Discussion on Papers

Soil-Cement Interaction*

by

K. S. Tyagi

1. C. S. MOHAN & K. VINCENT PAUL**

IT is always the case that the failure takes place in a soil specimen in an unconfined compression test along the line of least resistance. A natural soil specimen itself when tested, show some strength. For clays this may be purely due to cohesion. But, the same soil after stabilization with cement or some other materials will offer added strength, derived from the products of hydration, or otherwise. As the quantity of cement added for stabilization will be always small, it cannot be expected to get into all the pore spaces. Therefore, continuous cementing matrix on any cross-section of the specimen is out of question. Even if it is assumed to be existing it can never be a line of least resistance. Therefore, a failure line has to pass along some cementitious bonding and some natural bonding.

The author by his exhaustive work based on X-ray diffraction and differential thermal analysis has confirmed the formation of certain products akin to the products of hydration of cement. The tabular statement on endothermic reactions on clay and clay cement combinations, show that a reduction in peak areas result. This reduction happens between seven and 28 days of curing as seen from Table I, of the paper.

The writers who wanted to study the time dependent strength aspects on soil-cement noticed a conspicuous phenomenon after testing about 800 samples of soil mixed with different percentages of cement. The graph (Figure 1) may show the reduction in strength of U.C.C. values on all specimens during the first two weeks of curing. This was noticed in the case of soil specimen with no cement also. The soil used for this purpose was loose lateritic soil available widely all over North Kerala.

The authors of this contribution are left wondering whether there is any rational connection, as yet unexplained, between these two apparently diverse phenomena in the same parent system. The lack of dimensional

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relationship may be striking but equally striking the parallelism of behaviour in the two manifestations may not be simply dismissed as accidental without enquiry.

