The economical plastic soil: Cement foundations – PSC

Fondations économiques de sol: Ciment plastique – PSC

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ABSTRACT: Plastic Soil. Cement PSC foundations consists basically on the re-use of the soil that was withdrawn from the hole after it has been mixed with cement and water. The main paramenters that validate the aplication of the PSC on foundations of low capacity were analyzed: Compressive Strength, Deformability, Retraction, Durability and Costs. Laboratory tests were performed upon samples of different types of soils. Samples taken from the prototypes (real PSC foundations) and field load tests were performed. All the results showed that this new material can be employed in foundations, with a very simple execution methodology and with a significant reduction on its costs.

RESUMÉ: Les fondations en Sol. Ciment Plastique sont surtout basées dans la réutilisation du sol provenant du même trau de la fondation, lequel est, ensuite, mélangé avec du ciment et de l'eau. Les paramétres les plus importants, pour l'application convenable du sol. ciment plastique en fondations de faible capacité portante, ont été analysés: résistances à la compression, à la deformation et à la contraction, durabilitté et coût. Plusieurs échantillons, provenant de differents types de sol, ont été essayés en laboratiore. Des échanttions ont été prélevés aussi sur des protoypes (fondations réelles en SCP) et des essais de charge sur chantier ont élé faits. Tous les résultats ont montré que ce nouveau matériau peut être utilisé en fondations, avec une méthodologie d'execution tres simples et une significative reduction du coût.

1. INTRODUCTION

Thousands of concrete foundations for small buildings (up to 10 tons) have been used in very anti-economical ways.

Considering the great range of the application of low capacity foundations in habitational programs of low-cost housing, the author has been doing research since 1976 on the possibility of substituting the concrete for a less expensive material, and one that allows the use of a less sophisticated process for its fabrication.

The Plastic Soil. Cement, PSC, has showed good technical and economical characteristics, when used in foundations that are not under a stress greater than to 1,5 Mpa in its shafts.

The foundations in PSC here analyzed consist simply in returning to the foundation's hole the soil that has been excavated earlier, mixed wilh cement, generally in the proportion of 1:8 cement/soil, in the consistency of plaster mortar, without any vibration or compaction.

That fact occurs frequently in residences and small building due to executive procedures, one can't (and it's not convenient) dig shafts with a diameter of less than 30 cm, even when concretes with strength of 8 to 12Mpa are used, allowed by standards, although needing only 1,5Mpa to reach 10 ton.

The compressive strength, the deformability , the retraction, the cost, the long term strength and the durability of the PSC, vital parameters to guarantee the success of this new material, have been studied by many Authors, Berberian (1976, 1983), Andrade (1989), Cortopassi (1989), Mundin (1990), Ferreira et al (1992), Geraldo F. et al (1992), Segantini (1994), Silva (1994), Berberian et al (1996), whose results already allow the application of the PSC in the Engineering works.

These results obtained with samples of sandy and clayel soils, both in laboratoryes, prototypes samples and load tests, allowed the author to make more than 800 Mini.Bored Piles in Plastic Soil. Cement.

2. HISTORICAL

Men have been using soil as a construction material since the beginning of civilization. Many of Men's constructions have challenged centuries upon reaching the contemporany days.

The date when cement.soil was first used for constructions pouposes is very inaccurate. It's believed that the China walls are the oldest use of cement, built sometime in the third century.

In America, Peru, Mexico and the southwest of the United States, the use of soil as a construction material was increased due to the more favorable climate (hot and dry), (CEPEP,1984).

According to Freire (1976), the use of soil improved with cement began in the United States in 1916, when it was used to repair roadways used by vehicles that still had wooden wheels and metal rings.

After that the application of compacted soil developed much and is highly used as base for highways.

In 1976, Berberian, re-excavated large bored piles whose groups of shafts had collapsed years before due to intense rainy season, and was rebuilt with the application of plastic soil. cement, verified that it's strength hab been mantained, and there were no signs of retraction, maintaining close contact between PSC and the natural soil and between the PSC and the concrete shaft.

In the case of thase large bored piles the PSC acted as on intermediate for the transfer of a lateral aderence load of 400 tons from the concret piles to itself and from there to the soil.

Since then, due to these observations, the Author and many other researchers have worked in a line of research to make possible the application of Plastic Soil. Cement as a foundation material.

