Soil-waste interaction behaviour

Comportement de l'interaction sol-déchets

R. K. Srivastava & D. K. Joshi – *Department of Civil Engineering, M. N. R. Engineering College, Allahabad, India*

ABSTRACT : Developing nations have more serious problem of industrial waste disposal. Geotechnical and chemical characterization of wastes and its interaction behaviour with soil is likely to provide best solutions for development of appropriate technologies for disposal/utilization of industrial wastes. This paper presents Indian experience in waste disposal/utilization and results of investigations carried out to understand the interaction behaviour of wastes from four industries (lime sludge from two industries, red mud, flyash and a combination of lime sludge flyash) and typical Indian alluvial and expansive soils. The experimental programme included chemical analysis, SEM, geotechnical characterization and evaluation of the effect of varying percentage of wastes on engineering behaviour of soils. It has observed that 16% to 20% of waste in general can be added to soil without significantly deteriorating its engineering behaviour. A selected combination of wastes can be disposed off with soil, even in still higher quantities (20% to 32%). Selecting utilization of wastes can also be done for soil stabilization.

ABSTRAIT : Les pays en voie de dévelopment possèdent plusieurs problèmes des gaspillage industrial à disposer. <<Geotechnical>> et la characteristique chimique des gaspillages et leur interaction avec le terre peut donner le meilleur soluitions pour le dévéloppment des technologies appropriès pour disposer ou utilizer des gaspillage industrial. Ce papier prèsente l'expèrience Indien en <<waste disposal/utilization>> et les resultats d'investingations qui on a fait à Comprendre le <<Interaction behaviour>> des gaspillages de quatre industries <<lime sludge>> de deux industries <<red mud>>, <<flyash>>, et une combination de <<lime sludge, flyash>>, et typiquement Indien <<alluvial>> et terre <<expansive>>. Le programme experimentale s'inclut l'analyse chimique, <<SEM>>, <<Geotechnical characterization>> et evaluation des effects des gaspillage (aved le different pourcentage des quantities) sur la conduite inginierie des terres. It a observè que 16% à 20% des gapillages en gènèral peut itrè ajouter à terre sans dètèriorer sa conduite ingenièrie. Une combination choisie des gas pillages peut être disposé avec des terres. De plus, on peut faire Ca avec plus grende quantite de 20% à 32%. On peut aussi utilizer ces gapillages choisis pour la <<stabiliztion de terre>>

1 INTRODUCTION

Industries, along with socio-econimic development of a nation, generate large quantities of complex and varying type of wastes. Unplanned and indiscreet disposal of these wastes is cause of severe environmental problem in developing and underdeveloped nations. The nature and type of waste being produced is continuously changing, requiring development of new technologies and environment protection measures. But, in developing countries, even the available knowledge of waste management is not being utilized either due to ignorance, administrative will or economic constraints. Wastes generated in the form of liquids, sludges or solids are very often disposed on land. Thus soil and waste interact and influence behaviour of each other. Understanding and knowledge of soil-waste interaction behaviour can be identified for following situations.

1. Contaminant (waste effluent) transport through soil and subsequent changes in their engineering behaviour.
2. Addition of waste to soil for soil stabilization/waste disposal.
3. Addition of soil to waste for waste stabilization/ utilization.
4. Use of soil for purpose of cover and containment of waste disposed in landfills.

The endeavour of this presentation to report the results of investigations carried out to understand the interaction of several industrial wastes and their combinations with typical alluvial and expansive soils of India. To assess the effect of industrial waste on soil properties, waste has been mixed with alluvial and expansive soils in percentages varying from 4% to 20% and the engineering behaviour of soil-waste mix has been ascertained. SEM analysis has been carried out to observe the microstructural and fabric changes. Some typical SEM photographs are presented.

2 MATERIAL PROPERTIES

2.1 *Soil*

The properties of the soils are presented in table 1.

2.2 *Flyash*

The major constituents of flyash are silica (SiO_2) and alumina (Al_2O_3). When flyash is mixed with soil, the changes are largely physical because flyash is basically inert material. But when flyash is used in conjunction with lime, the soil-flyash-lime combination have proved to be effective due to triggering of reactions by lime with flyash in addition to lime-soil stabilization. The chemical and engineering properties of the flyash are presented in table 2.

2.3 *Red mud*

Red mud is a waste product from alumina manufacturing industry. It has three main constituents, Fe_2O_3, Al_2O_3, and $Ti\ O_2$. The chemical and engineering properties of red mud are presented in table 2.

