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REVIEW OF UNCONVENTIONAL METHODS FOR SLOPE STABILIZATION AND SOIL IMPROVEMENT

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ABSTRACT: Landslides and slope failures are the most challenging problems we face while design and execution of projects. Stabilization of slopes and strengthening them against these failures cost huge amount of construction materials and time which adds into the project cost. Modern day researches are carried out to make use of non-RCC, cost effective methods involving by-products from industries and energy sector, sludge from sewage treatment, and effective use of vegetation cover in stabilizing slopes. The methods considered are use of industrial byproduct binders such as blast furnace slag, alkali activation, fly ash, sewage sludge, lignin based bio energy co-products and use of vegetation cover. Stabilization using industrial by-products such as blast furnace slag based cementitious binders and alkali activation resulted in enhancement of engineering properties in soft soils. Stabilization using recycled materials such as fly ash and sewage sludge involves hybrid techniques.

INTRODUCTION

Increasing rate of urbanization, population growth and industrial development has put the pressure on us to find new land to meet these never ending demands. Since land is a limited resource and it is extremely scarce in urban areas, it has become mandatory to develop areas with poor soil and subsurface conditions suitable for construction. Occurrence of soft soils cause a serious setback to geotechnical engineers from providing suitable foundation for structures, embankments, dams etc. Duration and cost of project is increased due to soft soil deposits. Low bearing capacity, low shear strength, differential settlement of structures, swelling and shrinkage characteristics make these soils unsuitable for foundation. When acted upon by ground vibrations or cyclic loads, liquefaction of soil causes collapse of the entire structure. Various ground improvement techniques are in common use to overcome the disadvantages of soft soils and to avoid huge cost of construction for deep foundations. Methods such as lime stabilization, stone columns, dynamic compaction, chemical treatment, sand drains, grouting are proved highly effective methods for soil improvement.

Researches have proved other non-common soil improvement methods to be highly effective. Some of these methods include use of industrial by-products for deep mixing, alkali activation, bio energy co-products, fly ash and sewage sludge, effect of vegetation and influence of tree roots. P. Sargent et al (2012) discussed the use of blast furnace slag based industrial by-products and alkali activation for improvement of properties of soil, without causing environmental concerns which arises due to lime stabilization. Tao Zhang et al. (2014) proposed use of lignin based bioenergy co-products for stabilization of silt and improvement of properties such as unconfined compressive strength (UCS), pH and electrical resistivity.Use of fly ash and sewage sludge (E. Kosa et al, 2012) in stabilization of slopes have manifold applications. Effect of vegetation and root zones in improvement of soil properties and stabilization is being studied by engineers and researchers for a long time. Daniele Cazzuffi et al (2005), B. Indraratna et al

(2006), and B.Fatahi et al (2007), studied the various aspects related to this topic.

USE OF INDUSTRIAL BY-PRODUCTS AS BINDERS AND ALKALI ACTIVATION

Soil improvement using deep mixing of cementitious binders like lime and cement binders was developed in Sweden during 1970's. This method has been proved in improving strength, durability, volume stability and permeability of soils, especially soft soils with high clay content. Deep mixing improves compaction properties, reduces soil moisture content which in turn reduces shrinkage and swelling characteristics. Deep mixed soils usually tend to have 5 – 15 % binder contents. Portland cement has long been used as a binder, which is preferred over lime in providing rapid strength enhancements (Jegandan et al., 2010). Soil water reacts with calcium silicates/aluminates within binders to produce strengthening calcium silica hydroxide (C-S-H) and calcium aluminate hydroxide (C-A-H) gels, respectively.Use of cement and lime as binders causes several environmental problems, because their production consumes large amounts of energy. Therefore, it is necessary to findnew binders that are more environmentally sustainable than cement and lime, and which will exhibit comparable performance within similar curing duration. Arecent approach that has been employed for choosing new binders

