ROLLER COMPACTED CONCRETE DAMS

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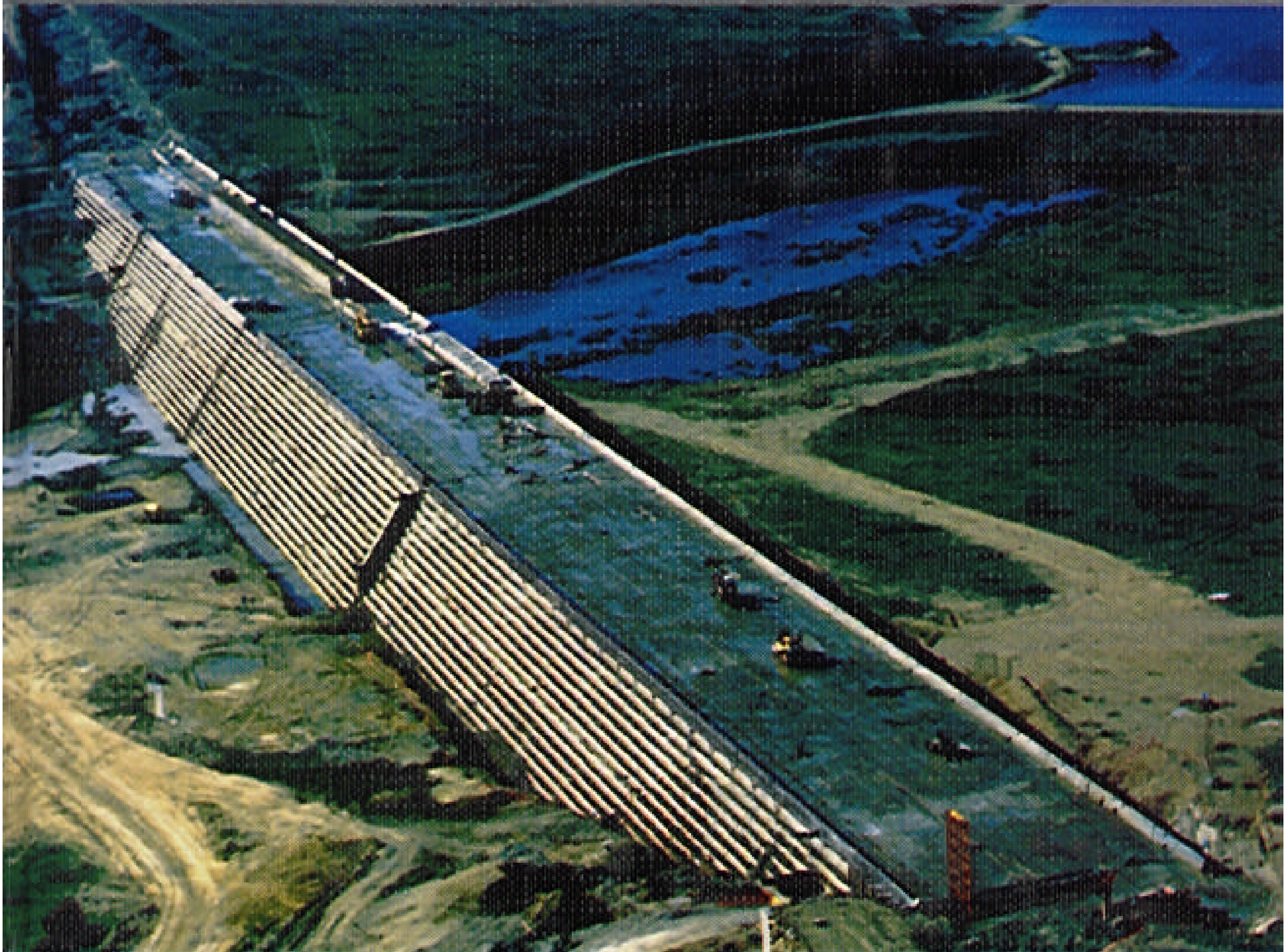
Soils & Cementitious Materials - A Technical Option for Use as a Structural Element for Dams



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Soils & Cementitious Materials - A Technical Option for Use as a Structural Element for Dams

