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Effect of Sand on Strain Modulus (Ev_2) Property of Clayey Soil

[1.] Pardeep Puri,
Student (M-Tech),
Guru Nanak Dev Engineering College, Ludhiana,
India & Deputy Chief Project Manager,
Dedicated Freight Corridor Corporation of India, Limited,
Ludhiana, India,

[2.] Pardeep Singh,
Asstt. Professor,
Guru Nanak Dev Engineering College,
Ludhiana, India,

[3.] Parshant Garg,
Asstt. Professor,
Guru Nanak Dev Engineering College,
Ludhiana, India,

[4.] Mandeep Singh, Executive,
Dedicated Freight Corridor Corporation of India,
Limited, Ludhiana, India.

***Abstract* - To build the structures on allotted site or make use of locally available soil for overall economy of the project, stabilization of clayey or clayey silty soil needs to be done. Soil stabilization is done by various methods like mechanical stabilization cement stabilization, lime stabilization, chemical stabilization, thermal stabilization, electrical stabilization & consolidation stabilization etc. Chemical stabilization is done by making use of material like lime, fly ash, cement, sodium chloride, calcium chloride, magnesium chloride etc. Soil stabilization of clayey soil is also done by using lime kiln dust, cement kiln dust, brick kiln dust, stone quarry dust etc.**

A Thermal Plant namely Nabha Thermal Plant has been installed and made operational in the year 2014 by Punjab State in Village Nalash, Tehsil Rajpura District Patiala. While constructing Thermal Plant, earth to the tune of 6 lac cum had been excavated for making lake and had been dumped near the plant in the form of heaps which has occupied about 100 acres of land. Consequently this heavy chunk of land has turned into desert like situation and cannot be used for cultivation or other purposes till the dumped material is disposed off.

Many infrastructure projects like Special Railway Project from Ludhiana to Kolkata called Eastern Dedicated Freight Corridor, Rajpura –chandigarh line and doubling of Rajpura-Bathinda lines have been announced by Govt, of India and construction works of two out of three have already been commenced recently. These projects require heavy quantum of earth for making embankments. There is scarcity of earth in this area due to high fertility of land.

An effort has been made by the researcher to utilise this surplus lying earth for above civil engg. projects involving earth work in embankment by blending it with locally available sandy soil. This may save cost and create environment friendly area by converting the land again into green belt after utilisation of this surplus earth.

Effect of mixing local sandy soil with clayey soil on Strain modulus (load deformation characteristics of soil at second loading cycle between 30% & 70% of maximum normal stress denoted as Ev_2) has been studied in this report. Field testing to study strain modulus on trail bed of varying thicknesses has been done. Results show that strain modulus values have increased..

Safety of any structure depends upon bearing capacity of the soil and its shearing strength. Weak soils like clayey, clayey silty soils exhibit lower bearing capacity, low shear strength and high settlements. Therefore to build the structures on allotted site or make use of locally available soil, stabilization of clayey or clayey silty soil needs to be done.

Much literature is available for improving index/engineering properties of soil particularly for Improving index properties, CBR ,MDD, and shear strength but limited literature is available for mechanical stabilization i.e. to improve strain modulus (EV_2) values by blending the locally available materials.

The available clayey soil (CH) to the tune of 6 lacs cum has been lying surplus to the requirement of Nabha Thermal Plant and has occupied a space of about 100 acres and efforts to utilize this surplus lying earth and make this fertile land available for agriculture or other purposes have not been made so far. Purpose of this research is to study the effect of sandy soil on strain modulus (EV_2) of soil when mixed clayey soil of CH category.

Keywords: Clay of high compressibility, Poorly graded soil, Strain modulus at second loading cycle.

1. INTRODUCTION

India is a developing country and lot of infrastructural works are announced by Government of India/ State Governments every year like Highways, Railways, Airports, Express Ways, Bridges, Tunnels and Buildings etc. Properties of soil changes frequently w.r.t. distance as well as depth. In certain locations the soil is soft and weak and does not possess the required engineering properties. Therefore before placing these structures on natural soil or using locally available natural soil for the above works, detailed soil investigation to know the properties of virgin soil needs to be done.

Bearing capacity and other engineering properties of soil decrease if the depth of water table is high and the type of soil is clay or silty clay. Clay swells and shrinks upon increase in moisture content and decrease in moisture content respectively. Mont morillonite mineral is responsible for swelling & shrinkage of clayey soil. Clayey soils generally have low bearing capacity, more settlements than sandy soils. Shear strength of pure clayey soil is also observed on lower side in comparison to sandy soil or clayey sandy soil due to non-existence of inter particle friction.

