Evaluation of pozzolanic activity of Pampean loess

Estimation de l'activite pouzzolanique de loess pampéenne

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ABSTRACT: Loessic sediments deposited in the Argentine plains are composed by silty particles, transported and accumulated by wind during Quaternary. At that period important aeolian process took place together with explosive volcanic activity in the western area of the country. The chemical and mineralogical composition of loessic sediments and also their pozzolanic behaviour depend upon the predominance of each geological process. Several attempts have been made to go deeper in the understanding of the geotechnical behaviour of the pozzolanic fraction. Methodologies based on mineralogical determinations, chemical tests and mechanical tests has been developed but all of them presents important problems. The present paper describes a method based in the measurement of conductivity of a calcium hydroxide saturated solution, to which increasing amounts of loess is added. Results are constrasted with the pozzolanic index determined by traditional methods in loess – cement mixtures and the characteristic of granulometry, plasticity, chemical and mineralogical composition of the loessic sediment.

RÉSUMÉ: Des dépôts de loess déposés dans les plaines de l'Argentine sont transportés et accumulés par le vent pendant le quaternaire. À cette période le processus éolien important a eu lieu ainsi que l'activité volcanique explosive dans la zone occidentale du pays. La composition chimique et minéralogique des dépôts loessic et également leur comportement pouzzolanique dépendent de la prédominance de chaque processus géologique. Plusieurs tentatives ont été faites d'aller plus profondes dans la compréhension du comportement géotechnique de la fraction pouzzolanique. Des méthodologies basées sur des déterminations minéralogiques, des essais chimiques et des essais mécaniques a été développées mais tous présentent des problèmes importants. L'article actuel décrit une méthode basée dans la mesure de la conductivité d'une solution saturée par hydroxyde de calcium, à laquelle l'augmentation des quantités de loess est ajoutée. Les résultats sont constrasted avec l'incrément pouzzolanique déterminé par les methhods traditionnels et par la caractéristique de la composition granulometrique, de plasticité, chimique et minéralogique du dépôt loessic.

1. INTRODUCTION

The pampean loess around the city of Cordoba are made up of two completely different types of minerals. This mineralogy derives from the alternate predominance of the aeolian processes over the volcanic ones and vice versa occurred during the end of the Tertiary and Quaternary in the regions producing silty particles (mainly the Andes Range and the regions of steppe in the south of the country). Such processes have been summarized by Iriondo et al (1995) in the following way:

- Falls of volcanic ashes corresponding to the explosive Andean volcanism from the end of the Tertiary and Quaternary. The volcanic activity in these periods was intense and a huge amount of volcanic ashes and piroclastic materials were thrown to the atmosphere. The regions of origin of these materials has been located in the Andes Range, where the main centers of volcanic eruption are situated and from where the rising winds - circulating permanently from west to east- carry these particles to the eastern plains, and deposit them on the grassy steppes.
- Aeolian processes carrying silty materials from the Patagonic and Andean regions, and from Pampean Mountains.

The volcanic ashes can combine naturally with water enriched with calcium and magnesium oxides, which leak through the loessic sediments producing a pozzolanic reaction. Pozzolans has been defined by Massaza (1974) as "those natural or artificial materials, reach silica and alumina, capable of reacting with lime in the presence of water and form through this reaction cementing compounds".

The pozzolanic reaction has a relevant influence on the geotechnical properties of loess and has been considered by some researchers as one of the causes of the presence of layers of hardened materials called "*toscas*" in the stratigraphic pampean columns.

In a different way, the materials coming from aeolian processes over crystalline rocks are made of quartz, feldspar, mica and other chemically inert minerals, only carrying the granular structure of the sediment.

The volcanic ashes as well as the rest of the particles forming the loess present are very small therefore, its differential behavior cannot be anticipated without special chemical and mineralogical tests.

2. GEOLOGICAL BACKGROUND

The main geological studies about the volcanic ashes in the Argentine loess have a scientific approach oriented only to the determination of mineral or chemical compositions.