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ABSTRACT

Large countries with few resources or where materials are not readily available must have technical options available for the execution of Dam projects. The purpose of the studies carried out in the Laboratory at Companhia Energética de São Paulo - CESP, on Ilha Solteira, was to make data from a lengthy study of Soil and Cementitious materials mixes available to the technicians, with the intention of using said materials as the structural element of dams. Test data of the normal properties in the Dam Projects are presented, taking into consideration the use of three types of soils, soil with cement, soil with lime and soil with lime and Pozzolanic material mixes. Tests of up to one year have been carried out. At one year, resistances of between 8 MPa to 12 MPa, with a low cement, lime and Pozzolanic material content have been achieved.

1- INTRODUCTION

More than 24 years ago, during the “Asilomar Conference - Rapid Construction of Concrete Dams”, Jerome M. Raphael, with the article “The Optimum Gravity Dam”[1] set the foundations for the use of Roller Compacted Concrete - RCC. In his paper, Prof. Raphael carried out various comparisons between soil embankments, soil with cement and mass concrete. Based on these comparisons he suggested that the **simplicity** of the methods used for production, transportation, placement and compacting of embankments be applied also to concrete dams. Although, large aggregates were already used in concrete for gravity type structures (in concrete), Prof. Raphael’s paper was pioneer in giving the idea for applying RCC methodology.

During the following years, RCC has been preferred in all studies and its application increased rapidly, more so in developed countries than in those lacking the employment of alternative materials and less expensive execution techniques allowing reduction in costs.

The search for stable, durable, and low-cost construction materials has been the lasting flame that guides today's researches. Tuned to the interests of the technical circles, CESP- Companhia Energética de São Paulo- Brazil, through its Central Civil Engineering Laboratory has defined the guidelines to carry out a broad study aimed at surveying the properties of soils stabilized with binders for use as structural elements for dams.

The first phase following this research study concerns the disclosure of the results obtained and the encouragement to establish a round of debates.

2- BACKGROUND

Application of soil and cementitious mixes has increased and become of great importance in engineering works The use of cement and lime for soil stabilization is old enough but in the latter years it has proven efficient in various other applications such as:

- paving of highways,
- airports,
- urban roads,
- railroad beds,
- building foundations,
- canals,
- reservoir floorings,
- dams,
- dams protection.

In 1951 [2] Portland Cement Association built an experimental section of slope protection at Bonny Dam Reservoir in Colorado, USA. This experimental section was built in an area exposed to severe climatic variations. Periodical inspections carried out over more than 10 years [3] have evidenced good performance of the material and have permitted the use of soil with cement mixes as alternative material for dam's slope protection at Merrit in Nebraska, and Cheney in Kansas, in 1961 and 1963 respectively. In 1967 the Sly Creek Dam [4] was designed for the Irrigation District in Oroville-Wyandotte, with height about 18m and construction with soil with cement mix. Design was approved for construction [5] by the California Division of Safety of Dams, but was not executed for lack of funds.

It is known [2 e 6], that in 1963, a solid dam was built near Corpus Cristi, Texas-USA to form a reservoir of 445ha capacity, for cooling the water from Barney M. Davis Power Plant. This dam was constructed using soil with cement (10% content) with height going from 2,4m to 6,7m, and an extension of 10,5Km with 268.000m3 total volume.

3- CONCEPT

Constructive processes using cementitious soils are simple and economical. The equipment used for mixing, placement and compacting are well known. Construction technique follows procedures resulting in the application of pulverized soil mixes with the correct proportion of water and cementitious mix to allow maximum compacting. After mixing is prepared, the material is spread, compacted and cured.

Fly Ash has been used with relative success in cementitious material-soil mixes, improving soil working conditions and characteristics. Almost all natural soils are acceptable for composition with cementitious material. Sandy types are preferred to clayey types for soil with cement mixes as these are more easily pulverized and require a lower cement content to attain the required strength and durability. For lime addition the best results are observed in clayey or medium clayish soils. For sandy or low plasticity soils, the addition of pozzolanic materials will help binder action.