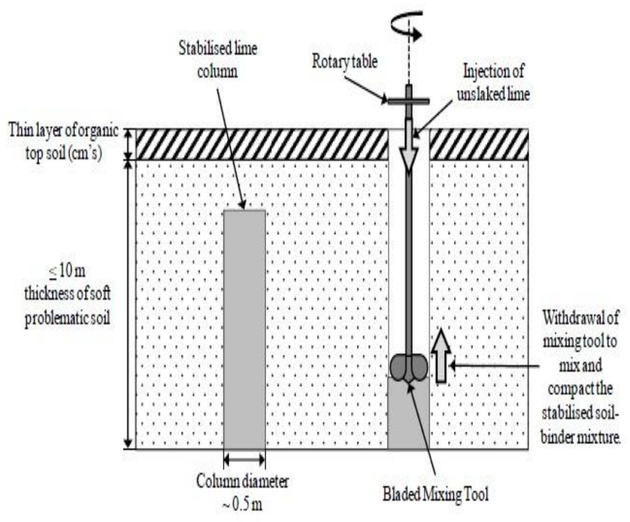
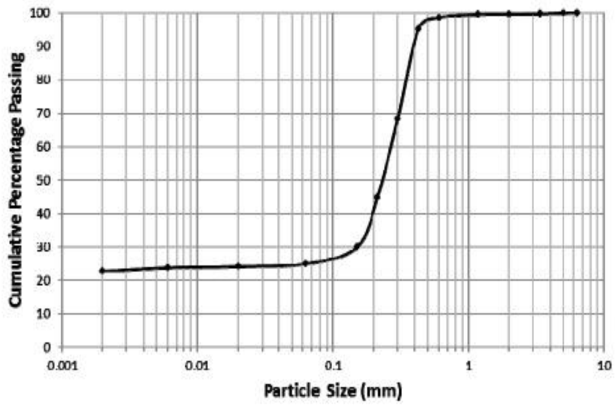


Fig. 1 Schematic of the deep dry mixing technique.(P. Sargent et. al 2012)

is the reuse of industrial by-products (IBP's); preferably those that have alumino-silicate compositions. Rather than using lime to activate pozzolanic reactions and subsequent cementitious bond formation within IBP stabilised soils, work by Palomo et al. (1999) determined that using other alkalis such as sodium hydroxide/silicate would further enhance rates at which the soil's mechanical properties are enhanced.



(a)

Atterberg Parameter	Value
Plastic Limit	11.46
Liquid Limit	23.48
Plasticity Index	12.02
Soil Classification (Casagrande Criteria)	CL

(b)

Fig. 2. Soil grading and Atterberg limits data obtained for the artificial alluvium tested, according to BS 1377: Part 2 (1990) procedures.

Alluvium contains high silt content, low strength and cohesion in dry as well as wet conditions. Therefore, it is unfavourable for construction. Composition of the synthetic soil used for obtaining results was 70% fine silica sand and 30% grade E kaolin.

The IBP's used as binders discussed here are ground granulated blast furnace slag (GGBS), pulverized fly ash (PFA) and red gypsum (RG). GGBS is a latent hydraulic cement produced during the manufacture of pig iron, PFA is a synthetic material produced from combustion within coal-fired power plants, and RG is a waste product from Titanium Dioxide manufacture that is produced in filter cake form during sulphuric acid neutralization.

Binders should be added to the soil at 10 % by dry weight and mixed for 10 minutes using a rotary mixing machine. To produce alkali activated (AA) samples, the sodium hydroxide/silicate is to be added at 20 % by dry weight to the IBP's. Optimum water content for the test is to be determined by compaction test. For comparative purposes, both non-alkali activated (C) and CEM-I binders can be tested. Post-mixing, the stabilized materials should be tamped into a split sample mould and compressed using a hydraulic press. Post-curing samples should be extruded, cut to their required dimensions and immediately tested.

This method aims at improving properties such as strength, compressibility, pH and mineralogical properties.

USE OF LIGNIN BASED BIOENERGY CO-PRODUCTS FOR STABILIZATION OF SILT

Plant biomass is widely perceived as a renewable source of energy and a viable alternative to fossil fuels. Plant biomass is a lignocellulosic material consisting of cellulose, hemicellulose and lignin which includes forest residues and agricultural residues. Production of bioenergy from plant biomass results not only in bioenergy but also in a large number of co-products (Angenent et al. 2004; Kim et al. 2012; Tingle et al. 2003). Among many different co-products is a lignin-containing co-products, which has been considered as a waste material or a low value co-product (Stewart 2008). Lignin is a kind of complex polymers which presents in the xylem of the most terrestrial plants. The presence of lignin in nature is very rich and the annual rate of 50 billion tons of regeneration (Bothast et al. 2005).

