Swelling Soils in the Campo de Calatrava Volcanic Field, Spain: General View

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SWELLING SOILS IN THE CAMPO DE CALATRAVA VOLCANIC FIELD, SPAIN: GENERAL VIEW

SUELOS EXPANSIVOS DE LA REGIÓN VOLCÁNICA DE CAMPO DE CALATRAVA, ESPAÑA: VISIÓN GENERAL

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ABSTRACT

Swelling soils are cohesive materials capable of experiencing large volume changes linked to variation of its moisture content. Campo de Calatrava is an area of Ciudad Real province, Spain, where this kind of soils can be found due to the weathering of volcanic deposits generated during the Neogene. They have been seldomly studied due to the lack of population in the area and the moderate swelling potential compared to more expansive materials that can be found in other zones of the Iberian Peninsula. This study presents a new dataset of laboratory testing results not previously published based on swelling pressure at constant volume on oedometer apparatus. This additional data obtained mostly from site investigations for building construction has been integrated with the available geotechnical data on the literature to provide valuable observations (but preliminary at this stage; additional research is forthcoming) about the expansivity of Campo de Calatrava soils and their index properties.

RESUMEN

Por suelos expansivos se entiende aquellos materiales cohesivos que experimentan grandes cambios de volumen vinculados a variaciones de la humedad. El Campo de Calatrava es una zona de la provincia de Ciudad Real, España, donde este tipo de suelos se encuentran relacionados con la meteorización de depósitos volcánicos generados durante el Neógeno. Éstos han sido raramente estudiados debido a la falta de población en la región y al potencial expansivo moderado comparado con materiales más expansivos que se pueden encontrar en otras ubicaciones de la Península Ibérica. En el presente trabajose presenta un nuevo juego de resultados de laboratorio no publicados hasta la fecha basados en ensayos de presión de hinchamiendo en edómetro a volumen constante. Esta información adicional obtenida principalmente de campañas geotécnicas para edificación ha sido integrada con la disponible en la bibliografía previa para proporcionar valiosas observaciones (aunque preliminares dado que se sigue investigando en el momento actual) sobre la expansividad de los suelos del Campo de Calatrava y sus propiedades índice.

1 - INTRODUCTION

The Campo de Calatrava Volcanic Field (from now CCVF) is an inner Iberic Peninsula volcanic zone inside the province of Ciudad Real (Fig.1). For the purpose of this study CCVF has the following boundaries: at the N the Montes de Toledo, at the S the Alcudia Valley; at the E part of the Azuer River and Alto Jabalón and at the W part of the Rivers Tirteafuera and Bullaque (Fig.2). The CCVF is composed by plains at around 600 m of elevation separated by ridges with elevations not higher than 900 m.

Figure 1 –Ciudad Real province inside the Iberic Peninsula (modified from Poblete Piedrabuena et al., 2016)

CCVF has been traditionally considered in the geological literature an intra-plate hotspot located at the SE of the Central Iberian Zone of the Iberian Massif linked to anomalous mantle. According to Rincón Calero (2014) the CCVF is a logical consequence of the lithospheric flexuring due to the superposition of two slip vectors on two main directions: Preneotectonic stress tensor along N-S due to the convergence of Africa and Eurasia plates acting on the Iberian Massif and the Neotectonic stress tensor along SE-NW acting after the generation of various continental basins (Mancha Plains, Argamasilla, Calzada-Moral, Alcolea, etc).

Poblete Piedrabuena et al. (2016) showed that on these continental basins, volcanic episodes have been associated (both in location and magma supply) to previous faults generated by the afore mentioned tensors. A very rich typology of volcanic landforms can be observed at the CCVF: extrusive domes, cinder cones and hydromagmatic maars.

The composition of the magma is mostly alkaline-ultrapotassic but eruption typology is varied, from explosive to effusive strombolian to explosive phreatomagmatic where the presence of aquifers regulate the eruption. The result is a set of fluvial and lacustrine inter-eruption sedimentary deposits with interbedded volcanoclastic deposits of different kind. These materials range from tephra fall of different sizes and bombs to directly deposed or reworked by lahar flows and fluvial action (Herrero-Hernández et al., 2015).