Brazil's vast dimensions enhances great possibilities for development and application of this technology, not only because of the existing soils and diversity of materials available in its territory, but also because of the geographic location of cement and lime plants.

4- RESEARCH PROGRAM

The research program being developed at CESP's Civil Engineering Laboratory in Ilha Solteira-São Paulo-Brazil, tries to evaluate properties and behavior of soil and cement , soil and lime and soil, lime and pozzolanic material mixes so that these mixes can be used as alternative materials for dam construction replacing conventional concrete, rockfill and soil dams.

4.1- Materials

4.1.1- Soils

Three very different basic soil types were selected, namely:

- A = Sandy Soil , type A-2-4;
- B = Medium Soil, Silty, type A-4;
- C= Clayey, type A-7-6, with characteristics as shown in Figure 1.

SOIL			A	B	C
CLASSIFICATION NBR			A - 2 - 4	A - 4	A - 7 - 6
CLASSIFICATION IG			0	4	15
pH			4,99	4,96	5,86
LL - %			23	26	48
LP - %			13	16	27
IP - %			10	10	21
ABSOLUTE SPECIFIC GRAVITY - g/cm3			2.73	2,74	2.85
% RETAINED ON SEPARATE SIZES	2,0 to 0,42 mm	MEDIUM SAND	10	2	4
	0,42 to 0,05 mm	FINE SAND	60	55	36
	0,05 to 0,005 mm	SILT	4	12	8
	< 0,005 mm	CLAY	26	31	52
OPTIMUM MOISTURE - %			10,5	12,8	20,5
MAXIMUM DRY DENSITY - g/cm3			2,008	1,914	1,697

FIGURE 1- CHARACTERIZATION OF SOILS USED TO CARRY THESE STUDIES.

4.1.2- Binders

The following materials characterized as shown in Figure 2 ,have been used:

- Portland cement
- Hydrated lime
- Pozzolanic material - (Fly Ash)

4.1.3- Mixes

Using appropriate routine techniques, mixes were prepared and a series of cylindrical test specimens (50mm)x(100mm), were molded for simple axial compression strength, diametral compression and modulus of elasticity tests at ages of 3, 7, 28, 90, 180 and 360 days. Figure 3 shows the mixes studied and respective binder contents added to the soil mix.

Maximum densities and optimum humidity values were established for each mix through compacting tests with result values as shown in Figure 4.

The “pH” values for each mix were established at mechanical test ages.

MATERIAL		CEMENT	FLY ASH	LIME
% RETAINED ON SIEVE # 325		14	57,5	
FINENESS SPECIFIC SURFACE - BLAINE - cm2/g		3154	2466	
AVERAGED DIAMETER - micron			11,6	
APPARENT SPECIFIC GRAVITY - g/cm3		1,12		
ABSOLUT SPECIFIC GRAVITY - g/cm3		3,15		
REACTIVITY WITH ALKALIES	REDUCTION OF EXPANSION - %		63,3	
	MORTAR EXPANSION - %		0,053	
POZZOLANIC ACTIVITY INDEX	WATER REQUIREMENT-%		106,3	
	WITH CEMENT - %		69,6	
	WITH LIME - MPa		3,5	3,5
WATER FOR	CONSISTENCY grams	130		
FLOW	%	25,9		
DRYING SHRINKAGE - %			-0,016	
TIME OF SETTING h:m		2:19		
AUTOCLAVE EXPANSION - %		0,054		
COMPRESSIVE STRENGTH CYLINDERS 50x100mm	3 DAYS MPa	22		
	7 DAYS MPa	28,8		
	28 DAYS MPa	34,5		
	90 DAYS MPa	35,6		
HEAT	HYDRATION 7 DAYS	89		
	cal/g 28 DAYS	93		
MOISTURE - %			0,03	
CHEMICAL ANALYSIS %	LOSS ON IGNITION	3,54	0,071	28,61
	INSOLUBLE RESIDUE	0,33		1,7
	SiO2	19,85	56,36	
	Fe2O3	3,57	6,08	
	Al2O3	5,07	30,54	
	CaO	63,68	1,58	57,29
	Mg	1,42	0,26	11,61
	SO3	1,81	0,34	0,08
	Na2O	0,1		
	K2O	0,92		
	Al2O3 + Fe2O3		36,62	0,62
	Al2O3+Fe2O3+SiO2		92,98	
	ALKALIES Eq	0,71	0,55	
	FREE LIME AS CaO	1,12		
	C3S	56,23		
	C2S	15,12		
	C3A	9,21		
	C4AF	8,96		