Silt usually does not satisfy the requirements of geotechnical engineering construction. Conventional methods used for soil stabilization include use of Portland cement, lime and fly ash. The objective of this proposed method is to investigate the use of bioenergy co-product containing lignin in silt stabilization and try to get the mechanism for lignin stabilization soil. Unconfined compression strength is used as the basic index of strength performance characterization. Electrical resistivity and pH tests gives idea of stabilization mechanism of treated soil. Scanning electron microscope test was can be used on representative samples to understand the stabilization mechanism at the particle level. The details of soil specimen are given in table.

Classification	**Classification**
AASHTO (Group index) A-4	AASHTO (Group index) A-4
TMSHE group symbol ML	TMSHE group symbol ML
TMSHE group name Low liquid limit silt	TMSHE group name Low liquid limit silt
Grain size distribution	**Grain size distribution**
Gravel (>4.75 mm)(%) 0	Gravel (>4.75 mm)(%) 0
Sand (0.075-4.75 mm)(%) 9.1	Sand (0.075-4.75 mm)(%) 9.1

Silt and clay (<0.075 mm)(%) 90.9	Silt and clay (<0.075 mm)(%) 90.9
Atterberg limits	**Atterberg limits**
Liquid limit (%) 32 %	Liquid limit (%) 32 %
Plasticity limit (%) 23 %	Plasticity limit (%) 23 %
Plasticity index (%) 9	Plasticity index (%) 9
Proctor test	**Proctor test**
Optimum moisture content (%) 16.1	Optimum moisture content (%) 16.1
Maximum dry unit weight (γdmax), kg/m31720	Maximum dry unit weight (γdmax), kg/m3 1720

Two types of bioenergy co-products containing lignin were used as additives (A and B). Co-product A is a dark brown, free-flowing liquid fuel with a smoky odor reminiscent of the plant from which it is derived. A contains approximately 8.2% lignin and up to 63.3% water with a pH value of 12.2. The water component in A for use of liquid fuel is not a separate phase because it lowers the viscosity of the fuel. Co-product B is obtained from an ethanol plant. Alkaline-washed corn hull is obtained in the process of converting the corn into ethanol, and B is a powdered version of this. B contains approximately 6.53% lignin, 47.16%hemicellulose, 21.56% cellulose, and other components. The dried natural soil that could pass a 2 mm sieve and air dried additives are to be used. The required amount of water and additives calculated by dry weight ofthe soil and added with thorough mixing. Specimen compacted with optimum moisture content is to be subjected to UCS test. Before the UCS test, the apparent electrical resistivity of each specimen and pH is to be tested.

USE OF FLY ASH AND SEWAGE SLUDGE IN STABILIZATION OF SLOPES

The flay-ash is basically a by product of the coal combustion process in power plants. The mineral and chemical composition of it is determined by the mineral elements present in coal. Landfill slope stability improvement also can be achieved by using the combination of sewage sludge application (fly-ash optional) and mulching, hydroseeding or injection techniques. For the preparation of the applied mixture the sewage sludge with the organic matter content higher than 50% could be used.

The mineral elements of the sewage sludge are developing slowly and are not directly exposed to erosion processes. This kind of material is danger when disposed but after appropriate treatment (additives) it is safely utilized by plants. Sewage sludge supply is free of charge, as it is a remaining material from the waste treatment. The mixture should be applied by hydraulic seeders, supplied with the high pressure pumps, which enables spraying on different soil/material types. Using the sewage sludge has several advantages; seeds are protected from the erosion and the excessive drying, high nutrition content, the viscosity of the sludge and its mixing ability with other components assure even and smooth protection cover, as well as high adhesion of the sprayed surface.

To sum up, the advantages of utilizing the sewage sludge and fly ash suspension with the hydroseeding method, as the effective technique for the erosion control and landfill slope stability improvement are: high level of works mechanisation, good quality of sod created (turf) on the high inclination slope, utilisation of waste, which is troublesome for the communal and environmental treatment plants, reclamation of the sanitary landfills: mineral capping system construction, acceleration of the vegetation cover establishment.

EFFECT OF VEGETATION AND ROOT ZONES IN IMPROVEMENT OF SOIL PROPERTIES

The use of vegetation in civil engineering as a method for erosion control and slope stabilization has grown in importance in recent decades and is now widespread. Vegetation plays an active role both at the surface, protecting and restraining soil, and at depth, reducing the pore water pressure (hydrological effect) and increasing the shear strength of soil (mechanical effect). Negative effects of vegetation in terms of slope stability are: slope surcharge from the weight of trees, wind leverage, increase in infiltration capacity due to root penetration and root wedging. Hence the effect of plant roots on soil shear strength needs to be evaluated.