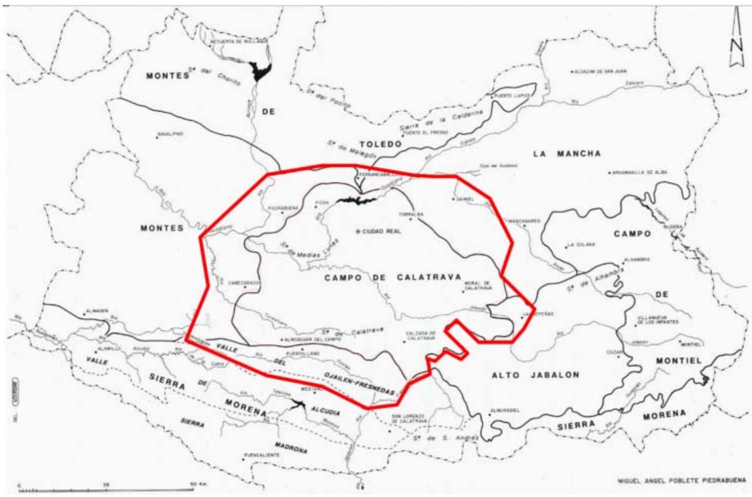

Figure 2 –CCVF considered for the present work; boundary marked by a red line (modified from Poblete Piedrabuena, 1995)

2 - GEOTECHNICAL BACKGROUND

Rincón Calero (2014) complains about the lack of investigation on the CCVF Geological literature until recent times.

On the Geotechnical scope the status is even worse. The partial coverage of the CCVF on the Geological Maps (MAGNA project; scale 1:50000) published by the Instituto Geológico y Minero de España (IGME) and the Estudios Previos del Terreno (EPIT) of the Dirección General de Carreteras which used the maps as source do not provided quantitative information from the geotechnical point of view.

This lack of published geotechnical information is partially related to the fact that CCVF is a low population zone that only in the last years is demanding better comunications and where most of the home construction is concentrated on the bigger cities (mostly Ciudad Real and Puertollano).

Swelling soils are defined as soils that include clay minerals that are able to experience volume change even when they suffer small variations in the moisture content. This behaviour may produce important damage to structures, buildings and facilities, thus swelling soils imply a geotechnical hazard for construction that has to be investigated and mitigated with proper countermeasures.

From the geotechnical point of view, the quantitative parameter that provides a better understanding of the expansivity of soil and their interaction with shallow foundations (footings or mats) or retaining walls is the swelling pressure of an undisturbed soil sample obtained from the oedometer. This pressure is the necessary value to counteract and compensate the mobilised swelling potential of the sample of soil when moisture content is increased in the sample. If the working stress of the shallow foundation is equal or higher than the mobilised swelling pressure, the foundation will not experience any swell or will settle as any other shallow foundation.

There are only two references on the literature treating directly the geotechnical properties of the CCVF soils, both of them with specific emphasis on their expansivity due to their impact on construction activities.

Ayala Carcedo et al. (1986) indicate that weathering of volcanic materials generates high expansive capacity due to the existance of Montmorillonite clay. Regarding the CCVF the authors comment that the presence of steady aquifers has mitigated the mobilisation of the expansivity of these materials. Unfortunately the quantitative information is not segregated between areas different than Madrid, thus the quantitative data includes CCVF but also Madrid and other areas of the South Plateau of the Iberic Peninsula.

The clay expansivity shown on the attached map (scale 1:1000000) for the CCVF (see Fig.3) appears as "low to moderate" (expected maximum swelling pressure in the rank 25-123 kPa) around Ciudad Real city and Daimiel and "moderate to high" (expected maximum swelling pressure in the rank 123-294 kPa) on two separate areas at the S, one around Almodóvar del Campo and Puertollano and another between Calzada de Calatrava and Valdepeñas.