Döering (1891) identified two main types of ashes:

- α volcanic ash, composed by acid silicates, generally of traquitic or andesitic nature with a low iron content.
- β volcanic ash composed by basic silicates, generally of basaltic nature.

Both types of ashes are spread inside the loess mass with variable percentages, from a very low level to pure cineritic layers.

Tricart (1969) defined the loessic sediments as eolocinerites.

Ricci (1966) performed mineralogical tests on the loess from the central region of the province of Cordoba and he found a fifty percent of volcanic glass in the fraction below 0,50 mm, and considerably higher percentage in the fraction below 0,045 mm.

Sanchez (1948) determined percentages of soluble silica between 35% to 54% and calcium oxides between 18% to 30%, in his study about loessic sediments in the south of the province of Cordoba.

According to last datation, most of the loessic sediments were deposited in the last 2,5 millions years (Orgeira, 1987), and they reached a volume of 34.000 to 45.000 km^3.

Following the scheme developed by Iriondo (Iriondo y Kröhling, 1995) the authentic loessic sediments corresponds to the Pampean Aeolian System, constituted by a Pampean Sea of Sand in the central region and a Periferic Loessic Belt reaching its typical level of development 18.000 years ago. The contact border between both has an extension of 1.800 km and an average width of 250 to 300 km. Its typical thickness is from 7 to 10 meters.

Kröhling (1993) identifies two mineral groups, with a predominance of the materials of crystalline basement from the pampean mountains, over the volcanic and piroclastic materials. To complete this outlook of the mineralogy of loess, several tests performed by differents authors and in the varied regions are presented.

Table 1. Mineralogy of the pampean loess.

Author	Region	Quartz %	Feldspar %	Volcanic Glass %
Strasser (1995)	San Luis	14	62	10
Strasser (1995)	San Luis	27	46	7
Kröling (1993)	Córdoba	27	41	20
Kröling (1993)	Córdoba	18	20	11
Bidart (1992)	Maggiolo	20	33	31
Bidart (1992)	Rufino	33	24	18
Bidart (1992)	Rufino	29	28	22
Kröling (1993)	Córdoba	15	6	76

Karlsson (1993) performed studies on the fraction of 100 to 60 microns, from samples of loessic and loessoid sediments of two geographic regions: pedemonts and pampean plains. In the first cases the volcanic glass represents a 4% of the total. In the samples corresponding to the pampean plains, an average value of 17 % is observed for the volcanic glass, with a maximum of 38 % and a minimum of 14 %.

Quintana et al (2000) obtained values between 10% and 50% of volcanic glass in loessic sediments in the surroundings of the city of Cordoba, for the fraction below 74 microns.

3. MATERIALS

The systematic sampling of several sedimentary columns, considered typical of the pampean formation, was performed. Samples every 50 cm were extracted, and according to the stratigraphic analysis and the results of the identification tests, diverse layers of loess were delimited:

- Loess Córdoba, upper member (Cordobense): 2,50 meters thick, primary light yellowish loess.
- Loess Córdoba, sandy intermediate member: 1,0 meter thick.
- Loess Córdoba, cemented intermediate member: 4,5 meters thick, with layers of volcanic ashes inserted.
- Loess Córdoba, lower member: reddish loess, 3,0 meters thick.

Different types of volcanic materials were used as parameters for comparison: volcanic ash type α from Santa Elena (Northern border of the Pampean Plain), volcanic ash type β, greenish, mixed with loess in different proportions from Jose de la Quintana (to the west of the Pampean Plain), piroclastic materials of recognized pozzolanic activity from the south of Lanzarote island, Canary islands, Spain.

4. LABORATORY TESTS.

Before the specific tests, identification ones traditionally used to classify these materials were performed:

4.1 Granulometry

Upper and lower members of the loess Cordoba show the characteristic percentages of sand, silt and clay of the sediments transported by the wind in Central Pampean Region, with a predominance of the silt fraction whose values are between 56% and 68%.

The intermediate member is characterized for being sandy in its upper part and clayed in the lower one, however, the values of the silt fraction are important. Finally, the volcanic ashes analyzed are mainly sandy - silty, with no clay fraction. The average values can be observed in Table 2.