3. APPLICABILITY

Many types of soil and its mixtures are being investigated, from clayel to sandy soils, all in the proportions considered economical (10% in weight, 1: 8 in volume) showed satisfactory strength (1 to 3Mpa), great durability, no retraction and deformability compatible (Young PSC moduli aprox. 300Mpa) with the allowable settlements.

For fine grained soil, with high plasticity index (fat soil), which slows down the construction, because it bounds to the working tools and to the mixer, it is recommended to add up to 20% of sand to gain workability and strength.

Due to the bad influence of organic substances on the strength of the cement, the organic soils have not been studied up to now.

The PSC showed to be useful to many type of foundations:

• Manually and Mechanically auger-bored foundations, for depths up to 10 m, for soils with SPT < 14, above water table, and foundation diameter equal to 30 cm, to carry loads up to 8 tons, see FIG.01 (a) Mini.Bored Pile, same as above with one or more enlarged base FIG. 01(b)

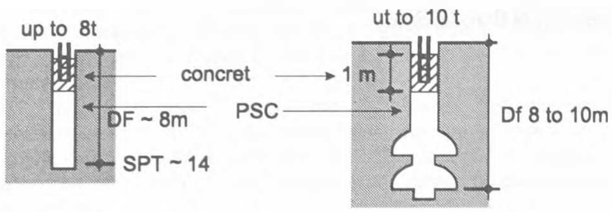

FIG.01. (a) Manually Auger Bored (b) Mini.Bored Pile

- Mechanically Bored Piles for a maximum diameter of 40 cm. An enlargement of its diameter to gain bearing capacity will increase the shafts stress beyond 1,5 to 2 Mpa, making anti-economical the application of PSC
- Large Bored Pile-Piers with shaft diameter of 60 cm or more, used for reinforcement or stabilization of soil, where the stress transmitted is low, showing very economical results, when the PSC is applied.
- Compacted Bored Piles

Segantini and Carvalho (1994) also researched the possibilities of the application of PSC in Compacted Bored Piles and verified that there was no any advantage. There was no additional gain of capacity, or cost nor of shaft or end bearing strength. Additional still required more researchers to reach better conclusions.

- Strauss type Bored Piles

Segantini and Carvalho (1994) started researching strauss piles, but no recommendations have been made up to now.

4. VALIDATION OF PROCEDURES

All possible ways are being used to validate the application of this new material. Samples of PSC were laboratory tested, samples extracted from real (prototype) foundations are tested, field-load tests are were performed, and prototypes of executed foundations were withdrawn to analyze the influence of execution on final dimensions.

Many types of soil were analyzed: S3C, S3C3G, G5SC, C4S, S3M, C5M, C5G, S5C, S5C4M, S5M, C4S4M, C5S4M, C7M and S6C, where the alpha characters, C, M, S and G are soil symbols according to USCS, and the numeric characters refer to the intensity of the secondary soil in the mixture, according to the Berberian soil classification system, were 3 means very little, 4 means little, 5 normal, 6 much, 7 very much, *i e.,* C3S means sand with very little clayel, *etc.*

4.1 *Compressive Strength*

The main parameters that have influence over compressive strength of PSC where studied.

- Grain size of soil particles
- Moist content
- Cement content
- PSC Density
- Cure time
- Shifting from dryness to wetness
- Methods of preparing the samples to test
- Mixing time of PSC
- Slump test
- Addition % of sand in the mixture

Due to the length limitation of this paper, only the more representative results will be presented here (FIG.2,3 and 4). Other interesting results could be obtained with author by request.

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	variable	28	1:07

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Brasflia	12%	variable	15:30

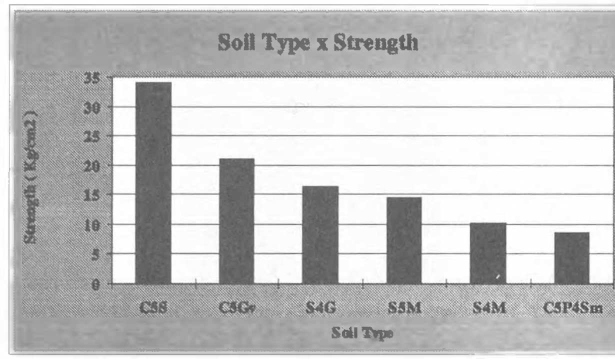

FIG.02. Variation of Strenght with Soil Type 1 Mpa = 10 kg/cm²

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	C5S	28	variable

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Campus UnB	variable	small variation	15:30