FIGURE 2- PHYSICAL-CHEMICAL ANALYSIS FOR BINDERS USED

PROPORTIONING MIX	BINDER									
	CONTENT %					CONTENT - Kg/m3				
SOIL+ CEMENT	2	4	6	8	10	32 3	64,2	94,7	125,8	155 8
SOIL + LIME	2	4	6	8	10	31,1	51 1	88,7	116	140,4
SOIL + LIME + FA	2 + 10	4 + 10	6 + 10	8 + 10	10 + 10	29 + 147	56 + 145	84 + 140	109 + 137	133 + 133
SOIL + LIME + FA	2 + 15	4 + 15	6 + 15	8 + 15	10 + 15	28 + 213	56 + 210	82 + 205	107 + 202	131 + 196
SOIL + LIME + FA	2 + 20	4 + 20	6 + 20	8 + 20	10 + 20	28 + 280	55 + 277	80 + 266	104 + 260	127 + 254

FIGURE 3- MIXES STUDIED AND CONTENTS OF BINDERS USED

BINDER	CONTENT %	SOIL A		SOIL B		SOIL C	
		MAXIMUM DRY DENSITY-g/cm3	OPTIMUM MOISTURE - %	MAXIMUM DRY DENSITY-g/cm3	OPTIMUM MOISTURE - %	MAXIMUM DRY DENSITY-g/cm3	OPTIMUM MOISTURE - %
CEMENT	2	1,986	10 7	1,852	13 1	1 68	20 6
	4	1,993	10,4	1,861	13	1 693	20 6
	6	1 99	10,6	1 864	12 9	1 698	19 7
	8	1,996	10,2	1,865	13 2	1,705	20 3
	10	2 008	10,2	1 868	12 5	1 717	19 7
LIME	2	1 94	11,5	1 824	12 7	1,68	20 7
	4	1,918	11,6	1,81	13,5	1,66	20 9
	6	1 914	11 7	1 811	13 9	1 65	21 1
	8	1 916	11,8	1,809	13 8	1 647	21
	10	1 886	12	1 789	14	1 644	21 5
LIME+10% FLY ASH	2	1,867	11,9	1,772	13,7	1 65	20 5
	4	1,865	11,9	1,768	13,7	1 655	20 8
	6	1 843	12 1	1,763	14 4	1 62	21 4
	8	1,84	12,6	1,747	14,4	1 634	20 8
	10	1 816	12 4	1,747	14,6	1,624	21,2
LIME+15% FLY ASH	2	1,822	12,4	1,744	14	1 634	20 3
	4	1 837	12,6	1 732	14 9	1,628	20 4
	6	1,821	12,7	1,73	14 7	[illegible]	20,7
	8	1,815	12,5	1,733	14,9	1,614	20 9
	10	1,798	12,6	1,718	15,2	1,613	21
LIME+20% FLY ASH	2	1,818	12,7	1,723	14 5	1,622	20 4
	4	1,804	12	1,714	14,4	1,611	20,8
	6	1,793	13,1	1,693	14,9	1 608	20 8
	8	1,787	13,3	1,697	15,5	1,604	21
	10	1,764	13	1,694	14 4	1,589	21 6

FIGURE 4- COMPACTION TESTS WITH NORMAL ENERGY ON MIXES STUDIED

4.3- Results of Mechanical Tests

Results for mechanical axial compression resistance tests are shown in charts of Figures 5, 6, and 7.

4.4- Supplementary Tests

Based on the tests results, the mixes for the next phase of research were defined. This will consist of:

· **4.4.1- Relation between standard test specimens, concrete and soils dimensions:** Correlation will be established between the results obtained with 50x100mm cylinders, and 150x300mm test specimens, normally used in concrete studies;

· **4.4.2- Special Tests for Massive Structures:** Specific tests will be carried out for soil-cementitious mixes to define characteristics and behavior as massive concrete structures. Figure 8 shows the list of mixes chosen based on resistance results and the series of tests programmed for the next phase.