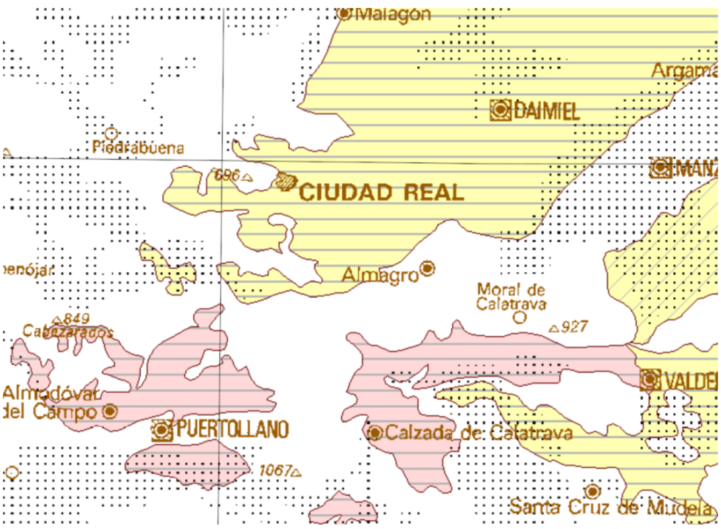

Figure 3 – Clay expansivity hazard in the CCVF. Yellow pattern: "low to moderate"; Pink pattern: "moderate to high" (modified from Ayala Carcedo et al., 1986)

The only quantitative new relationship provided by Ayala Carcedo et al. (1986) between different geotechnical properties and swelling pressure covers all the available data for Spain (110 samples), not only CCVF as shown on Fig.4. Anyhow, it seems that this chart has not been used for foundation design and swelling pressure estimation by the industry.

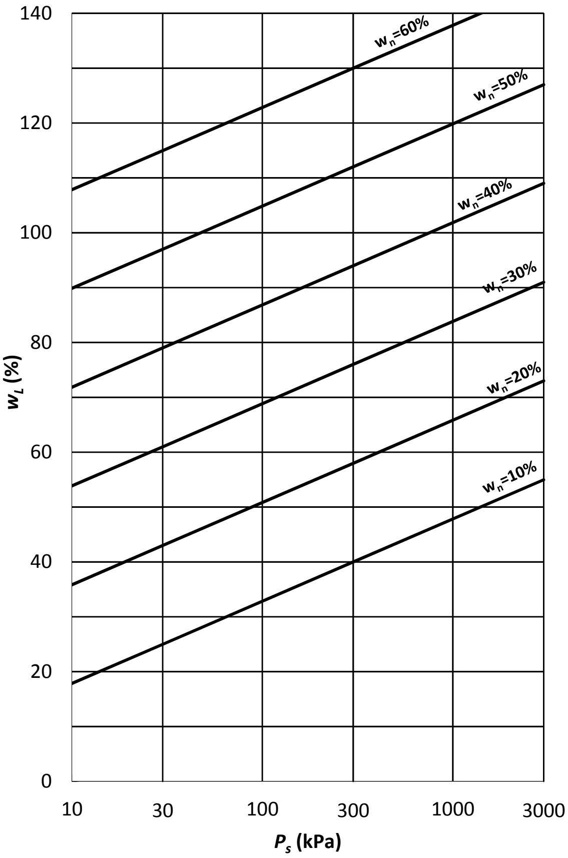

Figure 4 – Liquid limit $w_L$versus swelling pressure P_s and natural moisture w_n for Spanish soils (90% of confidence level for the interval $\pm$5% of the shown moisture content) (modified from Ayala Carcedo et al., 1986)

Oteo (1986) (also included in Ayala Carcedo et al., 1986) is another relationship not explicitely related to swelling pressure but widely used by the industry, especially when specific laboratory tests for swelling characterisation were not so usual. Four dominions of expansivity are defined for the Spanish soils on this chart (Fig.5): I "null to high"; II "low to medium"; III "medium to high" and IV "high to very high".