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To build the structures on allotted site or make use of locally available soil for overall economy of the project, stabilization of clayey or clayey silty soil needs to be done. Soil stabilization is done by various methods like mechanical stabilization cement stabilization, lime stabilization, chemical stabilization, thermal stabilization, electrical stabilization & consolidation stabilization etc. Chemical stabilization is done by making use of material like lime, fly ash, cement, sodium chloride, calcium chloride, magnesium chloride etc. Soil stabilization of clayey soil is also done by using lime kiln dust, cement kiln dust, brick kiln dust, stone quarry dust etc.

Many infrastructure projects like Special Railway Project from Ludhiana to Kolkata called Eastern Dedicated Freight Corridor, Rajpura –Chandigarh line and doubling of Rajpura-Bathinda lines have been announced by Govt, of India and construction works of two out of three have already been commenced recently. These projects require heavy quantum of earth for making embankments. There is scarcity of earth in this area due to high fertility of land.

Soil stabilization is done to enhance its engineering properties and performance to enable it bearing heavy loads of structures built upon it or to make use of locally available earth in earth work fillings like Railway Embankment, Highway Pavements, Ai fields & Dams etc. The main objective of soil stabilization is to enhance its bearing capacity, shear strength and reducing compressibility

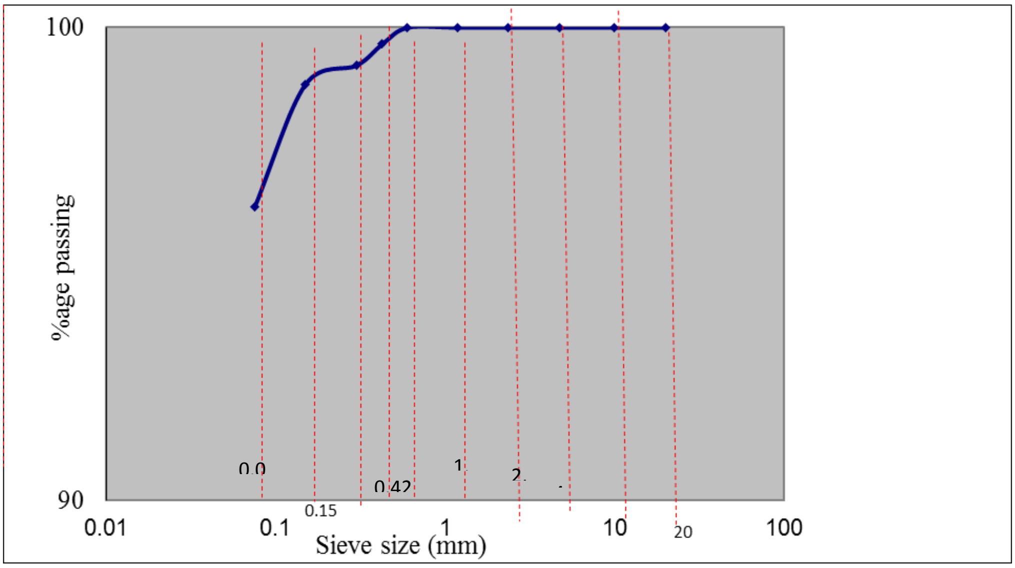
2. MATERIAL AND METHODOLOGY

Clayey Soil: Soil has been obtained from the premises of Nabha Thermal Plant, Village Nalash, Tehsil Rajpura, District Patiala. The soil is clayey soil of CH classification as per A- line plasticity chart of IS 1498. Parameters are as below:

Table No.1

Properties of Virgin Clay at a glance

SN	Test Parameters	Results			Test Method
		Property	Unit	Value	
1	Grain Size Analysis	Gravel	%	0	IS:2720 (Part-4)
		Sand		3.8	
		Silt & Clay		96.2	
		IS Classification		CH (Clay of High Compressibility)	
2	Atterberg Limits	Liquid Limit	%	52.7	IS:2720 (Part-5)
		Plastic Limit		28.1	
		Plasticity Index		24.60	
3	Modified Proctor Compaction Test	Maximum Dry Density (MDD).	g/cc	1.895	IS:2720 (Part-8)
		Optimum Moisture Content (OMC)	%	14.5	
4	Free Swell Index	Swelling Index	%	59	IS:P2720 (Part-XL)
5	CBR Value Tests At 97% MDD	Un soaked	%	14.7	IS:2720 (Part-16)
		Soaked		1.28	