2.4 *Lime sludge*

In the present study lime sludge has been obtained from two industries—Paper manufacturing factory in M. P. and from a fertilizer plant in U. P. One of main constituents a lime sludge is lime. The amount of CaO varies from about 40% to 60%. When lime is added to a reactive soil, there is reduction in plasticity and gradual increase in strength with time after compacting. The reaction that take place are (a) cation exchange (b) Flocculation and agglomeration (c) carbonation and (d) pozzolanic reactions. Lime reacts chemically with available silica and alumina in soils. The reaction product—calcium alumina silicate is cementitious. The reaction depends upon the effective concentrations of the reactant and temperature. The cation exchange and flocculation are immediate and rapid and are responsible for the amelioration effects. The corbonation and pozzolanic reactions are slow and long term reactions resulting in growth of cementitious products. The presence of large quantity of lime in sludge indicates its possible use in place of lime. The chemical and engineering properties of the lime sludge from two industries are presented in table 3.

Table 1. Engineering properties of the expansive and alluvial soils

Property	Expansive soil (1)	Expansive soil (2)	Alluvial soil
Particle size Analysis			
Gravel	3.0%	0.7%	0.3%
Sand	19.0%	6.0%	12.7%
Silt	58.2%	78.5%	80.0%
Clay	19.8%	14.8%	7.0%
Consistency Limits			
Liquid limit	71.8%	88.8%	32.7%
Plastic limit	35.2%	41.7%	21.3%
Shrinkage limit	12.2%	10.9%	15.3%
Plasticity Index	36.6%	47.9%	11.4%
Sp. gr.	2.70	2.68	2.64
Free swell	81%	90.0%	—
Optimum Moisture Content	28.9%	33.8%	15.2%
Maximum Dry Density (kN/m^3)	13.6	14.5	18.3
From soil remoulded at OMC & MDD			
Cohesion (k Pa)	82.0	73.5	11.8
Angle of Internal friction	6.15°	5.8°	22.5°
UCS (kPa)	62.8	159.1	98.7
Compression Index	0.324	.376	0.283

Table 2 Properties of flyash and redmud

Property		Flyash	Redmud
Significant chemical content (by weight)			
Unburnt carbon		11.80%	—
$Si\ O_2$		59.77%	8.7%
$Al_2\ O_3$		28.92%	18.5%
$Fe_2\ O_3$		9.56%	33.5%
Ca O		2.24%	4.1%
Mg O		1.28%	—
TiO_2		—	19.0%
pH		8.05	9.55%
Conductivity (μ mho)		9.2	7.1
Geotechnical Properties			
Specific Gravity		2.22	2.98
Particle size —	Sand size	1.89%	18.0%
	Silt size	95.25%	70.0%
	Clay size	2.86%	12.0%
Consistency limits —	liquid limit	43.90%	35.0%
	Plastic limit	Non plastic	30.0%
	Shrinkage limit	37.30%	44.8%
Optimum Moisture Content		33.50%	22.8%
Maximum Dry Density (kN/m^3)		11.27	17.7%
From Sample remoulded at OMC & MDD			
Cohesion (kPa)		16.4	17.56
Angle of Internal friction		17.3°	23.5
UCS (kPa)		39.6	188.3
Compression Index		0.171	0.117

3 RESULTS AND DISCUSSIONS

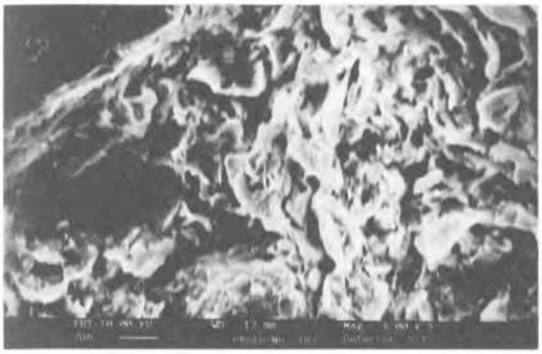
3.1 *Expansive soil (ES) Industrial waste interaction*

Photographs 1 to 4 show the scanning electron micrograph of expansive soil alone, expansive soil-lime sludge (16%), expansive soil-flyash (16%) and expansive soil-flyash (16%) lime sludge (16%) combination. The effect on microstructure and fabric of the soil is observed as different amount of wastes and their combinations are added to soil. The effect of lime present in lime sludge and activation of flyash when used in combination with lime sludge is expected to cause these changes. Tables 4,5 & 6 present the effect of lime sludge, flyash and combination of flyash and lime sludge on consistency limits, compaction behaviour and strength behaviour of various expansive soil-waste mixes.