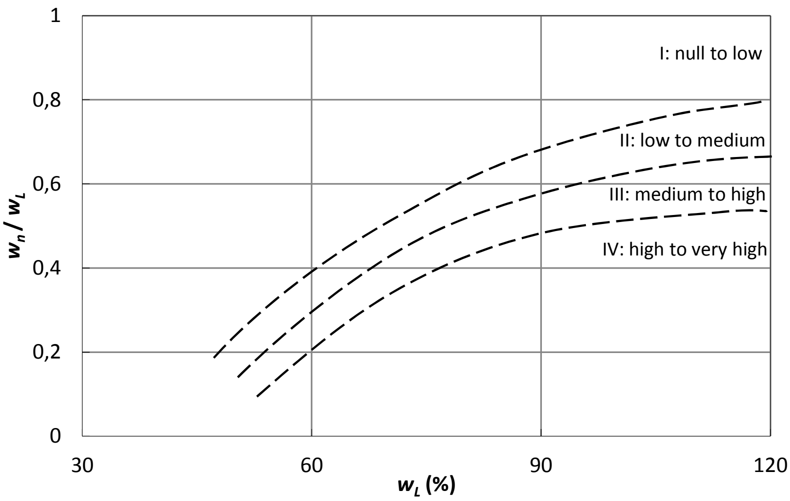

Figure 5 – Ratio ${}^{w_n}/_{w_L}$ versus liquid limit w_L and associated four dominions of expansivity: I null to high; II low to medium; III medium to high and IV high to very high (modified from Oteo, 1986)

Torrijo et al. (2004) provided results of 18 undisturbed samples taken in the CCVF with fines content higher or equal than 75% and liquid limit higher or equal to 50. The value n=36 that appears in the article seems to be the total number of results available, but not the analysed results complying with both previous conditions. Mineralogical analysis indicates the presence of clays of the Smectite group. A chart with a relationship between plastic limit, natural moisture and swelling pressure is given on Fig.6. Three dominions for the estimated swelling pressure are defined: P_s<50 kPa; 50 kPa<P_s<100 kPa and P_s>100 kPa.

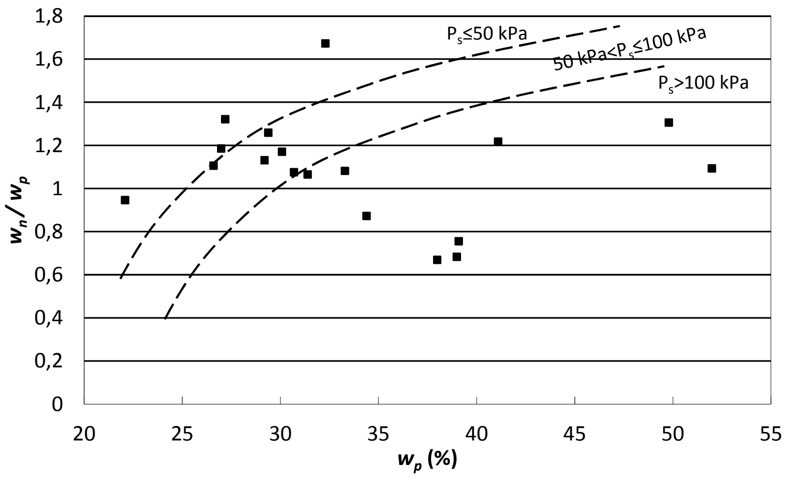

Figure 6 – Relationship between ratio $^{w_n}/_{w_p}$, plastic limit w_p and swelling pressure P_s (modified from Torrijo et al., 2004)

3 - METHODOLOGY

Present work shows the preliminary results of unpublished data of a set of undisturbed samples taken from boreholes and test pits mostly during site investigations for building construction (public, commercial and residential) in the CCVF. All laboratory testing was performed with usual Spanish commercial standards between the 90's up to 2005: first the NLT, generated by the Central Laboratory of Transport of the Ministry of Public Works and later the UNE, produced by the Spanish Standarisation Association (AENOR).

In particular Particle Size Distribution by sieving (UNE 103101:1995 or NLT 104/72; equivalent to ASTM D422); Atterberg Plastic limit (UNE 103104:1993 or NLT 106/91; equivalent to ASTM D4318); Atterberg Liquid limit using Casagrande spoon (UNE 103103:1994 or NLT 105/91; equivalent to ASTM D4318), Natural moisture content (UNE 103300:1993 or NLT 102/91; equivalent to ASTM D2216) and Swelling Pressure in Oedometer (UNE 103602:1996) were considered.