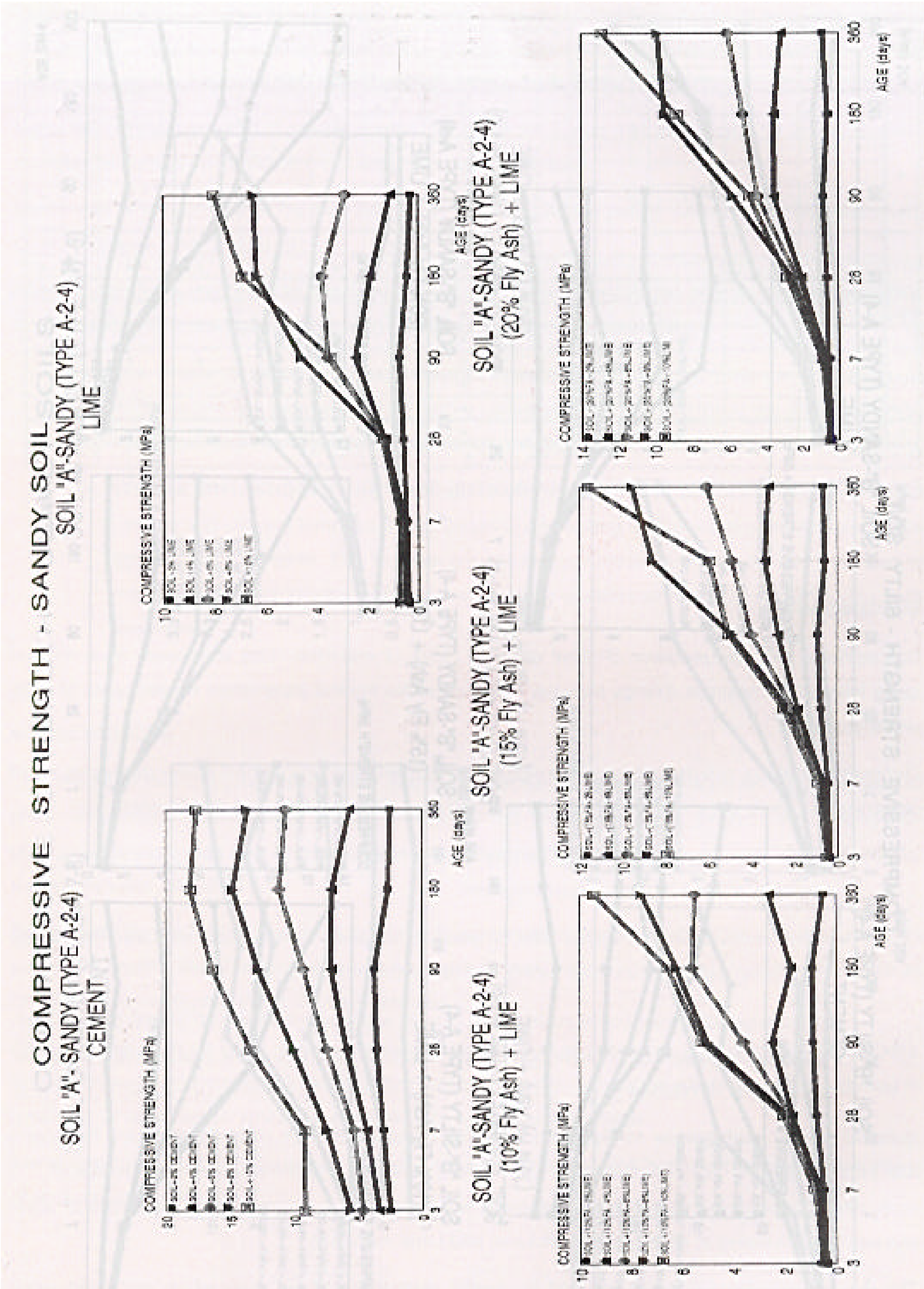

FIGURE 5- COMPRESSIVE STRENGTH OF SANDY SOIL