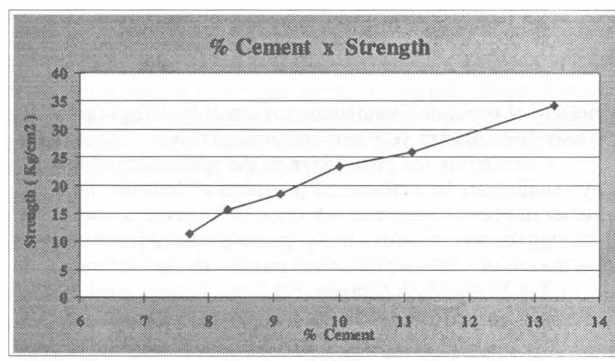

FIG.03. Variation of Strenght with Cement Content

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	C5S	28	variable

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Campus UnB	variable	small variation	15:30

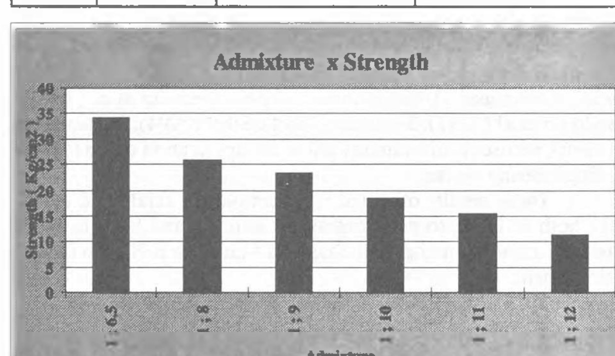

FIG.04. Influence of ratio C:S on Sandy Clay Soil Sthenght

4.2. *PSC Tangent (Young) and secant modulus are analyzed*

All the influence factors studied for compressive strength were analyzed for PSC Modulus. Some results are showed in FIG. 5, 6, 7, 8.

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	C5S	28	1:06

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
UnB	14%	30%	15:30

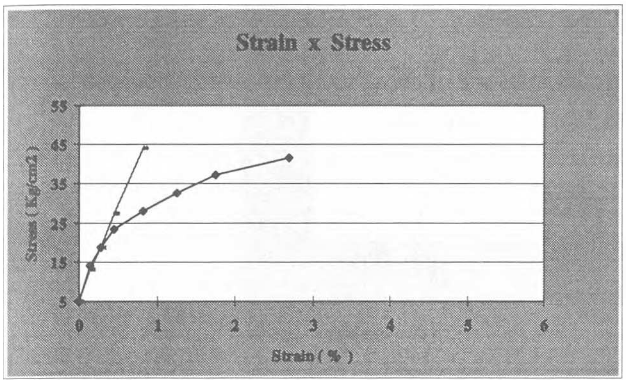

FIG.05. Typical Stress x Strain Curve 1Mpa = 10kg/m²

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	C5S	28	variable

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
DF	12%	variable	variable (5x10, 15x30)

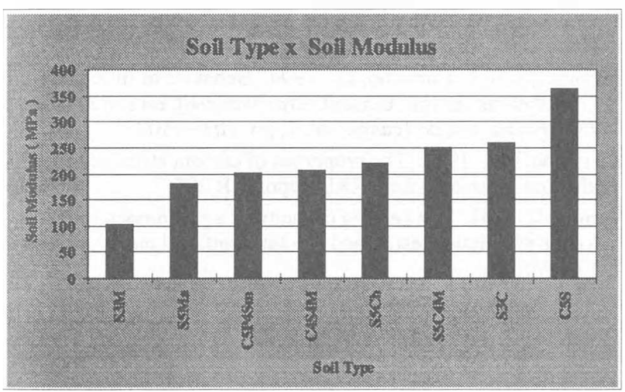

FIG.06. PSC Modulus for Many Studied Soils

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
Cortopassi	Oct-89	S3C	variable	1:09

