SOIL STABILIZATION BY EARLY INDIAN METHODS

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(*Received 25 August 1973*)

INTRODUCTION

There are two types of soil stabilizations. In one case, the soil to be used as foundation of a structure, say a building or a dam, if loose or trecherous has to be stabilized in its *in situ* condition, without removing it. After studying a number of treatise on *Śilpa Śāstra*, it was found that this aspect of soil stabilization did not progress much in India. Only one method is described the information of which is given later. The possible reason is that, in old times one could choose a suitable site from those of a large number. The area available was large and the population of the country was rather very small. The cost of labour at that time was negligible, some times nil, so that the trecherous part of the foundation could be removed completely and backfilled with suitable soil, with proper compaction.

The second type of the soil stabilization is the one in which the soil from one place can be removed, suitably sifted or the necessary stabilizing agent added in it and then it may be utilized at some other place. A large amount of information is available on this aspect of soil stabilization, as was followed by Indians.

The stabilized soil was used for constructing a mud wall, for fabricating bricks, for applying a water proof plaster to walls and sometimes for preparing statues of gods and goddesses and also for applying waterproof plaster to these idols.

In this article different methods of soil stabilization as followed by Indians from the pre-historic and Vedic period (upto 600 B.C.) to the period of *Śilpa Śāstra* (1500 A.D.) are described.

SOIL STABILIZATION OF PREHISTORIC AND VEDIC TIME

It is discovered from archaeological excavations that during Indus Civilization the art of burning bricks and utensils made of earth was made perfect to a very high degree. It is rather doubtful that the soil used for fabricating bricks, utensils etc. was purposely stabilized by adding sand and/or lime, although the chemical analysis of this soil shows that it contains sand and lime in adequate quantities and of proper proportions. There is a likelihood that the transported sediment deposited by Indus river contained these materials, i.e. the soil was naturally stablized. It is, however deserved that the utensils prepared in Maharashtra during Chalcolithic period, were prepared of soil which was purposely stabilized by adding sand in the

naturally available clayey soil. Such utensils when burnt were so strong that they give ringing sound when struck . One may infer that Indians in prehistoric time had developed, upto rudimentary stage, the art of mechanical stabilization of soil by addition of soil particles of desired sizes

Yajurveda Saṃhitā gives information about preparation and burning an utensil made of soil, which was called as *Ukhā*. This seems to be the first authentic information of soil stabilization by adding simple stabilizing agents, known at that time. First the soil was removed from the pit by a spade (*abhri*) and it was collected on the skin of an antelope. These sacks of antilope skins, filled with soil, were then carried to the place of sacrifice by loading them on a horse, an ass and a goat. Then to this soil were mixed the hair of a goat, very fine sand and iron filings. Some amount of rock floor obtained by grinding stones was also added. This soil with these stabilizing agents was then thoroughly mixed and ground so that the soil became homogeneous. Bricks of twelve *aṅgula* square (23 cms) and also the utensil *Ukhā* was then moulded of this stabilized soil. Then a pit was dug in which the square bricks and *ukhā* were placed along with the wooden pieces of *Ficus glomerata* (*udumbara*) and husk (*palāla*). Then the bricks and *ukhā* are burnt for twentyfour hours[2].

Burning of bricks and utensils prepared of soil is, of course, a method of stabilization. From the above description and that given by Sankalia[3], it may be concluded that the art of soil stabilization was perfected by Indians from ancient time.

The soil could be stabilized by adding fine powder of coarse sand, stones and rock. This method was known and it is mentioned as such in *Śatapatha Brāhmaṇa*[4].

The floor of burnt brick is called *surkhi*. It seems that Indians knew that addition of *surkhi* in the soil is one of the ways to stabilize it. The utensil *ukhā* mentioned above if broken during burning it was suggested that while preparing the soil for new *ukhā*, the finely ground powder of the broken and burnt *ukhā* should be added in it[5]. Such an *ukhā* prepared of stabilized soil by adding *surkhi* was found not to break easily.

Addition of ash of burnt coal is also another method of stabilizing soil and this method was known to Indians. *Baudhāyana Śulba Sūtra* gives very clear instructions that while preparing bricks for constructing a sacrificial *vedi* which is to be used for a year (*samvatsara*), ash of burnt coal collected in *ukhā* (*ukhya bhasma*) should be added in the soil. The ash should not be added to the soil of those bricks which are to be used for a sacrifice of duration of one night only[6]. This instruction shows that bricks prepared of soil stabilized by adding ash were known to be stronger than those that were prepared of soil that were not stabilized in this manner.

Soil Stabilization as given in Treatise of *Śilpa Śāstra* (1500 A.D.)