Daniele Cazzuffi and Enrico Crippa (2005) studied nine kinds of plants commonly used for slope stabilization in Italy: roots of green alder, willow tree, cordata alder, turkey oak and five kinds of perennial gramineae plants. Two types of growth conditions were considered for gramineae plants: plants grown in natural conditions, sampled on site (defined as S-Plants) and plants grown in pots (defined as P-Plants), all of the same age. The pots were plastic containers of 0.4 m x 0.4 m and 0.6 m in height and the soil used was the same found on site.

Roots were collected from different specimens with varying diameter. Tensile testing machine with deformation control was used to measure the tensile strength of the root. A minimum of 20 root specimens for each type of plant was tested. Graph was plotted to correlate the relationship between maximum tensile stress, T_r, and root diameter, D (Fig 3). Three hypothetical different reference curves of rooted area ratio (A_r/A) vs. depth (z) have been applied for the stability analyses (Fig 4). In this study, all these formulations were used for a maximum depth of 2 m and a maximum rooted area ratio of 0.4% and 0.5%.

For the site characterization, the mean inclination of the slopes, the length, the width and the surface of the considered vegetated areas were measured. Geotechnical tests were carried out on the soil. Sand cone test was conducted to determine the natural bulk density of soil. Particles size analyses were also performed. The results are illustrated in figure 5. Direct shear tests was conducted under consolidated drained conditions to determine the cohesion and friction angle.

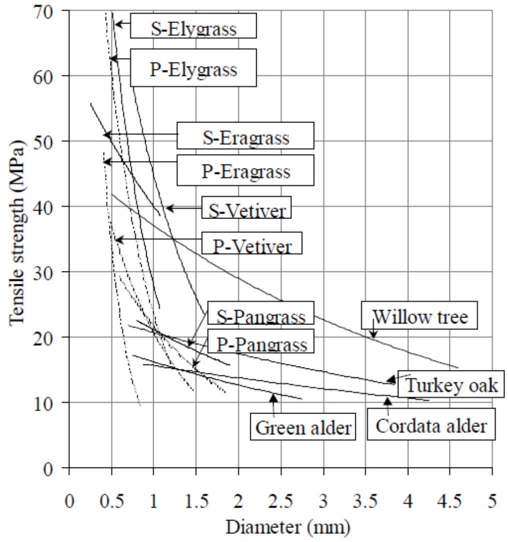


Fig 3: Maximum tensile stress vs. Root diameter (Daniele Cazzuffi et. al 2012)

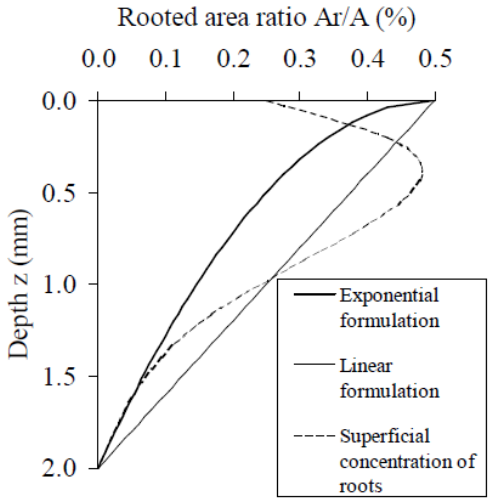


Fig 4: Different hypothetical curves of rooted area ratio (A_r/A) distribution (Daniele Cazzuffi et. al 2012)

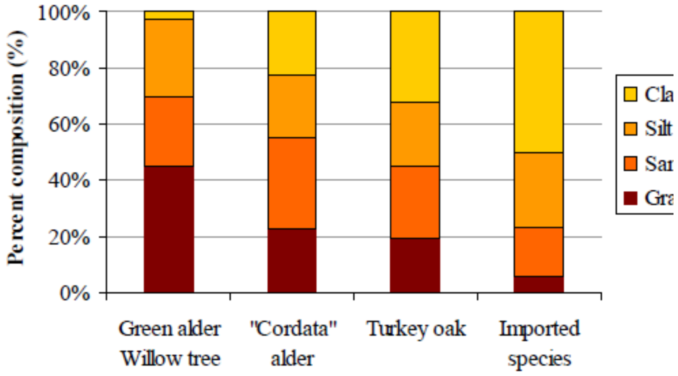


Fig 5: Particle size analysis results for the soils surrounding the different types of plants **(**Daniele Cazzuffi et. al 2012)

