ANILINE-FURFURAL AS A SOIL STABILISER

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A comparison has been made of aniline-furfural and cement as soil stabilisers with the Gangetic alluvial soil of Delhi. Three compositions of aniline-furfural and two of cement were employed. The 7 day unconfined compressive strength of soil stabilised with resin composition—5% aniline and 2½% furfural is nearly equal to the strength of soil stabilised with 20% cement. Treatment with aniline-furfural produces high strength of nearly 1 ton per sq. in. when the resin composition is 8% aniline and 4% furfural on soil weight basis. The reduction in strength of the aniline-furfural and cement stabilised soils on being subjected to successive wetting-drying and freezing-thawing cycles is almost the same for both the soils. Stabilisation of soils with aniline-furfural is better suited to cold climates.

The stabilisation of soils by the addition of artificial resins and chemicals was investigated during World War II. The non-availability of stone and other stabilising agents like bitumen etc. in remote and not easily accessible regions where roads and runways had to be constructed rapidly, led to the necessity of adopting chemical methods of stabilising the soils *in situ*. The treatment of soils with chemicals has its own advantage in that they are lighter in weight than stone and are required in smaller quantities than cement or stone thereby greatly reducing the cost of transportation. In the post war period, a large number of chemicals including aniline-furfural combination were investigated. In this paper, the performance of aniline-furfural resin on the Gangetic alluvial soil of Delhi is presented and compared with that of cement.

EXPERIMENTAL PROCEDURE

The Soil

The Gangetic alluvial soil of Delhi was used in this study. The soil was air dried, sieved through 1 mm sieve and then employed for moulding and compacting into test cylinders 3″ high and 1·5″ dia. The physical characteristics of the soil are as follows:—

Texture	Plasticity constants	
Clay 16·4%	Liquid limit	24·7
Silt 12·4%	Plastic limit	17·4
Sand 71·2%	Plasticity index	7·3

Chemicals

The two chemicals Aniline ($C_6H_5NH_2$) and furfural ($C_4H_3\ OCHO$) were commercial grade German products. It was established by Scheeler *et al.*[1] that the optimum ratio for bringing about a satisfactory stabilising effect was 2 parts of aniline and 1 part of furfural by weight. This ratio was maintained in all these experiments.

Mixing and compaction

Soil may be stabilised by mixing it with the requisite amounts of the chemicals and water followed by compaction and an adequate period of curing. In any stabilisation operation, compaction of the soil mass is an integral part. For a given compactive effort, the maximum dry density is obtained only against optimum moisture content. Therefore the optimum moisture content of Delhi soil was determined and found to be 18%. In this case since definite amounts of the two organic chemicals were added to the Delhi soil, care was taken that the total liquid content (water+chemical) was 18% or slightly in excess. As furfural is more soluble in water than aniline and is absorbed by clay to a greater degree than aniline, a mixing sequence of water, furfural and aniline was maintained for moulding the soil before compaction. The exact procedure was as follows.

A weighed quantity (about 200 gms) of soil was spread in an enamelled tray and a calculated quantity of water was uniformly sprinkled on the soil surface. The wet soil was next thoroughly mixed by means of spatulas to insure uniform moistening of the soil. Furfural was added to wet soil followed by aniline and the wet soil mass was thoroughly mixed in each case as before. The treated soil mass was then tightly packed in a split mould (3·38″ high, 1·5″ internal dia.). The mould containing the treated soil was supported on the metal base of the Dietert Compactor[2] and a cylinderical weight of 18 lb was allowed to drop ten times from a height of 2″ by means of a can on to a steel plate rigidly attached to the piston through a rod. After giving ten blows of the weight, the mould was inverted and a further ten blows were given. The compact soil cylinder was carefully extruded from the mould and allowed to age for a week at room temperature. With ten blows at each end of the soil specimen and with a total liquid content equalling the optimum moisture content, the maximum dry density attained with the treated soils was as follows:

Soil	*Maximum dry density*
Normal soil (treated with water alone)	1·95 gm/cm^3
Cement stabilised soil (with 5% cement on soil weight basis)	2·00 ,,
Aniline-furfural stabilised soil Aniline : Furfural : : 5% : 2½% (on soil weight basis)	2·17 ,,

Curing

The extruded soil cylinders were allowed to age for a week before their strength was evaluated. Soil cylinders of normal soil as well as those of aniline-furfural resin treated soil were allowed to age for 7 days at room temperature whereas cement stabilised soil cylinders were cured at 100% relative humidity in a closed system.

Strength evaluation

The 7 day unconfined strength of stabilised soil cylinders was determined by employing an unconfined compression strength machine which comprised a 5-ton loading frame with an attached proving ring of 3-ton capacity. The soil cylinder was held between a metal plunger fitted to the proving ring and a metallic base plate. The unconfined strength of the test specimen was obtained by dividing the recorded load at the point of failure by the cross-sectional area of the soil cylinder.