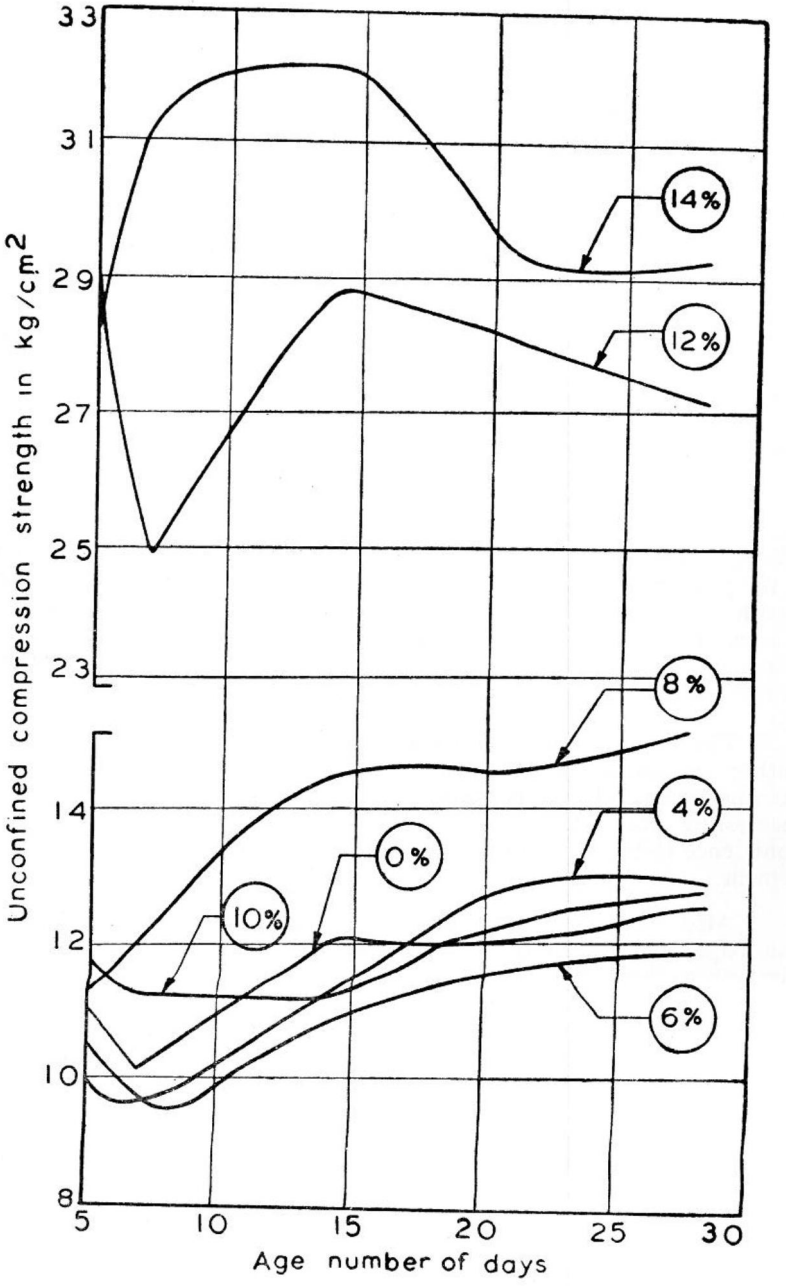

FIGURE 1 : Relation between unconfined compression strength at O.M.C. and age in number of days.

Reference

MOHAN, C.S. and VINCENT PAUL, K. (1974): "An Attempt to Improve Friable Laterite Through Cement Mix". *Proceedings of the Symposium on the 'Economy in Construction'*—Thiagarajar College of Engineering, Madurai.

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2. R. K. M. BHANDARI*

A NUMBER of studies have been documented in the past on the mechanisms governing the development of strength in cement treated soils. These studies have clearly established that because a cement treated soil can achieve sufficiently *high strength with rather meagre quantities* of cement (say 2 to $2\frac{1}{2}$ percent by dry weight of soil), process of mere cement hydration could not be taken as the sole mechanism responsible for imparting excessive strengths to the treated soil. This led Herzog and other workers to believe that clay-cement interaction in addition to normal cement hydration process is likely. This was later abundantly proved by several laboratory studies. Herzog propounded that mechanism of clay-cement stabilisation takes place in two stages, i.e., (*i*) primary reactions which constitute normal hydration process, (*ii*) secondary reactions which take place between soil alumina and silica and calcium hydroxide liberated in the primary reactions. The long-term high strengths of cement treated mixtures have been explained on the basis of these secondary reactions. It is apparent from the above discussion that the paper does not bring out a systematic study of the soil-cement interaction lending lack of justification to the title of the paper.

The period of curing (7 days + soaking for 24 hrs) employed by the author to assess the effectiveness of cement in clay-cement specimens does not seem to be sufficiently long to permit secondary reactions, as mentioned above, to play a significant role thereby allowing only a scanty confidence to be placed in the authors finding regarding the effectiveness of cement.

Also it is to be pointed out that validity of the main conclusion of the paper that strength of clay-cement and sand cement is less than the strength of the same amount of cement depends upon the levels of density and moisture content used for preparation of specimens. Could the author comment whether the levels of these two factors were the same in the specimens prepared from clay-cement and cement and state these levels.

Was the formation of any cracks noticed at the end of the curing period ? If the specimens contained any cracks, the measured strengths would not be reliable.

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3. C. E. G. JUSTO*

THE author Shri K. S. Tyagi has brought out the DTA and X-ray test results on clay-cement very well and he deserves appreciation for the useful work.

From the strength values reported in page 312 of the Journal, it seems that some errors have crept in, probably due to the procedure adopted in preparing the soil-cement specimens. It is not necessary that the strength of 100 percent cement paste should be higher than soil-cement mixes. This is particularly true when a well-graded sandy soil is stabilized using Portland cement. The plot of strength versus cement content in such cases indicates an increase in strength values with cement content up to a certain value and subsequently shows even a decreasing trend as the cement content approaches 100 percent value. Specimens prepared out of 100 percent cement paste often develop cracks and are found to have lower strength values than the cement stabilized sand. Further the strength values of graded sand (reported in page 312) with particle size range 0.075 to 1.632 mm stabilized with 11 and 15 percent cement have been found to be lesser than F_2 and F_3 mixes obtained using uniformly graded sands (of particle size ranges 0.249 to 0.638 mm and 0.638 to 1.632 mm) and the same values of cement contents, respectively. Obviously the specimens prepared with well graded sand should have given much higher strength values when compared with uniformly graded sands, cement contents being the same.

The above points therefore indicate the necessity of re-checking the experimental procedure adopted for preparing the specimens and testing them. The author may kindly elaborate on the procedure adopted for preparing and testing the specimens and indicate the following :

(*i*) Whether the specimens were prepared by static or dynamic compaction.