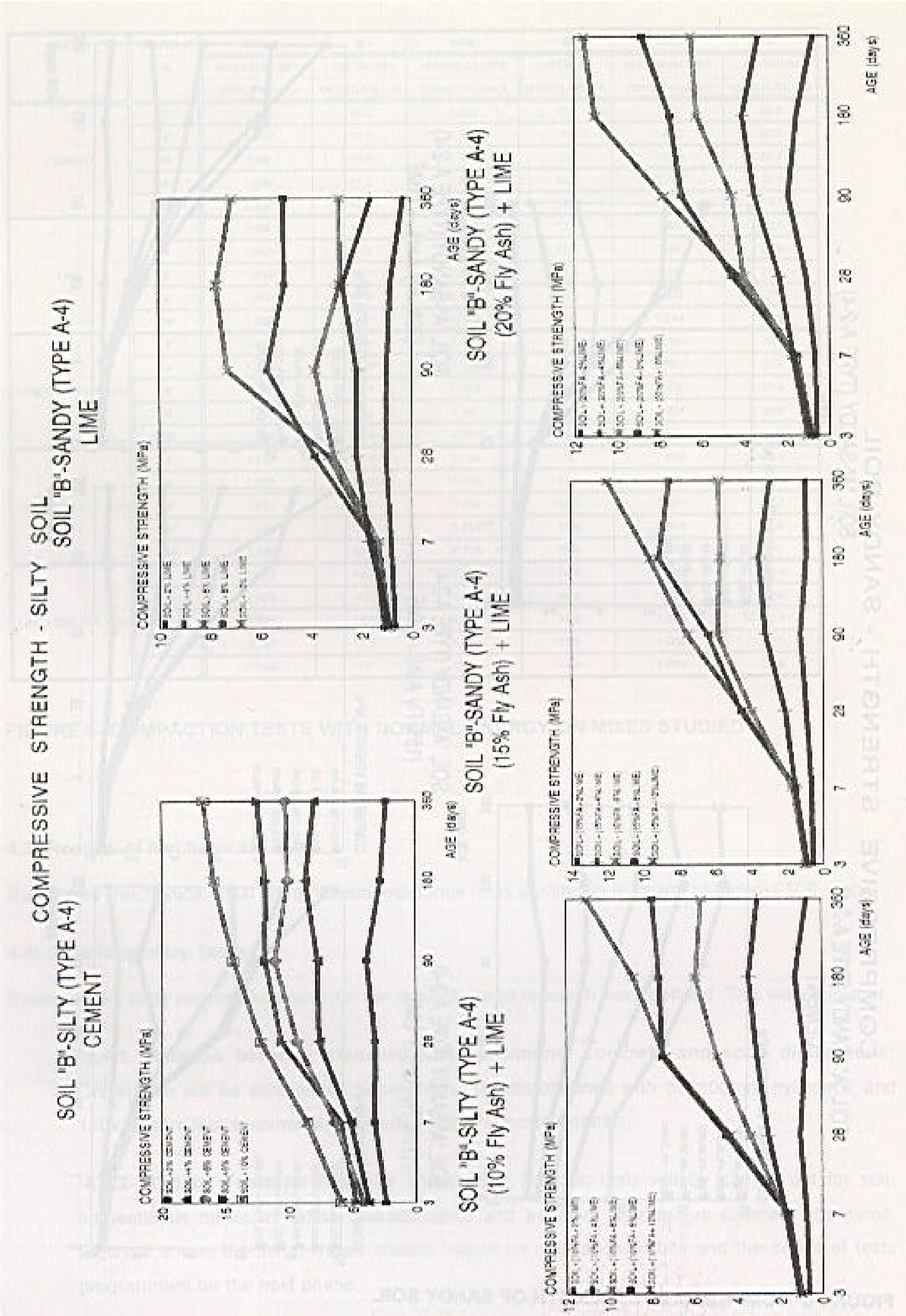

FIGURE 6- COMPRESSIVE STRENGTH OF SILTY SOIL