Particle size distribution curve for Virgin Clayey Soil
Figure No.1

- Sandy Soil: It has been obtained from Village Prithipur, Tehsil Samrala, District Ludhiana, where this soil is available in abundance. The soil is non-plastic. Test results are as under:

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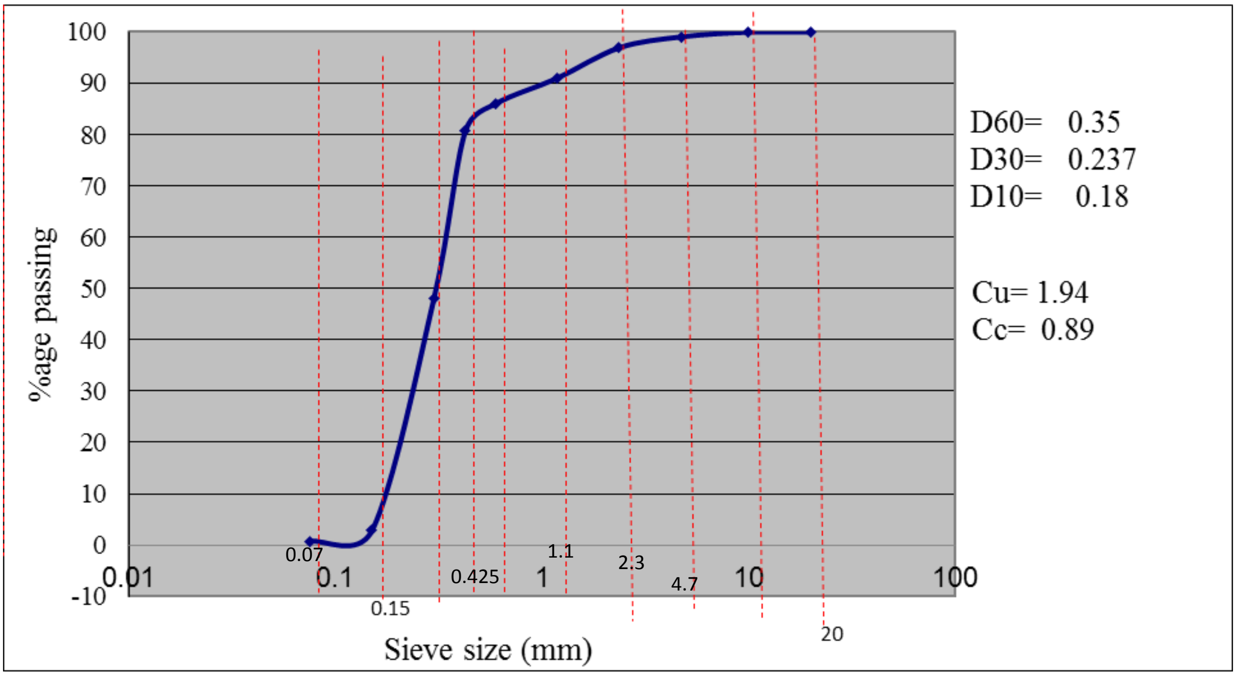
Table No.2
Properties of Virgin Sandy Soil at a glance

S.No.	Sieve Designation	%age passing	Remarks
1	20mm	100	(Gravel = 0.9%)
2	10mm	100	(Sand = 98.35%
3	4.75 mm	99.1	(Silt & Clay = 0.75%)
4	2.36 mm	96.95	
5	1.18 mm	91	IS classification : SP
6	600 mic	86.1	Cu = 1.94
7	425 mic	80.7	CC = 0.89
8	300 mic	48.2	MDD = 1.73 gm/cc
9	150 mic	2.8	OMC = 6.6%
10	75 mic	0.75	CBR (Un soaked) = 13.74
11	Pan	-	CBR (Soaked) = 11.78



Particle size distribution curve for Virgin Sandy Soil
Figure No.2

WATER: Drinking water has been used for experimental purposes.