(*ii*) (*a*) Whether the load/compacting energy per unit volume/unit weight of the specimen was kept constant irrespective of dry density obtained.

or

(*b*) Whether the dry density was kept constant (using static compaction in constant volume moulds) irrespective of compacting pressure required.

(*iii*) How many specimens were prepared with each mix to check the repeatability of test results or to take the average strength values.

If constant compacting energy or pressure, is used in dynamic or static compaction with the same cement content, the density and strength values would naturally be different for different types of materials and would depend on the type of soil, particle size distribution, shape and texture of soil particles, properties of the fines, etc. However if all the specimens are compacted to constant density the compaction of a well graded sand may not be adequate whereas a high compactive energy will be spent in compacting uniformly graded sand.

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Thus it is obvious that the strength gain in soil-cement mixes should not be merely expressed in terms of cement content only, when the various other factors affecting the strength value are not controlled. The arguments given in the paper under the head "Effectiveness of Cement in Soil-Cement" therefore need revision.

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AUTHOR'S REPLY

Reply to Sarvashri C.S. Mohan and K.V. Paul

In view of the results reported in literature (Woods 1960) and also author's own experience with soil-cement it appears that several inconsistencies exist in the results of the discussors, which are shown in Figure 1, e.g.,

(*i*) The unconfined compressive strength of untreated soil was as high as 12 kg/cm^2.

(*ii*) The unconfined compressive strength of soil treated with 6 percent of cement is less than the strength of the soil sample without any cement.

(*iii*) The strength of soil-cement mix decreases with curing period.

(*iv*) The strength of soil treated with 6 percent cement is less than the strength of soil treated with 4 percent cement.

In view of this, author would not like to discuss the cause of decrease in strength with curing time. It is likely that discussors may not have controlled one or more of the various variables indicated in Figure 4 which are associated with the strength development in soil-cement.

The reference to a dimensional relationship for strength of soil-cement appears at present to be pre-mature, but is thought-provoking. There appears to be two difficulties in obtaining such relationship.

(*i*) Large number of variables involved.

(*ii*) Adoption of suitable dimensional representation for some of the qualitative factors involved.

Reply to Shri R.K.M. Bhandari

The author disagrees with the statement of the discussor that '..... studies have clearly established that sufficiently high strength with 2 to 2½ percent of cement can be obtained' more so, because no references are given. In the opinion of this author much higher amount of cement is needed for obtaining sufficiently high strength, more so in the case of clayey soils (and still more in the case of black expansive clayey soil which was used in this investigation). Cement requirement for silty and clayey soils containing more than 35 percent of material finer than No. 200 sieve, for satisfactory strength and durability ranges from 7 to 16 percent by weight (1956). The addition of up to 6 percent cement to black cotton soil gives 28 days time of less than 4 kg/cm^2 (1966). The specimen obtained by adding 2 to 2½ percent of cement to 1 micron fraction of black cotton soil (which was used in this investigation) after 7 days of curing and 24 hours of soaking crumbled

during soaking before the application of any load ! Author, however, agrees that soil-cement interaction lead to (*i*) hydration of cement (*ii*) alternations in soil minerals due to reaction between soil components and hydration production of cement. This is in fact substantiated by the results presented in the paper and is so stated while discussing the X-ray results. Author emphasizes that under the conditions of testing used by him total strength contributed by primary and secondary reactions is less than the strength which would have been developed by the same amount of cement in a specimen of cement alone. A comparison of this type does not appear to have been made by earlier workers.

The information about the density levels sought by discussor, has already been given in lines 32, 33 and 34 on page 311 of the paper. No crack formation was noticed at the end of the curing period.