Table 2. Average values of the granolumetric fractions.

Materials	% Sand > 50μ	% Silt 50 – 5μ	% Clay < 5μ
Upper Member	31	62	7
Intermed. sandy Member	57	36	6
Intermed. cemented Member	35	48	17
Lower Member	30	62	8
Volcanic ash – Type α	53	46	1
Volcanic ash – Type β	56	44	0

4.2 Atterberg Limits and Unified Classification.

The loessic sediments keep their characteristics of plasticity according to the normal values for these materials (LL average = 26%, IP average = 4%), belonging to the ML group, in accordance with the Unified Classification of Soils.

The volcanic ashes present very low percentages of alteration, so the subproducts of clayed type have a minimum influence and there is no plasticity values in these materials.

4.3. Determination of pozzolanic activity.

According to the definition of pozzolane, the laboratory tests must be of two categories.

The first category of test is based mainly on chemical determinations which permit to identify inside the sediment the presence of materials which shows potential aptitude to react with lime. This material must satisfy three conditions (Largent, R, 1978):

1. To be acid, which means to contain a high proportion of silica and alumina.
2. To contain an important proportion of glassy or slightly crystallized fraction.
3. To present a big specific surface.

4.4. Chemical analysis.

The percentages of silica and alumina were determined in the samples of loess and ashes through Fluorescence X ray tests. Ashes of type α presents the highest values, ashes of type β and loess presents a great similitude in the results, as it is shown in Table 3. The percentages are always higher than 75% average, which satisfies widely the first condition.

The high proportion of silica and alumina is produce by the glassy components as well as the crystalline ones (quartz, feldspar and silicates in general).

The glassy or slightly crystallized fraction is the most important for the pozzolanic reaction. The crystalline silica can be considered inert in spite of the recent determinations of Benezet et al (2000), performed on quartz industrials dusts, where an incipient reaction in finely pulverized quartz particles, with specific surfaces of 10.000 cm2/gr, is appreciated.

Table 3. Average percentages of silica and alumina. Total samples: 20

Materials	Chemical analysis.		
	% SiO_2	% Al_2O_3	% $SiO_2 + Al_2O_3$
Upper Member	62.43	13.88	76.31
Intermed. sandy Member	63.05	13.85	76.90
Intermed. cemented Member	62.20	13.19	75.39
Lower Member	61.68	13.48	75.16
Volcanic ash – Type α	67.82	12.30	80.12
Volcanic ash – Type β	63.48	13.19	76.67

4.5. Mineralogical Analysis.

Mineralogical analysis were performed to determine the proportion of the glassy and slightly crystallized fractions. The determination of the mineralogy of the samples was carried out to the clayed silt granulometry, used a polarization microscope.

The results of the loess column confirm the presence of the glassy fraction made of acid volcanic glass main, with a low refraction index, in variable percentages (7% a 54%).

The Upper Member of the Loess Cordoba presents amounts of volcanic glass ranging from 14% to 28% and a low percentage of alteration with the presence of sericite and kaolinite at 2,8% maximum.

In the Intermediate sandy Member, the percentages of glass are low, ranging between 8% and 13%, with an important alteration degree in feldspars (up to 34% of sericite plus kaolinite).

The Intermediate cemented Member presents the highest values of glass (49% to 54%), which together with the scarcity of carbonates, confirms the pozzolanic reaction as the cause of cementation.

Finally, in the Lower Member variable values of volcanic glass are observed (7% to 37%).

The samples corresponding to the volcanic ashes type α presented high percentage of volcanic glass (76%). Volcanic ashes type β present even values, between 26% and 31% of glass. The alteration of potassic and calcium-sodium feldspars - shown in the presence of kaolin and sericite- is scarce: 5% to 13%, as well as its contribution to the pozzolanic fraction.

4.6. Determination of Blaine Specific Surface (IRAM 1623).

Blaine's permeabilimeter is normally used to determine the specific surface of hydraulic binders.
Table 4 shows the values for the whole sequence of materials studied in their natural state and after pulverization performed to comply with the requisites of IRAM 1668.