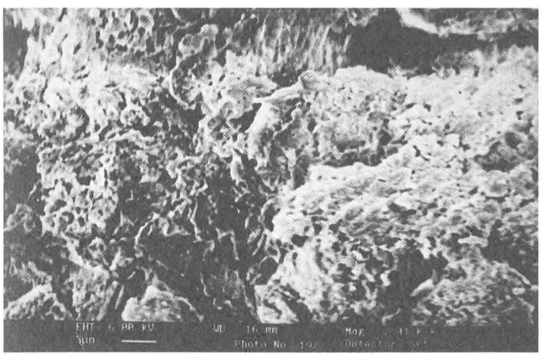
It has been observed that in general the effect of wastes (lime sludge or flyash or their combination) is to reduce the liquid limit, increase workability, reduce compressibility, reduce volume change behaviour and increase the strength of the expansive soil. From among the various amounts of wastes added to soil, the maximum effect is observed for 16% addition of lime sludge or 16% addition of flyash or an overall best effect in a combination of 16% flyash and 16% lime sludge, resulting in about 35% reduction in liquid limit plasticity index and an increase of more than 100% in UCS value of soil.

Table 3. Properties of Lime Sludge

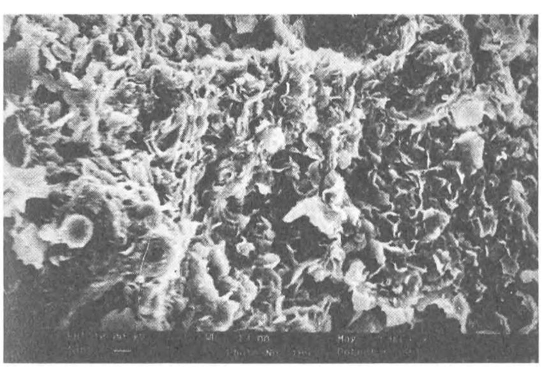
Property		Paper mill lime sludge	Fertilizer Plant lime sludge
Significant chemical content (by weight)			
Ca as Ca O		49.7%	60.0%
Mg O		4.3%	4.5%
$Na_2\ O_3$		3.0%	0.2%
S as Sulpher		6.3%	7.5%
Si as $Si\ O_2$		3.7%	2.0%
loss on ignition		29.3%	—
moisture content		20.3%	27.3%
pH		8.10	10.3
Conductivity (m mho)		8.2	8.3
Geotechnical Properties			
Particle size —	Sand size	11.1%	20.6%
	Silt size	79.1%	72.1%
	Clay size	9.8%	7.0%
Consistency limits —	liquid limit	95.2%	66.2%
	Plastic limit	89.9%	42.0%
	Plasticity Index	5.3%	24.2%
	Shrinkage limit	84.5%	60.78%
Sp. Gravity		2.40	2.28
Optimum Moisture Content		18.0%	15.2%
Maximum Dry Density (kN/m^3)		7.74	10.18
From Sample remoulded at OMC & MDD			
Cohesion (k Pa)		35.2	31.6
Angle of Internal friction		10.9°	13.4°
UCS (kPa)		58.4	62.3
Compression Index		0.498	0.404



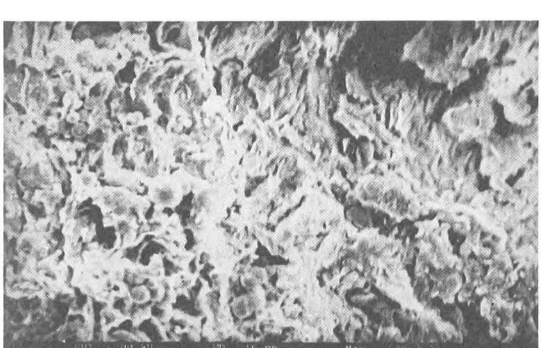
Photograph 1. Expansive soil



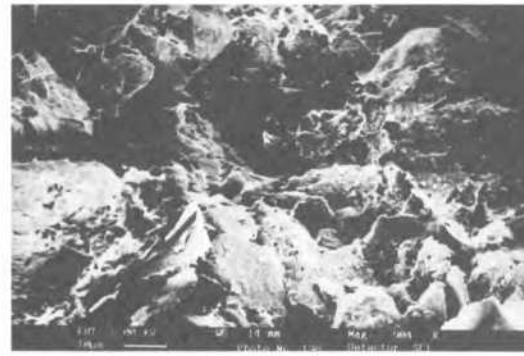
Photograph 2. Expansive soil + 16% lime sludge