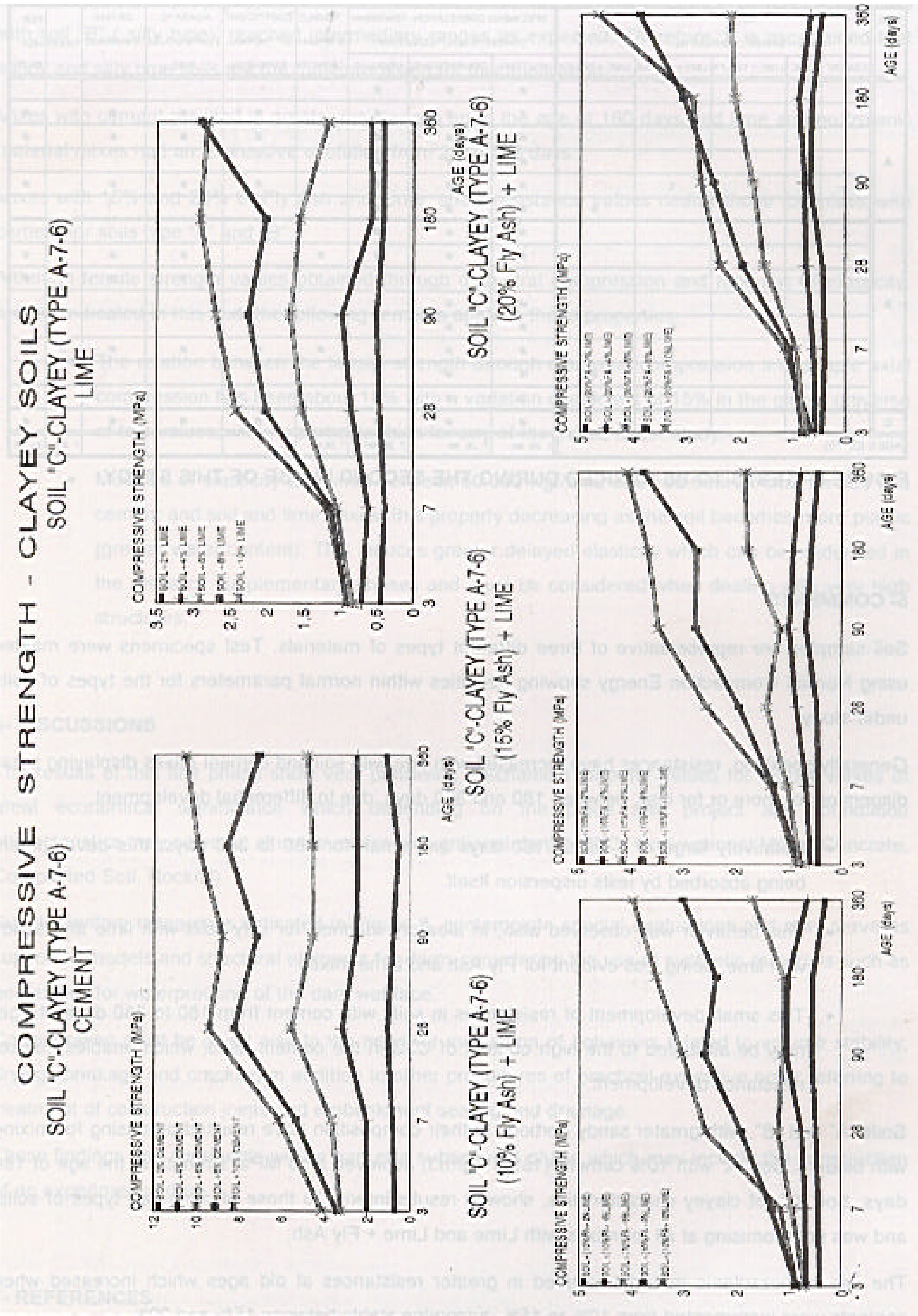

FIGURE 7- COMPRESSIVE STRENGTH OF CLAYEY SOIL.