The procedure for obtaining the swelling pressure in oedometer as per UNE 103602:1996 is equivalent to Method C of the ASTM D4546–90 at constant volume of the sample. The sample after being saturated is forced to keep the same initial volume prior to saturation with lateral confinement. In order to avoid the volume change, the vertical stress applied by the oedometer to the sample is increased with time in small increments until the sample reaches a steady state where the final vertical stress applied by the oedometer equilibrates the pressure mobilised by the sample at no vertical displacement of the sample (initial height of the sample $\pm$0,01 mm).

4 - GEOTECHNICAL CHARACTERISATION

4.1 - Statistical summary

The same constraints as Torrijo et al. (2004) for the selection of the samples have been considered: $w_L \geq$50 and Fines content ≥75%. A summary of the statistical parameters of the properties of these materials are shown on Table 1 for this study dataset:

Table 1- Geotechnical properties of the CCVF cohesive soils (n= 43)

Geotechnical Parameter	Min. Value	Max. Value	Average	Standard deviation
Fines content < 0,08 mm (%)	75,0	99,0	85,1	7,9
Liquid limit w_L (%)	49,5	145,5	67,4	17,5
Plastic limit w_p (%)	14,1	55,5	32,9	8,8
Natural moisture content w_n (%)	12,8	54,2	31,6	10,0
Dry density (Mg/m^3)	1,02	1,94	1,49	0,23
Swelling pressure P_s (kPa)	9,8	348,3	75,0	80,7

Values of the index parameters are in general on the same rank as Torrijo et al. (2004) samples. It is important to note that present data show maximum value of P_s much higher than Torrijo et al. (2004) (about 147 kPa) but average is quite close (about 60 kPa).

Histograms of the liquid limit, plastic limit, moisture content and swelling pressure are provided on Fig.7, Fig.8, Fig.9 and Fig.10 respectively. In all the cases the distribution seems to be non-symmetrical but it is a consequence of the decision of considering $w_L \geq 50$ at least for w_L, w_n and w_p. For P_s the distribution is clearly non-symmetrical; if all the samples would have been considereded then additional smaller values of P_s would be expected and the skew would be increased even more.