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Brasília	10%	21.1	5:10

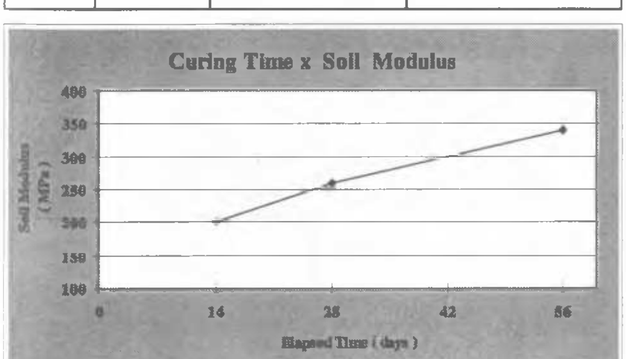

FIG.07. PSC Modulus x Cure Time

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
A.C.D.	Jan-96	C5S	28	1:06

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Campus UnB	variable	small variation	15:30

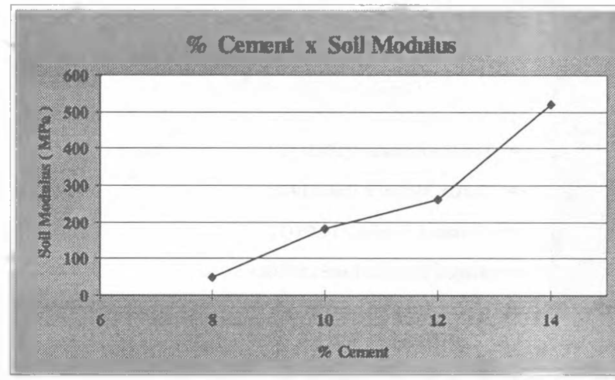

FIG.08. Influence of Cement. Content on PSC Modulus

4.3 *Durability*

Many lab samples were tested for durability, on the long term (aprox. 300 days) constantly alternating from dryness to wetness.

To obtain results on the worst possible hypothesis, the samples with the lowest cement rates were tested, assuming that an increase on the cement rate also increases the strength of the PSC against field aggressiveness.

As an example we show a typical case studied: FIG.9

Many piles have been tested one to two yeas after its execution. None of the tests showed significant loss of strength, and in some cases an increase of strength was reported.

Author	Date	Soil-Type	Curing Time (days)	Admix - C:S (vol)
Dickran, at all	Jan-96	Clayey	variable	1:10

Location	% of cement	Moisture rate (%)	Test Sample Size (cm)
Cidade Jardim	9%	26 liters	15:30

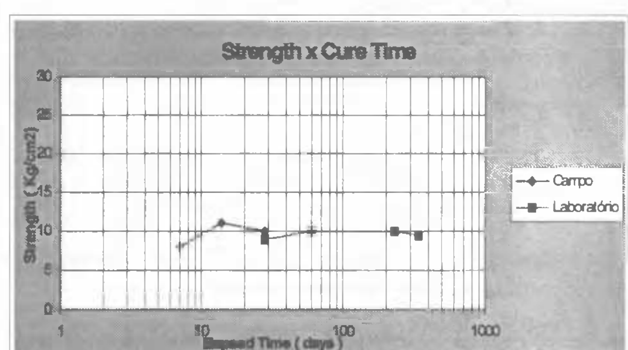

FIG.09. Variation of Compressive Strenght with Time

4.4 *Retraction*

Retraction measurements haver been performed on laboratory samples and on field prototype. Curiously, in both cases the measured retractions were insignificant.