Field tests for determining Strain Modulus as per GE:14/ DIN 18134 have been performed on natural ground, virgin clayey soil and mixed soil with a ratio of clayey soil : sandy soil :: 60:40 to find strain modulus (EV_2) i.e. modulus at 2nd loading cycle. Strain Modulus explains deformation characteristics of soil which is calculated from secants of load & settlement curves within a range of 30% and 70% of maximum stress. For this, trail beds of virgin clayey soil & mixed soil were made about 15m long and 3.50m wide each of varying thicknesses like 150 mm, 300 mm and 450 mm in each case as shown below: Heavy mechanical compaction has been done at OMCs and 97% of MDDs for each trail bed.

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Compaction of Trail Bed Vibratory Roller
Figure No.3

Prepared Trail Bed of Varying Thicknesses of 150mm, 300mm & 450mm
Figure No.4

First test was conducted on original ground upon which these trail beds have been prepared to know the effect of original ground which had already gone through the stages of consolidation in the past. Diameter of the loading plate of apparatus was 300mm. Following procedure was adopted.

Maximum stress given was 0.5 Mpa. Load of 0.01Mpa was given initially and kept constant for 30 seconds. Thereafter initial reading of dial gauge was set to zero. Total stress of 0.5Mpa was reached by giving load in increments of 1/6th of total load/stress i.e. each increment of 0.083Mpa. Change of load from stage to stage was completed within a period of 30 seconds. Time period of 120 seconds was elapsed between each stage of loading. Time period of 120 seconds was also made to be elapsed after final load of 0.5Mpa (maximum stress). This completed 1st cycle loading.

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Field Testing of Strain Modulus (EV2) on Natural Ground.
Figure No.5

Testing of Strain Modulus on Trail Bed.
Figure No. 6

Thereafter the applied load was released in 3 stages of 50%, 25% & 2% of maximum stress with a gap of 120 seconds between each stage. This completed first cycle unloading stage.
Again reloading was done i.e. 2^{nd} cycle loading adopting the methodology as mentioned above, but maximum load was kept up to 0.416Mpa i.e. loading has been limited to one stage below the ultimate loading stage of 1^{st} cycle. The load was maintained for 120 seconds and thereafter complete load was released. Settlements for each stage as above were recorded. Lever ratio for all the tests was kept as 1:1. Final corrected settlements were computed which were equal to the measured settlements being multiplying factor as one for 1:1 lever ratio. Values of Strain modulus have been found through empirical formulae as given in DIN-18134.

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3. RESULTS AND DISCUSSION

Field tests for determining Strain Modulus as per DIN 18134 have been performed on virgin clayey soil, virgin sandy soil and mixed soil with a ratio of clayey soil : sandy soil :: 60:40 to find strain modulus (EV_2) i.e. modulus at 2nd loading cycle.

Strain modulus (EV_2) i.e. at 2nd loading cycle has been calculated from the following formula as given in GE:14 and DIN 18134.

$$Ev = 1.5.r \frac{1}{a_1 + a_2 \,.\, \sigma_0 max}$$

Where Ev = Strain Modulus in Mpa

r = radius of loading plate in mm, which is equal to 150 in this case.

$\sigma_0 max$= Maximum normal stress below the loading plate during 1st cycle of loading in Mpa, which is 0.5Mpa in our case. The constants a_1, a_2 shall be calculated from 2nd degree polynomial equation as given below:

$$s = a_0 + a_1 \cdot \sigma_0 + a_2 \cdot \sigma_0^2$$

Where s = Total settlement in mm

a_0 = Constant in mm

a_1 = Constant in mm/ MN^2

a_2 = Constant in mm/MN^2/m^4

σ_0= Average Normal Stress below the plate in Mpa.

Thereafter three equations of each test results were framed as per DIN 18134 and values of constants a_0, a_1, a_2, have been found.

Strain Modulus (EV_2) test results at a glance are tabulated below:

Table No.3

Strain Modulus (EV2) Test Results (As per DIN 18134)

SN	Layer thickness in mm	Strain Modulus in Mpa			Percentage improvement.
		Original Ground	Virgin Clayey Soil	Clayey Soil : Sandy Soil :: 60:40	
1	150	98.89	64.88	74.90	15.44
2	300		49.75	56.86	14.29
3	450		46.19	52.13	12.86

Field observations, Graphical presentation of load v/s settlement curve, polynomial equations for working out constant and calculation of EV_2 are produced below for test performed on original natural ground.