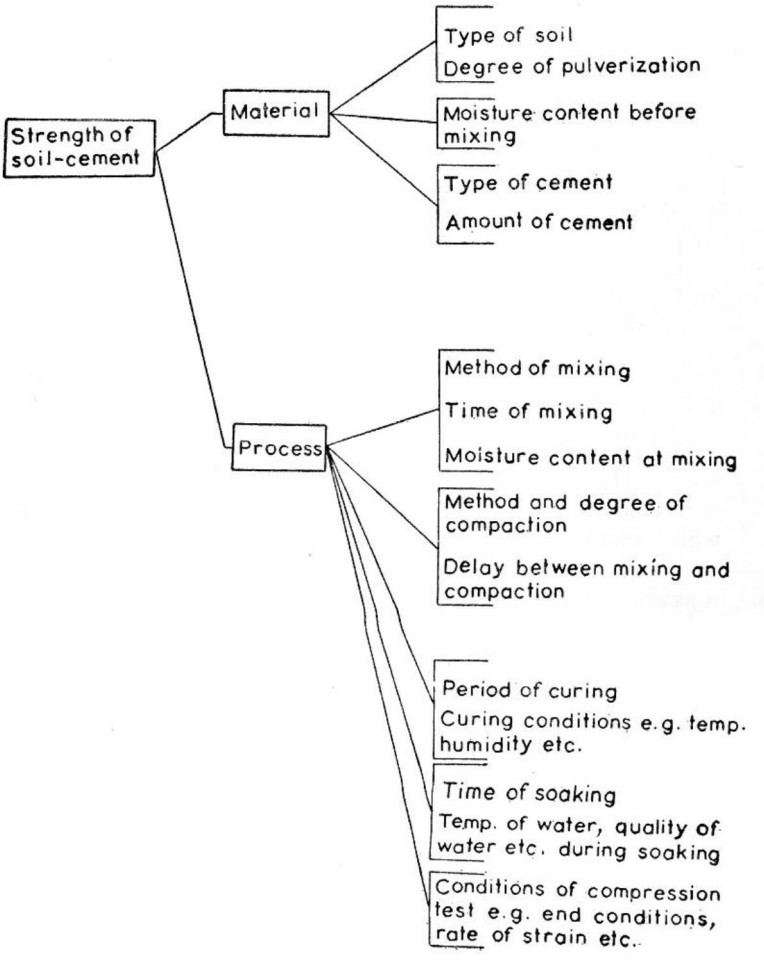

FIGURE 4 : Variables associated with strength development of soil-cement.

It is understood that several factors affect soil-cement interaction as shown in Figure 4. Author does not claim to have presented in this paper, a thorough consideration of all these factors. Author has, however, tried to develop in this paper; (*i*) A concept for the strength mobilization in soil-cement. (*ii*) An understanding of the products formed, making use of X-ray Diffraction and Differential Thermal Analysis Techniques and (*iii*) A comparison of the strength of soil-cement with that of same amount of cement in a specimen of cement alone, which in the opinion of the author lends ample justification to the title of the paper.

Reply to Dr. C.E.G. Justo

Author thanks the discussor for the appreciation of his work. Author may be permitted to take an exception to various statements made by the discussor, e.g.,'.....some errors have crept in','.....necessity of re-checking the experimental procedure', 'The arguments.....need revision,' more so, because such statements have not been backed by any logic, or supported by literature or experimental work by the writer, and instead seem to be based on personnel whims and fancies about soil-cement interaction.

1. Author disagrees that with increasing cement contents the strength may decrease. 'Effect of cement content on soil-cement is clear from Figures 21-23, where it is shown that with increasing amount of cement content in the case of a sandy loam the strength are increasing (1960).

2. Author has tested several specimens of cement and have not yet observed the development of cracks during curing and soaking.

3. Author disagrees that it is 'OBVIOUS' that specimens prepared with well graded sand should have given much higher strength values when compared with uniformly graded sands, cement contents being the same, as in this case it is the 'density' which has been kept constant, as stated in the paper, and not the compacting energy. In this connection the attention of the discussor is drawn to Figure 4, which lists the various factors affecting strength of soil-cement.

4. Specimens were prepared by static compaction applied on both the sides of the specimen.

5. Dry density was kept constant.

6. Three specimens were prepared with each mix and the average values are reported.

7. It is not possible to keep the density and the compacting energy constant simultaneously. In this study, density has been kept constant, and the conclusions are subject to this test condition.

8. Author has nowhere suggested that the strength gain in soil-cement mixes should be merely expressed in terms of cement content only.

In view of the answers given above, which are supported by the literature and by authors own experimental work, the arguments given in the paper do not need revision, and in fact, author humbly feels that the ideas of the discussor on soil-cement interaction, obviously seem to require a revision.

Additional References

Portland Cement Association (1956) : "*Soil Cement Laboratory Handbook*". Chicago.

KATTI, R.K. et al (1966) : "Strength Development in Black Cotton Soil without and with Inorganic Additives". *Road Research Bulletin*, No. 10, published by Indian Road Congress.

WOODS, K.B. (1960) : "*Highway Engineering Handbook*". McGraw Hill.