5. FIELD LOAD TEST

Many field load tests were performed, in short piles, long piles with-

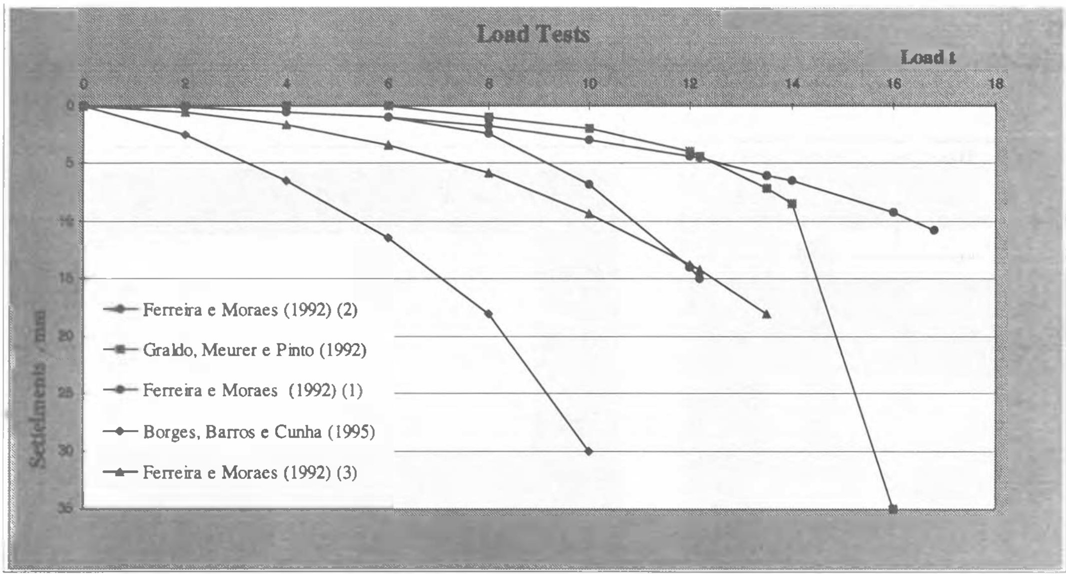

FIG.10. Field Load Tests Performed on Experimental Fields

out enlarged bases, instrumented with tall-tales, etc.

All these load tests were performed on SML (Slow Maintained load) mode. When these tests did not reach the ultimate load, the Van der Veen method was applied to estimate the probable ultimate load.

All the piles showed satisfactory failure load at its full length, and at the recommended proportion of cement (aprox. 10%) , varying from 16 to 40 ton., just more than two times the nominal working load of each foundation type. Some of them tested with low % of cement, showed a lower capacity (10 to 14 ton).

Figure 10 presents a typical load test result, performed over bored piles, with a diameter of 30 cm, performed on typical unsaturated lateritic clay at experimental fields in Brasília, Brazil.

6. CONCLUSION

1. The researches concluded up to this moment show that the compressive strength, the deformability, the durability and the retraction of the plastic soil. cement is adequate for use in foundations of low bearing capacity.

2. The application of PSC in foundations where the shaft stress is low, from 1 to 2 Mpa, proved to be very economical, with results ranging from 15% to 38% economy, with a very simple technology, once that, in the field, all the dosage of the soil. cement can be done on a volume basis.

3. This research program is still on its first step. Several other types of soils are being studied under other conditions and in other types of foundations.

Due to length limitations, only a few of the most representative results of load test were presented in this paper.

REFERENCES

Andrade, F.J. 1984. *Soil reinforcements with applications of soil. cement piers.* M. Sc thesis. EEJP/USP.

Berberian,D. 1976. Plastic Soil. Cement applications to lateral piers load transfer. Infransolo Ltda. Tech. Papers Series.

Berberian,D. 1983. Plastic Soil. Cement applications to foundations of very low costs. Research Report, Infrasolo Ltda.

Berberian,D. 1992. Plastic Soil. Cement executions with top enlargements. UBEC/Catholic University - Brasília.

Borges, P.C.P., Barros, G.S., Cunha, M.A. 1995. *Plastic Soil.Cement Foundations III.* Unb/ Infrasolo Ltda.

Cortopassi, R.S. 1989. *Plastic Soil.Cement foundations of low cost at Federal District.* UnB.

Ferreira, I.F.S., Moraes, L,G 1992. *Plastic Soil. cement foundations I applications to Mini Bored piles* UnB/ Infrasolo LTDA.

Geraldo Filho, A. Meurer, M.S. Pinto, N.R 1992. *Plastic Soil. Cement foundations II.* Geotechnical parameters, Bearing. capacity UnB/ Infrasolo LTDA.

Mundim, L.A.G. 1990. *Behavior studies of plastic soil. cement.* Unb

Segantini, A.A.S., Carvalho, D. 1994. Behavior of little diameter Goundations on Soil. Cement. *Brazilian conf. on soil Mech and Eng. Found. Foz do Iguaçú* Vol. 1, pp: 103 - 110.

Sherwood. P.T. 1968. The properties of cement stabilized materials. *Road Research Lab.* RRL Report LR 205.

Veen, C.V. 1957. The bearing capacity of a pile predetermined by a cone penetration test. Procd. 4th Int. Conf. soil mech and found. Eng. Vol. 2