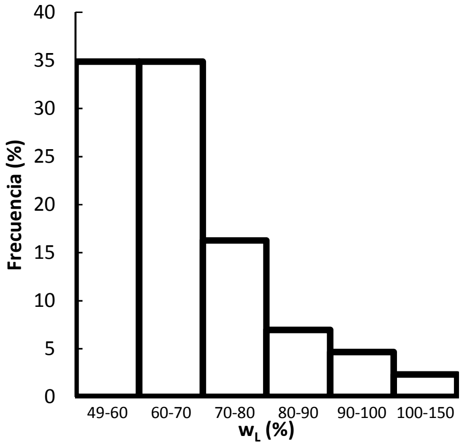

Figure 7 – Histogram for the liquid limit w_L

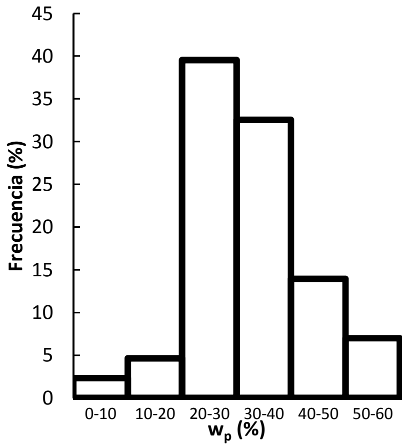

Figure 8 – Histogram for the plastic limit w_p

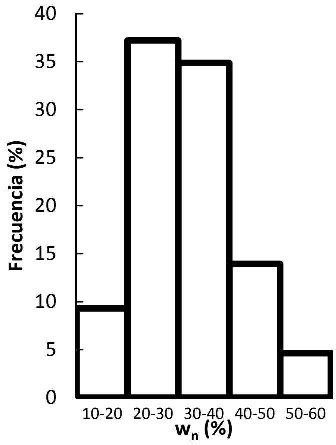

Figure 9 – Histogram for the natural moisture content w_n

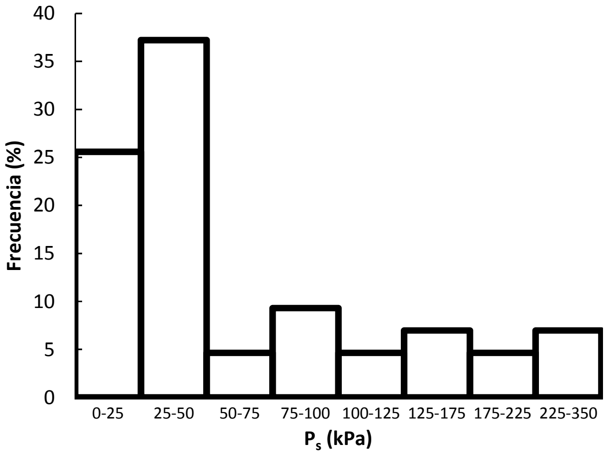

Figure 10 – Histogram for the swelling pressure P_s

4.2 - Casagrande Chart

If graphed on the Casagrande Chart (Fig.11) both data sets are distributed along the Line A in a very similar way, but with slightly higher scatter for present work results. Note that according to Holtz and Kovacs (1981) most of the clay minerals on the samples would be Illites (above Line A) and Kaolinites (just below Line A). Only a couple of samples are located so close to Line U that they can be considered Montmorillonites. The assertion of Torrijo et al. (2004) regarding the prevalence of the Smectite clays minerals over kaolinites and illites does not match, apparently, with Line U relative location. If Smectites are present in samples, minimal Montmorillonite would be mixed with less active Smectite and other clay minerals.

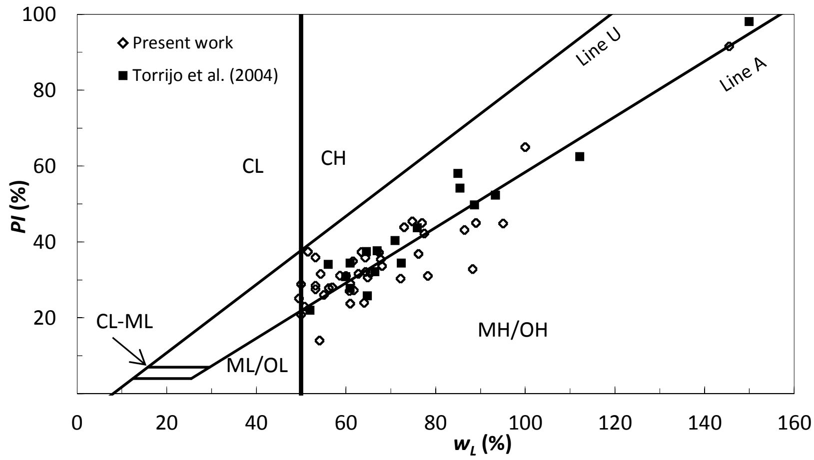

Figure 11 – Casagrande Chart showing Torrijo et al. (2004) and present work datasets. PI is the plasticity Index

5 - RELATIONSHIP BETWEEN SWELLING AND INDEX PROPERTIES FOR CAMPO DE CALATRAVA VOLCANIC FIELD SOILS

5.1 - Estimation of the swelling pressure by means of liquid limit and natural moisture content (Ayala Carcedo et al., 1986)

On Fig.12, liquid limit versus swelling pressure are represented with samples segregated by natural moisture content considering the correlation provided by Ayala Carcedo et al. (1986) for Spanish soils.

Any marker located above the corresponding straight line with its moisture content provides an estimation of the swelling pressure on the safe side (expected value higher than the value obtained from laboratory tests). This is the case of all the samples of the CCVF with $w_n \leq$20%.

On the contrary, markers located below their corresponding straight line provide an estimation of the sweeling pressure smaller than the swelling pressure mobilised on laboratory test. This happens with the sets 20%<$w_n \leq$30% and 30%<$w_n \leq$40%; where markers below the straight lines for 30% and 40%, respectively can be found.

Thus, Ayala Carcedo et al. (1986) criterion for estimation of the swelling pressure for the present work data seems to be useful only for $w_n \leq 20\%$.