Soil Stabilization in situ : It was known that the best way of increasing the strength of marshy water logged mud flat is to drain off its excess quantity of water by constructing a grid of drains filled with rock pieces. The drained water is to be

led to an existing nalla. Soil described as *anūpa* is of this type and this is the method suggested in *Bhṛgu Saṃhitā* to stabilize it.[7]

Indians have not developed machines like reciprocating pumps or vibrators etc. by A.D. 1500 and hence methods of stabilizing soil by cement grouting, vibro-floatation etc. were not developed. These are not mentioned anywhere even in rudimentary form.

Soil Stabilization of Second Type : According to modern science of soil mechanics there are methods of soil stabilization wherein the soil from one place is removed, stabilized and utilized somewhere else. Out of these methods only those are mentioned below which are given in treatise of *Śilpa Śāstra*.

Soil stabilization by,

i) Compaction;
ii) Rearrangement and addition or removal of soil particles;
iii) Chemical reactions, i.e. (*a*) by adding hydraulic lime; (*b*) by adding different salts; (*c*) by adding waterproofing agents;
iv) Thermal processes, i.e. by burning.

i) *Soil stabilization by compaction :* A rampart wall surrounding a town was a usual feature in India. The construction of such a wall is a very old tradition in India, as old as that of Harappa Civilization[8]. A very large trench was used to be dug all arround the city, which later on was generally kept filled with water. The soil removed from this trench was carried to the site of the wall by means of elephants, asses and manual labour. After adding water to this soil, as and when found necessary the soil was compacted by walking elephants on it or by using compacting tampers of shapes like a foot of an elephant or a cow[9].

For laying the foundation of a building, a large pit was generally dug which was of the area equal to that of the plinth and to a depth upto water table or rock level, whichever was smaller. The pit was filled by adding large stones, gravels and coarse sand etc. and the soil was compacted layer by layer. At the time of compaction the soil mass was saturated with water. In fact it is insisted on to compact the soil mass with excess of water[10]. It appears that compaction of coarse soil by seepage force of the water passing through the soil was known, which method is used even in modern times effectively. This saturated soil is further to be compacted by heavy tampers.

ii) *Soil stabilization by removal or addition of soil particles :* It is stated in treatise of *Śilpa Śāstra* that if a soil contains large amount of course sand then it should be removed from the soil. On the other hand, if the soil does not contain enough fine sand size particles then they should be added in sufficient quantiity for improving the properties of soil. It is further mentioned that if a soil contains undesirable materials like salt, wooden chips, corn husk etc. then these materials should be removed from the soil before adding stabilizing agents in it[15].

Any Soil to be utilized for fabrication of bricks or for the construction of the mud wall was stabilized by beating it thoroughly for a long time, sometimes for months, under the feet of men experienced in this art[16-17]. The beating of soil for a long period was the process by which all the soil particles were brought to their natural sizes. This is particularly true for clay size particles, which improve the bond strength of the soil.

iii) *Soil stabilization by chemical reaction :* Addition of *kaṣāya** of barks of fig trees and of three myrobalans taken together (*triphalā*) as well as the resinous exudation formed on the bark of these trees, to the soil, is a form of soil stabilization. These agents act like chemical salts and also as binders improving the strength of the soil[16-17].

Addition of hydraulic lime was one of the approved methods of soil stabilization. Some of these methods are described below where lime was a main constituent.

Stabilized soil for wall plaster : Fine sand is first to be washed thoroughly by water to remove dust. Then lime is to be added in it. Cotton thrashed to very fine pieces is to be added. *Kalka*† of *triyava* (rice, barley and maize) is to be prepared in which very finely powdered ripe banana, equal to half the *kalka* is to be mixed. Very fine sand, lime and finely thrashed cotton are taken in equal proportion and mixed thoroughly. To this mixture the above mentioned *kalka* with banana powder is added and beaten very thoroughly so as to make a homogeneous paste. It is applied to the wall as a plaster[18].

According to the other treatise the preparation of this mixture is described somewhat differently. Hydraulic lime is formed by burning shells, conches etc. This lime is mixed with sand in equal proportions. Water of *mudga quatha*‡, of molasses and the powder of over ripe banana are mixed together. Each of these ingredients is quarter part of that of the lime. These are mixed with lime and sand mixture and beaten thoroughly. Then this mixture is rested for a period of three months and afterwards again ground so as to become as smooth as butter. This plaster is to be applied to the wall. This is specially meant for plastering that wall on which murals are to be painted. It is stated that this plaster remains on the wall for a long period and it is free from atmospheric weathering[19].

Stabilization of soil for preparing idols : Idols of gods and goddesses were prepared from stabilized soil and these idols were preferred to those that were moulded first and burnt later. The aim in stabilizing the soil for this purpose was

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* Water is added in proportion of 4 : 1 to the powder of bark of fig trees and boiled so much that the proportion of the water decreases from four to one.

† The flour of *triyava* is to be mixed with water in 1 : 8 proportion and boiled so that quantity of water decreases to 1 : 1 proportion.