Accuracy

The 7 day unconfined strength values of compacted cylinders of normal soil treated with water were determined. From the results of 6 experiments the accuracy of strength measurement was found to be $\pm 6\%$ p.s.i.

Durability tests

A stabilised soil is required to maintain its compact structure when it is subjected to the disruptive forces generated by adverse climatic and environmental conditions. These natural conditions are best simulated in durability tests which comprise wetting-drying and freezing-thawing cycles. In wetting-drying cycle, the 7 day cured soil cylinders were first fully submerged under water for 24 hours at room temperature and next dried at 40°C in an air oven for 24 hours. These were then tested for strength evaluation. In freezing-thawing cycles, stabilised soil cylinders were first frozen at —10°C for 24 hours and then thawed under water at room temperature for 24 hours prior to testing for unconfined compression strength.

RESULTS AND DISCUSSION

The values of 7 day unconfined compressive strength of soil stabilised with three different compositions of aniline-furfural resin are given in Table 1. To facilitate comparison, the values of soil compacted at optimum moisture content as also those of cement stabilised soil are given.

TABLE 1

7 DAY UNCONFINED COMPRESSIVE STRENGTH OF SOILS STABILISED WITH ANILINE-FURFURAL, CEMENT AND COMPACTION WITH WATER ALONE

Soil	Treatment	7 day unconfined compressive strength (p.s.i.)
Blank Gangetic alluvial	Compacted at optimum moisture content (18%)	213
Aniline-furfural stabilised	Resinified with 5% aniline to $2\frac{1}{2}$%furural on soil weight basis plus water.	580
do.	Resinified with 8% of aniline to 4% furfural on soil weight basis plus water.	2056
do.	Resinified with 10% of aniline to 5% furfural on soil weight basis plus water.	1877
Cement Stabilised	Compacted after admixing 15% cement on soil weight basis plus water.	393
do.	Compacted after admixing 20% cement on soil weight basis plus water.	612

It is seen that the strength developed on resinification with Delhi soil having the resin composition 8% aniline to 4% furfural is nearly 1 ton. This is a tremendous strength and is nearly 10 times the strength of normal soil compacted at optimum moisture content and 5 times the strength of soil stabilised with 15% cement. The 7 day compressive strength of aniline-furfural stabilised soil with the resin composition 5% aniline to $2\frac{1}{2}$% furfural is nearly equal to the strength of soil stabilised with 20% cement. This means that the stabilisation of the soil with aniline-furfural combination is highly successful. When the composition of resin is enhanced to 10% aniline to 5% furfural, there is a marked decrease in strength to the extent of about 200 p.s.i. over the resin composition of 8% aniline to 4% furfural which seems to be the optimum. In that case it is reasonable to assume that part of the two chemicals remain unreacted and hinder the formation of strong bonds between resin to resin, resin to clay and resin to sand etc.

Table 2 shows the decrease in strength of aniline-furfural stabilised soil (resin composition 5% aniline to 2½% furfural) and cement stabilised soil (stablised with 20% cement) on being subjected to one complete cycle of wetting-drying and of freezing-thawing. Normal soil stabilised by compaction with water alone was also included in the study for comparison.

TABLE 2

SINGLE CYCLE DURABILITY TESTS FOR NORMAL COMPACTED SOIL AND SOIL STABILISED WITH ANILINE-FURFURAL AND CEMENT

Soil	No. of cycles	Strength (p.s.i.)	
		Wetting and drying	Freezing and thawing
Blank-Gangetic alluvial compacted at optimum moisture content.	0	213	213
	1	Nil Disintegrates within 5 mts. on immersion in water during wetting.	Nil Disintegrates rapidly during thawing under water.
Aniline-furfural stabilised soil (5% aniline to 2½% furfural).	0	580	580
	1	364	314
Cement stabilised soil (20% cement)	0	612	612
	1	377	289

The performance of soil stabilised with aniline-furfural is at par with that of the cement stabilised soil on undergoing single cycle durability tests. In sharp contrast to the behaviour of these two stabilised soils, the normal compacted soil, which has an initial strength of 213 p.s.i., crumbles rapidly when submerged in water during wetting or thawing to form mud. This shows that stabilisation by mere compaction is not permanent for the unconfined soil systems.