SOIL	MIX SOIL + BINDER / CONTENT %					SPECIMENS CORRELATION- 150x300mm CONCRETE-SOIL TECHNOLOGY			TENSILE & STRAIN CAPACITY	COEFFICIENT OF THERMAL EXPANSION	ADIABATIC TEMPERATURE RISE	DRYING SHRINKAGE	CREEP	PERMEABILITY
	CEMENT	LIME	LIME + 10% FA	LIME + 15% FA	LIME + 20% FA	SPLITTING	COMPRESSIVE	MODULUS						
A	4					#	#	#						
	6					#	#	#		#	#	#		#
		8				#	#	#		#	#	#		#
			8			#	#	#						
				8		#	#	#		#	#	#		#
					8	#	#	#						
B	4					#	#	#						
	6					#	#	#	#	#	#	#	#	#
		8								#	#	#		#
			8			#	#	#						
				6		#	#	#						
				8		#	#	#	#	#	#	#	#	#
					6	#	#	#						
					8	#	#	#						
C	6					#	#	#		#	#	#		#
AGES (DAYS)						7 28 90	7 28, 90	7, 28, 90	7,28 90				7 90	28 90

FIGURE 8 - TESTS TO BE CARRIED DURING THE SECOND PHASE OF THIS STUDY

5- COMMENTS

Soil samples are representative of three different types of materials. Test specimens were molded using Normal Compaction Energy showing densities within normal parameters for the types of soils under study.

Generally speaking, resistances have increased with age with soil and cement mixes displaying small dispersion for more or for less, between 180 and 360 days, due to differential development.

- Relatively large of 7 for 90/180 days and small for 180 to 360 days, this development being absorbed by tests dispersion itself.
- This behavior was observed also, in aleatory manner, for silty soils with lime and sandy with lime, being less evident for Fly Ash and Lime mixes.
- This small development of resistances in soils with cement from 180 to 360 days of age, may be attributed to the high content of C3S in the cement used, which enables quicker resistance development.

Soils “A” and “B”, with greater sandy portions in their composition have resulted promising for mixing with binders. Soil “A” with 10% cement (155,8 Kg/m3) achieved a 18 MPa. strength at the age of 180 days. Soil “C”, of clayey characteristics, showed results inferior to those of other two types of soils, and was not promising at all for mixes with Lime and Lime + Fly Ash.

The use of pozzolanic material resulted in greater resistances at old ages which increased when contents were incremented from 10% to 15%, becoming stable between 15% and 20%.

Mixes with soil “C” (clayey type) showed the lowest indexes for mechanical properties, while mixtures with soil “B” (silty type), reached intermediary ranges as expected. Therefore, it is ascertained that sandy and silty type soils are the most promising for this application.

Mixes with cement resulted in greater resistances up to the age of 180 days and lime and pozzolanic material mixes had an expressive evolution from 28 to 360 days.

Mixes with 15% and 20% of Fly Ash and Lime, show resistance values nearer those for mixes with cement for soils type “A” and “B”.

Although tensile strength values obtained through diametral compression and modulus of elasticity, are not indicated in this text, the following remarks apply to these properties:

- The relation between the tensile strength through diametral compression and simple axial compression has been about 10% with a variation coefficient of 15% in the global universe of test values, with no particular bias for any of the mixes under study;
- Modulus of elasticity remained between 60.000 Kgf/cm2 and 100.000Kgf/cm2 for soil and cement and soil and lime mixes, this property decreasing as the soil becomes more plastic (greater water content). This induces greater delayed elasticity which can be evidenced in the research supplementary phases and must be considered when dealing with very high structures.

6- DISCUSSIONS

The results of this first phase show very promising mechanical property values for certain mixes of great economical significance which depending on the place and project and foundation characteristics may serve as alternatives for conventional dams (RCC, Conventional Mixed Concrete, Compacted Soil, Rockfill).

Supplementary researches indicated in Figure 8, contemplate special evaluations and may serve as support to models and structural elements for dams considering the use of synthetic materials such as geotextiles for waterproofing of the dam wet face.

Consideration must be given also to the need for evaluation of behaviors related to volume stability, drying shrinkage and cracking in addition to other procedures of practical-executive order referring to treatment of construction joints and embankment sealing and drainage.

These findings and comments will be part of a subsequent phase which may include the construction of an experimental dam.

7- REFERENCES

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