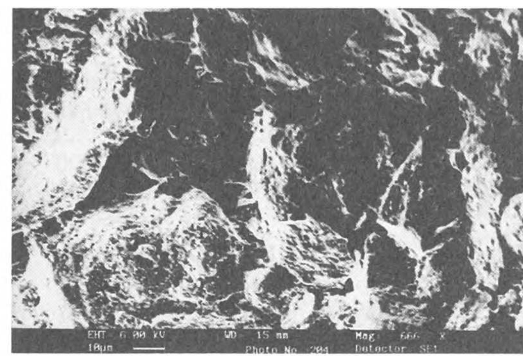
Photograph 3. Expansive soil + 16% flyash



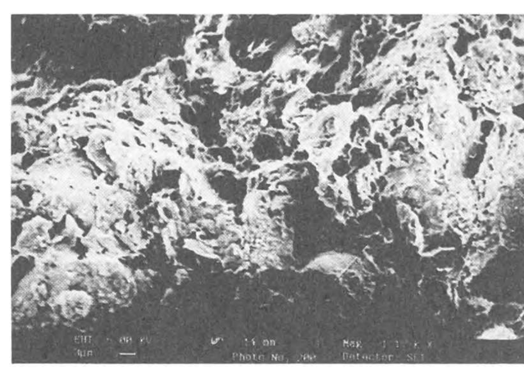
Photograph 4. Expansive soil + 16% flyash + 16% lime sludge



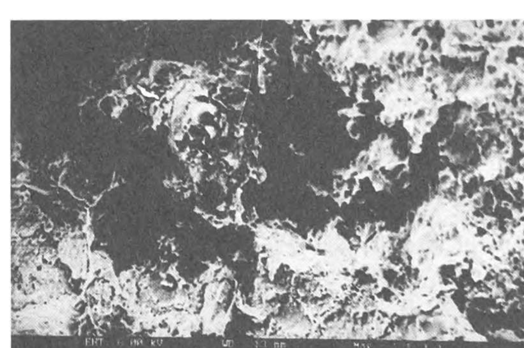
Photograph 5. Alluvial soil



Photograph 6. Alluvial soil + 12% lime sludge



Photograph 7. Alluvial soil + 8% flyash



Photograph 8. Alluvial soil + 8% flyash + 12% lime sludge

Table 4. Expansive Soil (1) (ES)—Lime Sludge (LS) (Paper Mill)

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
ES	71.8	36.6	12.2	28.9	13.6	62.8
ES + 4% LS	70.5	30.7	20.7	30.3	13.8	102.8
ES + 8% LS	68.3	28.2	20.9	31.7	13.5	104.9
ES + 12% LS	65.0	25.5	23.1	33.3	13.2	82.3
ES + 16% LS	59.0	15.5	27.0	31.3	13.4	151.5
ES + 20% LS	59.0	26.1	26.6	31.2	13.8	171.3

Table 5. Expansive Soil (2) (ES)—Flyash (FA)

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
ES	88.8	47.9	10.9	33.8	14.5	159.1
ES + 8% FA	65.0	36.4	12.1	31.9	14.3	198.8
ES + 12% FA	60.0	29.9	18.9	28.2	14.7	192.1
ES + 16% FA	58.2	30.2	20.4	27.2	14.8	227.6
ES + 20% FA	61.7	27.5	20.9	27.7	14.7	226.7

Table 6. Expansive Soil (2)—Flyash—Lime Sludge (Fertilizer Plant)

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
ES + 16% FA + 8% LS	66.9	36.0	25.7	26.9	14.6	285.0
ES + 16% FA + 12% LS	60.3	29.5	34.1	27.3	14.7	294.7
ES + 16% FA +16% LS	58.7	30.8	23.9	26.3	14.5	379.4
ES + 16% FA + 20% LS	59.7	30.7	25.1	27.4	14.6	291.8

3.2 *Alluvial soil-Industrial waste interaction*

Photographs 5 to 8 show the scanning electron micrograph of alluvial soil alone, alluvial soil lime sludge (12%), Alluvial soil-flyash (8%) and alluvial soil flyash (8%) lime sludge (12%) combination. (The SEM for alluvial soil-Red mud combination is not shown).

The changes in microstructure of soil on addition of flyash and lime sludge are observed in SEM photographs. Table 7 to 10 percent present the effect of interaction of lime sludge, flyash and combination of flyash and lime sludge and red mud respectively.