In the course of cycle of wetting-drying, percentage loss in weight suffered by the two stabilised soils was determined as also percentage moisture absorbed by them. The percentage loss in weight suffered by aniline-furfural stabilised soil is 0·24 (negligible) and by cement stabilised soil, none. This means that both the stabilised soils are water stable. However there is nearly four-fold difference in their moisture absorption capacity, the percentage moisture absorption is 2·8 and 12·56 for aniline-furfural stabilised soil and cement stabilised soil respectively. From moisture absorption data, it is clear that although aniline-furfural resin is principally a bonding type stabiliser, it does function as a water proofing agent also probably due to the fact that a successfully bonded soil absorbs less of moisture owing to reduced ability of the bonded soil to swell.

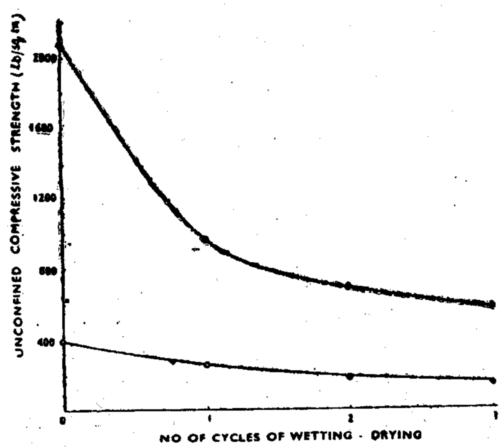

FIG. 1—Variation in strength of stabilized soil on undergoing successive cycles of wetting drying. ●—●: aniline furfural stabilised soil (8% aniline to 4% furfural. o—o : Cement stabilised soil (15% cement).

In Table 3 and Fig. 1 and 2 are presented results of 3 cycle durability tests conducted

TABLE 3

3 CYCLE DURABILITY TESTS FOR SOILS STABILISED WITH ANILINE-FURFURAL AND CEMENT

Soil	No. of cycles	Strength (p.s.i.)	
		Wetting and drying	Freezing & thawing
Aniline-furfural stabilised soil (8% aniline to 4% furfural).	0	2056	2056
	1	973	797
	2	703	577
	3	566	628
Cement stabilised soil (15% cement)	0	393	393
	1	264	176
	2	176	126
	3	151	126

on aniline-furfural stabilised and cement stabilised soils. 3 cycle tests were performed because the criterion of a successfully stabilised soil for use as a construction material is not only its minimum value of 250 p.s.i. 7 day strength[3] but also its resistance to a few cycles of wetting-drying and/or freezing-thawing without suffering substantial loss of material.

The performance of both the stabilised soils is nearly indentical, for instance the cement stabilised soil is superior to the aniline-furfural stabilised soil as far as wetting-drying tests are concerned whereas in the freezing-thawing tests the aniline-furfural stabilised soil is superior to the cement stabilised soil. It has also been found out that of the two durability tests, the freezing-thawing test is more severe and brings about a greater reduction in strength of the stabilised soils. The force developed by freezing of water is enormously high as a result of which, the stabilised soil suffers loss in strength.

In the course of wetting and drying tests, loss in weight of the two stabilised soils after undergoing three successive cycles was determined and found to be 2·4 per cent and 2·0 per cent in regard to aniline-furfural and cement stabilised soils respectively. This loss, though comparable, is hardly significant since the two stabilised soils appear to be intact and retain their shapes without serious surface erosion. The moisture absorption capacity of the two soils in the third cycle remains very much the same as in the first cycle, being 2·7 per cent and 12·36 per cent for aniline-furfural and cement stabilised soil respectively.

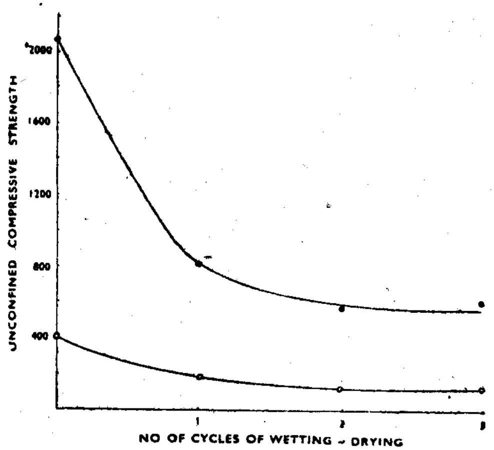

FIG. 2—Variation instrength of stabilised soils on undergoing successive cycles of freezing thawing.
●—● : Aniline furfural stabilized soil (8% aniline to 4% furfural).
o—o : Cement stabilised soil (15% cement).

CONCLUSION

As the aniline-furfural stabilised soil loses less strength than cement stabilised soil when subjected to freezing-thawing, it is better suited to cold climates. Secondly since aniline is poisonous and furfural toxic, a soil that has been stabilised with these chemicals will hardly be suceptible to microbial attack in relation to a soil that has been stabilised with natural resins and other chemicals. It must be due to these advantages that stabilisation of soils with aniline-furfural has been practised on field scale both in Russia[4] and the United States.[5]

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