The increase in soil shear strength due to plant roots were calculated using a theoretical model based on the original formulation proposed by Wu et al. (1979). The model considers roots as elastic vertical elements crossing the shear zone perpendicularly, and considers them sufficiently long and rough so that the bond between the roots and the soil exceeds the maximum tensile stress of the roots. The increase in shear along the failure surface progressively mobilizes root tensile stress. Because of their firm anchoring in the soil mass, the roots in tension supply an increase in shear strength to the soil directly by a resisting shear (tangential) component and indirectly by an additional confining stress (normal) component.

Tensile tests of roots confirmed that smaller root diameters correspond to higher root strength. The tensile test results were used to evaluate the reinforcement effect of roots on slope stability. It was noted that this effect is limited only to the first 2 m of depth. There was considerable increase in shear strength and factor of safety of soil due to vegetative growth of plants.

To examine the effects of tree transpiration on ground condition, a numerical model using the finite element analysis has been developed by B.Fatahi1, B.Indraratna and H.Khabbaz (2007) considering the coupled flow-deformation equations. The finite element mesh was formulated using partially or fully saturated soil elements, which are capable of capturing the role of unsaturated permeability and the degree of saturation at various levels of matric suction. The soil water flow differential equation, including the sink term, $S(x, y, z, t)$, was written as:

$$\frac{\partial\theta}{\partial t} = \nabla.(k\nabla\varphi) - \frac{\partial k}{\partial z} - S(x,y,z,t)$$

where, $\theta = V_w/V$ is the volumetric moisture content, V_w = volume of water, V = total volume, $\bigtriangledown$ is the divergence vector, φ is the soil suction, k is the hydraulic conductivity, and z is the vertical coordinate (downward is positive).

The proposed root water uptake and transpiration model predicts the suction induced by the tree roots. It was found out that there was substantial gain in shear strength. Similar to prefabricated vertical drains, the tree roots induce good drainage, pore water pressure dissipation and in addition provide natural reinforcement of the soil. As the influence zone of each tree can be several meters in radius, the methodological planting of native trees along rail corridors at a practical distance away from the track is currently considered by rail organizations in Australia.

A similar study was conducted by B. Indraratna, B. Fatahi and H. Khabbaz (2006) on numerical prediction of vadose zone behavior by vegetation. They developed a mathematical model to study the influence of vegetation on soil matric suction, shrinkage and ground settlement. Based on that proposed model, the distribution of moisture and the matric suction profile adjacent to the tree are numerically analysed. The mathematical model was used to find out the distribution and rate of root water uptake.

The numerical studies conducted prove that vegetation has a great importance in erosion control and slope stabilization, protecting and restraining the soil (at the surface) and increasing the strength and competence of the soil mass (at depth). Apart from the reinforcement effect, tree roots establish sufficient matric suction to increase the shear strength and stiffness of the soil.

CONCLUSIONS

Various non-conventional, eco-friendly and economically feasible methods for slope stabilization and ground improvement were discussed. Alkali activated IBP binders have good potential for use as environmentally sustainable replacements for cement and lime in stabilising soft soils through soil mixing techniques. Studies suggest that the strength, stiffness and compressibility of the activated IBP-soil mixtures would be suitable for construction purposes. Lignin is mainly as a cementing material in the soil stabilization, flocclated cement materials produced in the soil bonded the soil particles and filled pores to form an aggregate or grain cluster. Changes of soil microstructure are consistent with the mechanical and electrical characteristics, confirmed the mechanism for lignin-based bioenergy co-products is different from the traditional soil stabilizers. Bioenergy co-products can significantly improve the strength of silt. The use of fly ash and sewage sludge for the reclamation of the surface of landfill is a viable method for reclamation of landfills without causing significant damage to environment. The benefits from the utilization of the fly-ash are: decreased leachate penetration through the landfill, and its partial neutralization. It also solves the problem of the ash storage which, from the economical and environmental point of view, is very positive. The use of vegetation as a method for erosion control and slope stabilisation shows significant results and evaluation of extend of improvement is discussed.

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