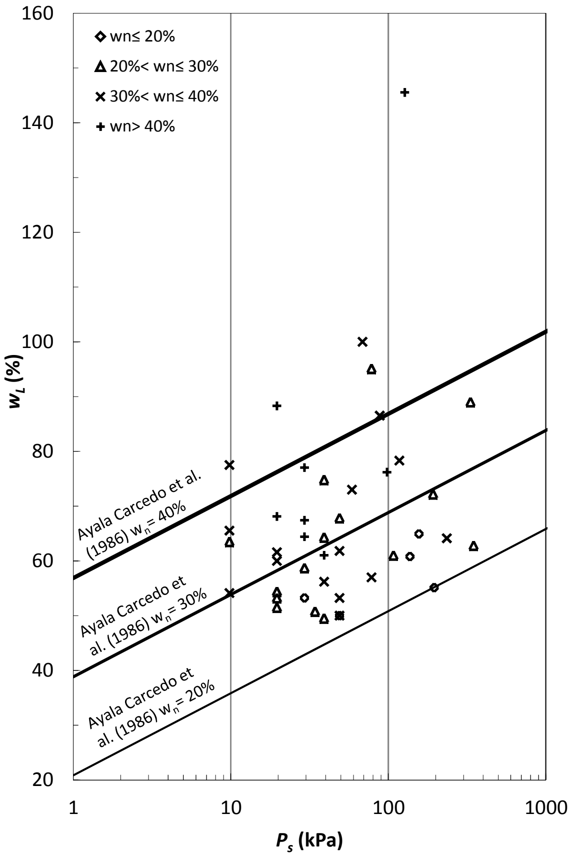

Figure 12 – Liquid limit w_L vs. swelling pressure P_s with samples segregated by natural moisture content w_n including Ayala Carcedo et al. (1986) criterion for Spanish swelling soils

5.2 - Estimation of potential expansivity by means of liquid limit and natural moisture content (Oteo, 1986)

Ratio $^{w_n}/_{w_L}$ versus liquid limit w_L with samples segregated by swelling pressures have been graphed on Fig.13, including Oteo (1986) four potential expansivity dominions, ranging from I "null to low" to IV "high to very high". As can be seen for the present dataset, two values with P_s>125 kPa and twelve values inside the range 25 kPa<P_s≤125 kPa appear on zone I: expansivity null to low (P_s<25kPa as per Ayala Carcedo et al., 1986). In addition, one value with P_s>300 kPa is located in the dominion III: medium to high where P_s<300 kPa are expected

Thus, Oteo (1986) criteria for estimation of the potential expansivity for the present work data seems, if applicable, only useful for dominions II and IV.

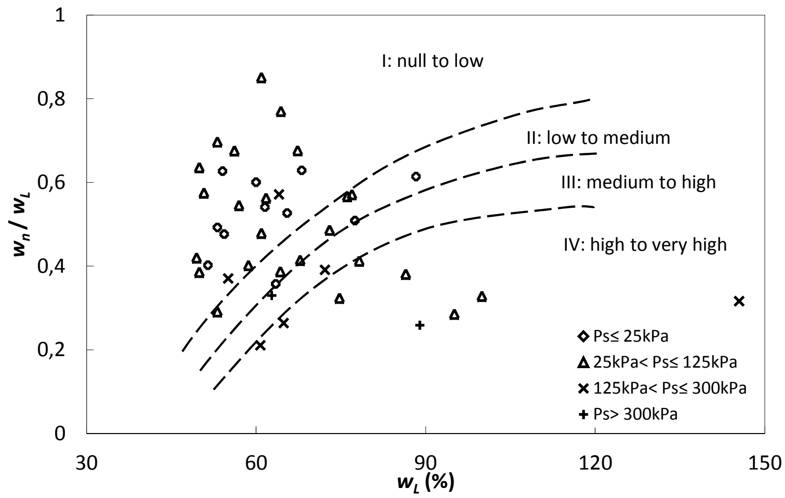

Figure 13 – Ratio $^{w_n}/_{w_L}$ versus liquid limit w_L with samples segregated by swelling pressures P_s, including Oteo (1986) four expansivity dominions

5.3 - Estimation of potential expansivity by means of plastic limit and natural moisture content (Torrijo et al., 2004)

Ratio $^{w_n}/_{w_p}$ versus plastic limit w_p with samples segregated by swelling pressures, have been graphed on Fig.14, including the two boundaries established by Torrijo et al. (2004) for P_s especifically for CCVF soils.

