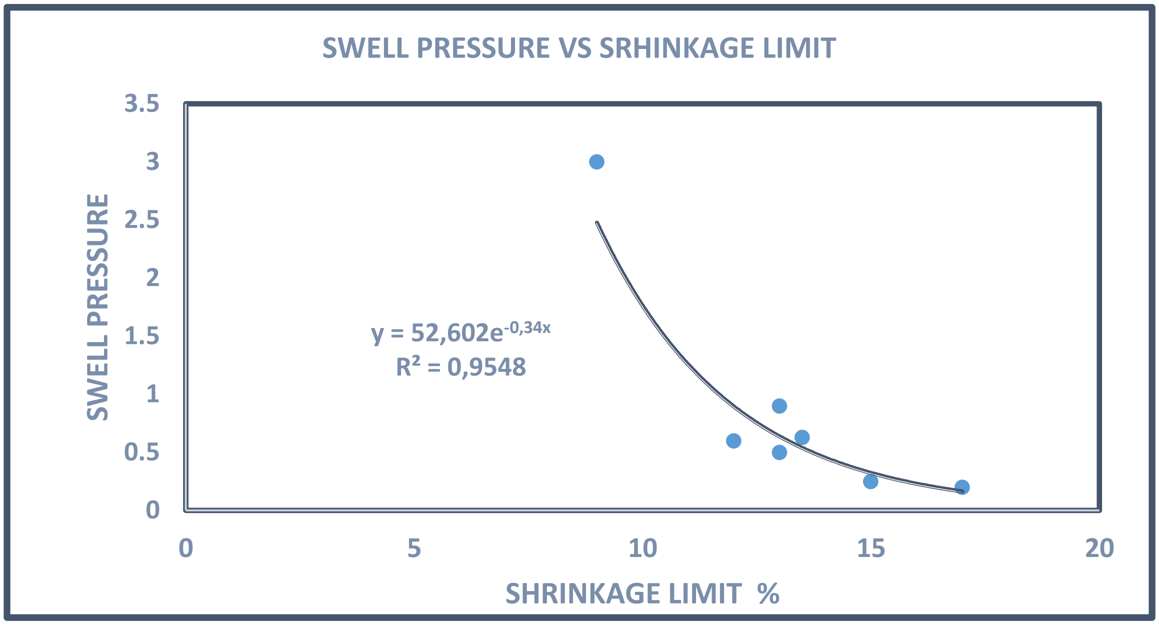
Drawing 8: *Swelling pressure versus shrinkage limit, for location 8.*

Location 9. Diversion of traffic in PATRAS, (Peloponnese).

In the upper west part of Peloponnese and in a distance of 200km west of Athens is located the City and Harbord of Patras connecting Greece and Italy. For the needs of improving and enlarging the ring road in the suburbs of Patras and diverse the traffic out of city center. For the geotechnical investigation 16 boreholes of 15 m depth were drilled. The area is hilly, has good drainage, lush vegetation, olive trees and plenty of water. Sampling was limited to the black and gray clay layer and did not have to enter the flysch formation in the deeper. A total of 21 disturbed and 15 undisturbed samples were collected in shelby.

Table 11:

LL	**PL**	**PI**	**SL**	**MC%**	**Ic**	**SWELL Kg/m2**	**PATRAS**
45	20	25	15	23	0,88	0,25	
45	15	27	9	14,2	1,14	3.0	
46	20	26	17	25	0,807	0,2	
34	17	17	13	17,3	0,982	0,9	
51	18	33	13	22	0,878	0,5	
37	16	21	13,5	19	0,857	0,63	
43	19	24	12	19,8	0,966	0,6	



Drawing 9: *Swelling pressure versus shrinkage limit, for location 9.*

CONCLUSIONS

From the correlation of Swelling pressure versus shrinkage limit in all the above mentioned locations in Greece, it was concluded that between them there is one strong relation having exponential type of $y=ax^b$ and coefficient of correlation R^2 fluctuated between 0,8281 and 0,9548. Only in two locations the relation had a moderate coefficient of correlation R^2 varying between 0,680 and 0, 7076. So, we can conclude that from shrinkage limit test result we can predict the existence of swelling pressure in one clay soil, but we must confirm it with a large scale laboratory investigation.

REMENTIAL WORKS

In order to assist any fellow reader of this paper, the author feels obliged to explain the remedial works in all locations to reduce effectiveness of active clay. In most cases concerning motorway improvement or new construction, the stabilization of embankment clay sub-grade has been used. For this, the upper meter of parent material was excavated and divided in two layers. The first layer having 0,50 cm thickness, after deep plowing with one caterpillar D-10 ripper was mixed with 5% lime or 5% cement and in some cases with a mix of both in percent 3% +3%. Afterwards the mixing with ripper was repeated three times without leveling. Next step was to drive a water tank truck on top of mixed material pouring water and continuously testing for optimum moisture content. After reaching O.M.C. the compaction with one sheep-foot roller started, until the material had reach maximum dry density higher than 95%. Similar procedure was repeated for each next layer.

The construction of motorway in Shimatari location was most difficult because a swelling pressure 5, 80 Kg/m2, liquid limit = 70% and plasticity index = 54%, were determined in the soil laboratory. After a long discussion the conclusion was, to excavate from the sub base and replace one meter clay soil material with silty sand and gravel mixture. The material was brouth with dump trucks, moisterized and compacted with vibrating roller of 30 tons at 95% of laboratory dry density and at O.M.C..Finally on top, the motorway embankment was constructed from cellected material.

In Anthoxori location, the site to build a new community center, containing several offices and one nursery school in semi-detached construction, due to high liquid limit, plasticity index and swell pressure, it was decided to stabilize the sub grade of the site with lime slurry mikro-piles. For this sort boreholes

(5 m depth) were drilled using one cutting ring T101, in a square pattern 3m x 3 meters. Each hole was filled up with a mixture of cement 3% and lime 3%. After 28 days the building was started.

In the case of Agia anna rebuilding a new Health center, in order to avoid any uplift force on the new building, it was decided to stabilize the earth material underneath the basement. For this, one meter of clay material from building area was excavated and stabilized in 3 layers with 5%cement. Finally, each layer was compacted up to 95% of dry density at O.M.C. and the construction of new building was followed.

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