‡ A mixture of resinous exudation of fig trees, triphala, seeds of *masa* and preboiled flour of gram or maize are taken in equal proportions to which water is added in proportion of 16 : 1. The mixture is boiled so that water remains in 1 : 1 proportion.

to make it waterproof so that daily bath of water would not effect the idol. A soil of white colour was supposed to be the best soil. Soils of red and yellow colour were preferred in that order. Soil with black colour was outright rejected. Once the right type of soil was collected, it was mixed with cow's milk, curd, ghee and linseed oil. Linseed oil is a waterproofing agent. In this mixture floor of gravel, rock and iron filings, each of equal proportion were added. The proportion of this floor is one fourth of that of the soil. Then *kaṣāya* of barks of *Acacia catechu* (*khadira*) and of *Terminalia arjuna* (*Arjuna*) is added to this mixture and it is beaten smooth. A mixture of terpentine, resinous exudation of a *Śāla* tree, saffron paint, *kuṣta* (a sort of poison) a kind of a grass called *kunduru*, is added. Then the soil that is deposited at the confluence of two rivers is collected and added to this mixture. This mixture is then beaten smooth for a period of one month. The idol is prepared of this stabilized soil and is allowed to dry for three days. It is stated that such a soil becomes as hard as a stone or iron[20].

After the statue is ready, a plaster of soil is applied. This plaster is prepared by adding powder of *trikaṭuka*, 1/20th part, and finely thrashed coir in the stabilized soil described above. Water of coconut and *kaṣāya* of *triphalā* are also added and all the ingredients are mixed thoroughly so as to make it homogeneous. Four applications or layers are applied one over the other. Each layer of plaster is to be applied when the previous one has dried. The last layer of the plaster is to be applied in such a uniform manner that air does not remain entrapped and there are no holes[21].

Another method of soil stabilization for making idols is given in *Apārajita Pṛcchā*[22]. It is, however, not described.

In the procedure given above, the addition of terpentine linseed oil, gum from *Śālā*, *bilwa*, *khadira* and other trees to the soil makes it waterproof. These react with soil chemically also. *Kaṣāya* of *triphalā* is added to the soil primarily to save it from the attack of bacteria. Lime, rock floor and iron filings are added to the soil to increase its compressive strength. The milk of cow, curd, butter, saffron paints etc., are added to the soil probably to make it sacred. It is possible that these are added as flocculating agents. Stabilization of soil by adding lime was practised. Manufacture of lime by burning lime stone in a kiln was also known as described in *Apārajita Pṛcchā*[23].

iv) *Soil Stabilization by Thermal Process:* It is described above that the method of burning moulded articles of soil was perfected from Vedic period by Indians. Sankalia[1] had stated that from protohistoric period the method of manufacture statues by *cire perdue* technique was known to Indians. The technique requires a mould with inner and outer layers of soil with cavity in between. The outer layer of the mould was prepared of stabilized soil. It is described that for preparing statues of copper, silver and gold from such a mould, the soil to be used should be mixed with rice husk, cotton and salt and must be ground thoroughly. After three days the outer part of the mould is prepared of this stabilized soil[24].

For melting metals like gold, silver, iron etc., it is necessary to place them in a capsule (*mūṣa*). This is placed in a furnace. These capsules were prepared of stabilized soil such that it can bear the intense heat of a furance. More information on this aspect of soil stabilization can be had from Satya Prakasha[25].

Conclusion

It may be stated that a number of methods of soil stabilization were developed by Indians and were used successfully for various purposes, before the advent of Western knowledge in India.

The lime stabilized soil used as a plaster to the wall is the best plaster known as yet. The mural paintings of Ajanta caves as well as those existing on the walls of palaces built during Marhatta period are the best proof of its excellence. It shows that the art of preparing such a plaster was known to Indians upto eighteenth century. Now this art is almost extinct and is improperly understood. To-day's need is to revive this art again on modern lines and to make improvements, if found required.

Acknowledgement

Part of this article was published in the Hindi section of the *Journal of the Institution of Engineers (India)*[26].

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[3] Same as ref. 1.

[4] *Śatapatha Brāhmaṇa* (B.C. 1400), Research Institute of Ancient Scientific Studies, New Delhi (6.5-1.6). It is clearly mentioned that "*Śarkarā Aśmā Ayorasastena Samsrujety Sthemne* ....", where the word *sthemne* means for making it strong.

[5] *Ibid.*, 6.6.4.9.

[6] *Baudhāyana Śulba Sūtra* (B.C. 800) Research Institute of Ancient Scientific Studies, New Delhi (2.78–79).

[7] The lines in *Bhṛgu Saṃhitā* are as under : "*Anūpam jalapaṅkamayam deśam pūrvottarkhātābhiriṣṭkopala pūritābhirgartābhirāsravayet*".

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