As can be seen, the present dataset agree with the boundaries of Torrijo et al. (2004) being possible to perform estimations on the safe side of the swelling pressure for CCVF soils with Torrijo et al. (2004) chart.

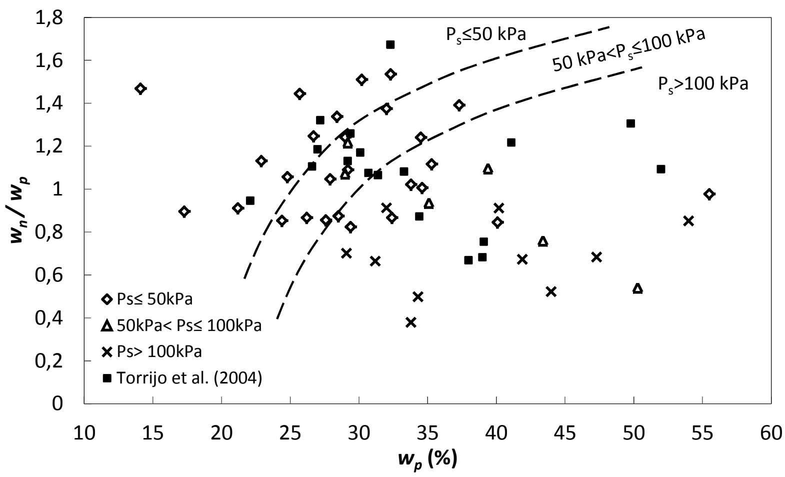

Figure 14 – Relationship between plastic limit w_p, natural moisture w_n and swelling pressure P_s for present work. Samples segregated by P_s. Torrijo et al. (2004) dataset and their three dominions for P_s are also graphed

6 - CONCLUSIONS

The Campo de Calatrava Volcanic Field (from now CCVF) is an inner Iberic peninsula volcanic zone inside the province of Ciudad Real (Spain) that suffered monogenetic volcanic episodes with very different eruption tipologies not only on the Iberian Massif but on the continental basins. As a result, volcanoclastic materials appear interbedded with sedimentary deposits.

These volcanic materials if weathered may contain clay minerals able to experience important volume change even when they suffer small variations on the moisture content. These swelling soils imply a geotechnical hazard for construction and the best characterization for shallow foundations is via specific laboratory tests like swelling pressure at constant volume.

Present work provides a new dataset of index geotechnical properties and swelling pressure at constant volume obtained from undisturbed samples taken on the CCVF through standard commercial laboratory testing with minimum liquid limit w_L of 50% and minimum fines content of 75%.

Ayala Carcedo et al. (1986) provided a chart with natural moisture content and liquid limit for the estimation of swelling pressure covering all over Spain, not only CCVF but very focused on data from Madrid area and Andalucía. Present work data suggests that this correlation is only on the safe side for the estimation of the swelling pressure when natural moisture content of samples is lower or equal than 20%.

Oteo (1986) shows another relationship for swelling soils from Spain but in this case widely used by the industry, especially in order to discard the expansivity of a soil based just on index testing with no additional specific laboratory tests for swelling characterisation. Ayala Carcedo et al. (1986) comment that Oteo (1986) correlation "shall be used carefully because it has not been contrasted sufficiently". Present work data suggests that, at least for discarding existence of swelling soils for CCVF, Oteo (1986) relationship is not on the safe side.

Torrijo et al. (2004) provided results of undisturbed samples taken in the CCVF with fines content higher or equal than 75% and liquid limit w_L higher or equal to 50. A chart with a relationship between plastic limit, natural moisture and swelling pressure was given including three dominions for the estimation of the swelling pressure. Present work data fit to the three dominions thus it seems that Torrijo et al. (2004) is appropriate for estimate swelling pressures of cohesive soils of the CCVF using index properties.

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