The IRAM 1668 establishing the condition for the industrial use of puzzolanes in the Argentine Republic, sets a minimum of 3.000 cm2/gr of specific surface according to IRAM 1623.

4.7. Determination of pozzolanic activity with lime.

According to the Massaza's definition, the pozzolanic material must be capable of reacting with lime in the presence of water. To study such condition, a methodology proposed by Luxon et al (1989), was used in the whole series of sediments analyzed. This method consists in determining the decrease in conductivity (measured in miliSiemens/cm) occurring in a saturated solution of calcium hydroxide, when a certain amount of puzzolane is added keeping it under constant stirring during the measure time. The test can be performed in a very short period (2 minutes) in which the adsorption phenomena is predominant and with a very small quantity of materials (5 g).

An indirect measure of the pozzolanic activity is obtained and the materials can be classified according to it in the following way:

Table 4. Blaine's specific surfaces

Materials	Natural	Pulverized
	BSS	BSS
Upper Member	1707	3688
Intermediate sandy Member	1495	3825
Intermediate cemented Member	2851	4353
Lower Member	2091	3741
Volcanic ash – Type α	1569	3792
Volcanic ash – Type β	2367	4549

- Without pozzolanic activity: < 0,4 mS/cm
- Variable pozzolanic activity: between 0,4 and 1,2 mS/cm
- Good pozzolanic activity > 1,2 mS/cm.

The results obtained in the loessic sediments are shown in Table 5.

Table 5. Average values of pozzolanic activity index in loess.

Materials	IAP
Loess Córdoba – Upper Member	0.78
Loess Córdoba - Intermediate sandy Member	0.87
Loess Córdoba - Intermediate cemented Member	0.81
Loess Córdoba - Lower Member	0.97

As it can be appreciated, there is a variable average pozzolanic activity for each layer, in accordance to the geologic characteristics of such materials. Maximum values of 1,19 and 1,20 mS/cm have been obtained in thin intercalated layers of ashes. The pozzolanic activity of the piroclastic material from Canary Islands -representatives of a very recent volcanic activity- presented a value of 1,53 mS/cm, confirming the behavior of these kind of volcanic products.

4.8. Determination of pozzolanic activity with portland cement.

This test belongs to the second category and it is based on the last part of the definition of puzzolanes, which is the capacity of the pozzolanic materials to form products with cementing properties. It is regulated in Argentina by the norm IRAM 1654 and it consists in the measure of the resistance to the compression of cylindrical samples of a mixture of siliceous sand and cement plus a determined percentage of pozzolanic material. The index of pozzolanicity (IP) is determined in relation to the resistance at 28 days of reference sample mixture (siliceous sand and cement) with the mixtures having pozzolanic materials. If the pozzolanicity index is superior to 75%, the materials are considered pozzolanic according to the norm.

Table 6. Pozzolanic activity index with portland cement.

Materials	IP
Loess Córdoba – Upper Member	73.1
Loess Córdoba - Intermediate sandy Member	67.2
Loess Córdoba - Intermediate cemented Member	72.0
Loess Córdoba - Lower Member	70.4
Volcanic ash – Type α	90.6
Volcanic ash – Type β	73.8

As it can be observed in Table 6 there is a good correlation in the results with those obtained through the previous method, placing these loessic materials near the inferior limit required by the current norms.

5. CONCLUSIONS.

It has been demonstrated through this research that the loessic sediments corresponding to the Pampean Formation of the Central Region of the Argentine Republic have chemical and mineralogical characteristics which give them a variable pozzolanic activity.

From the chemical point of view, it has been proved the existence of an important quantity of silica and alumina, distinguishing the glassy fraction through the mineralogical analysis.

The reaction with lime was tested trough and indirect technique based on the measure of the electric conductivity. Together with the assessment of the pozzolanic activity with Portland cement performed with the traditional methods variable values were obtained, but these situate these materials as pozzolanic.

In this way all the aspects related to the pozzolanic activity of materials have been evaluated. The results obtained permit to starts a next stage in the research, consisting in the measure of the influence of this activity over the geotechnical properties of the loessic sediments.

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