It is observed that there is an increase in liquid limit of alluvial soil on interaction with lime sludge or flyash or their combination. Whereas for red mud, there is about negligible effect. The variation in plasticity index is not regular. The effect on shrinkage limit, of lime sludge or red mud is to increase it, whereas flyash alone tends to slightly decrease it. The effect of 8% to 16% addition of lime sludge is of critical importance. The maximum effect is observered by 12% addition of lime sludge to soil (maximum increase in UCS value). In case of flyash, 8% addition of flyash to soil is observed to increase its UCS value to a maximum. When a combination of flyash and lime sludge is added to alluvial soil, the most effective combination is observed to be that with 8% flyash and 12% lime sludge. An over all increase in UCS value from soil alone is about 82%.
In case of alluvial soil-red mud interaction, the most effective amount of red mud is observed to be 16%. For this amount, the liquid limit and plasticity index are minimum, and shrinkage limit is maximum. The red mud tends to increase the OMC which is an advantage in case of working with wet soils. Flocculation and cementation make the soil more difficult to compact, therefore MDD achieved with a particular compactive effert is reduced. The UCS value is also highest for red mud percentage of 16% and then it decreases.

Table 7. Alluvial Soil (AS)—Lime Sludge (LS) (Paper Mill) Mix

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
AS	32.7	11.4	15.3	15.2	18.3	98.7
AS + 4% LS	30.5	11.7	17.9	16.2	17.8	120.0
AS + 8% LS	30.0	12.4	23.6	16.7	17.4	134.0
AS + 12% LS	40.0	15.9	25.5	16.8	17.0	148.0
AS + 16% LS	42.5	18.3	26.6	19.7	16.3	122.0
AS + 20% LS	43.5	14.3	29.2	22.4	15.8	97.0

Table 8 : Alluvial Soil (AS)—Flyash (FA)

Mix Designation	LL %	PI %	SL %	OMC %	MDD kN/m^3	UCS kPa
AS	32.7	11.4	15.2	15.2	18.3	73.4
AS + 4% FA	35.8	12.3	14.7	16.7	17.7	76.9
AS + 8% FA	37.6	10.6	14.3	16.7	17.2	77.6
AS + 12%FA	39.2	12.0	14.0	17.6	17.1	71.3
AS + 16% FA	41.1	12.9	13.8	18.2	16.8	65.6
AS + 20% FA	43.3	14.3	12.7	18.8	16.5	61.8

Table 9. Alluvial Soil—Flyash—Lime Sludge (Paper Mill)

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
AS + 8% FA + 8% LS	35.7	11.5	14.8	17.2	16.9	18.5
AS + 8% FA + 12% LS	41.2	11.1	15.2	17.8	16.5	19.2
AS + 8% FA + 16% LS	43.1	12.4	17.2	18.2	15.9	13.9

Table 10. Alluvial Soil—Red Mud (RM) Mix

Mix Designation	LL %	PI %	SL %	OMC %	MDD (kN/m^3)	UCS (kPa)
AS	32.6	12.0	14.2	15.2	18.3	72.3
AS + 4% RM	32.8	11.3	16.2	16.1	17.8	73.4
AS + 8% RM	31.5	8.8	19.6	17.2	17.6	93.7
AS + 12% RM	31.0	7.4	22.3	18.0	17.5	114.0
AS + 16% RM	30.0	6.8	24.4	18.5	17.4	116.1
AS + 20% RM	31.0	9.8	17.7	17.1	17.2	82.8

4. CONCLUSIONS

1. There is an optimum quantity of industrial waste which when mixed with particular type of soil may improve its engineering behaviour depending upon the chemical constituents of the industrial waste.
2. Lime sludge has a significant content of lime (40% to 60%). This has stabilizing effect on both alluvial and expansive soil. The amount required for best effect are 12% for alluvial soils and 16% for expansive soil.
3. Flyash has significant silica and alumina content and has pozzolanic properties. Around 8% of flyash can be, mixed with alluvial soil and 16% of flyash can be mixed with expansive soil to improve their engineering behaviour.
4. Addition of lime sludge to soil-flyash mix, triggers of the puzzolanic reactions (because of presence of lime in lime sludge) and the combination of wastes becomes more effective.
5. Red mud has significant iron, alumina and titanium contents. If disposed off alone, it would be important to study the water leaching through red mud. Around 12% to 16% addition or red mud is observed to improve the strength behaviour of alluvial soils.
6. In the context of only disposal aspect of industrial waste, about 20% of a waste alone or about 35% in selected combination of waste can be mixed with soil without causing significant deterioration in soil properties.