Table No.4

Field observations for original natural ground

Loading Cycle	Loading Stage	Normal Stress σ_0 [MN/m²]	Load in kN	Settlement s [mm]
1st cycle loading	1	0.010	0.71	0.00
	2	0.083	5.87	0.36
	3	0.167	11.81	0.73
	4	0.250	17.68	1.07
	5	0.333	23.55	1.44
	6	0.417	29.49	1.85
	7	0.500	35.36	2.20
1st cycle unloading	8	0.250	17.68	2.03
	9	0.125	8.84	1.70
2nd cycle loading	10	0.010	0.71	1.15
	11	0.083	5.87	1.30
	12	0.167	11.81	1.47
	13	0.250	17.68	1.66
	14	0.333	23.55	1.85
	15	0.417	29.49	2.04

2nd cycle unloading

Graphical presentation of load v/s settlement for test performed on natural ground has been done as below:

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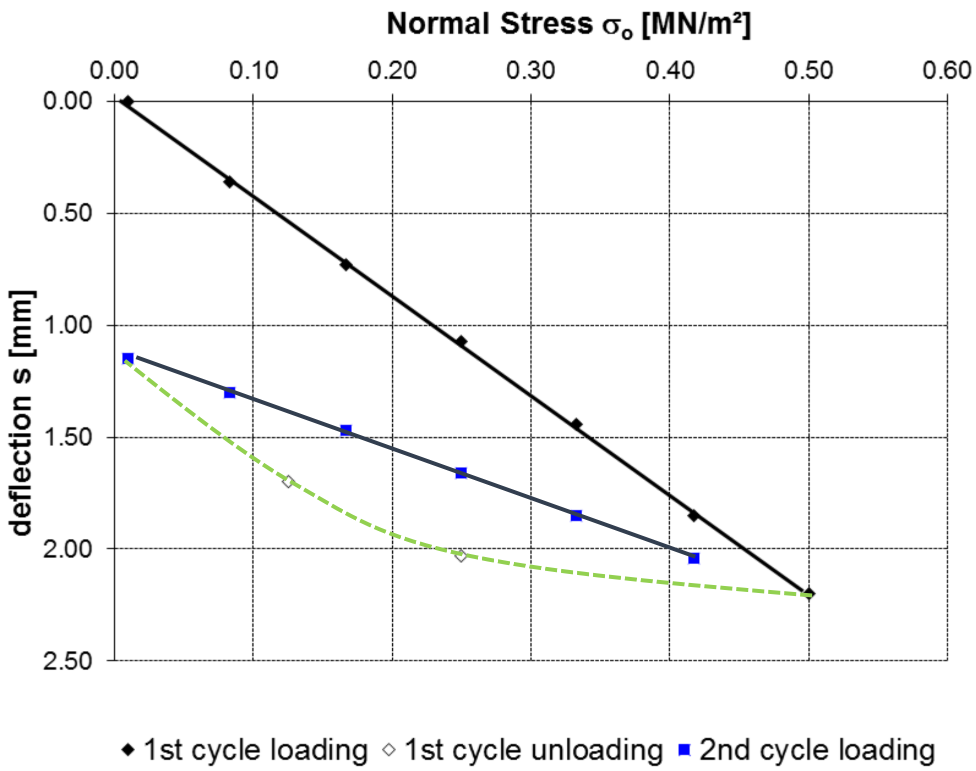

Load-Settlement Curve of Original Ground

Figure No.7

Table No.5
Calculations for constants based on 2nd loading cycle

Normal stress in MN/m2 (σ_0^1)	Normal stress in MN/m2 (σ_0^2)	Normal stress in MN/m2 (σ_0^3)	Normal stress in MN/m2 (σ_0^4)	Settlement 's' in mm	(σ_0^1).s	σ_0^2.s
0.01	0.000	0.000	0.000	1.15	0.012	0.000
0.083	0.007	0.001	0.000	1.3	0.108	0.009
0.167	0.028	0.005	0.001	1.47	0.245	0.041
0.25	0.063	0.016	0.004	1.66	0.415	0.104
0.333	0.111	0.037	0.012	1.85	0.616	0.205
0.417	0.174	0.073	0.030	2.04	0.851	0.355
1.260	0.382	0.130	0.047	9.470	2.247	0.714

Polynomial Equations used for calculation of constants are under

$$a_0 \cdot n + a_1 \sum_{i=1}^{n} \sigma_{0i} + a_2 \sum_{i=1}^{n} \sigma_{0i}^2 + \sum_{i=1}^{n} s_i$$

$$a_0 \sum_{i=1}^{n} \sigma_{0i} + a_1 \sum_{i=1}^{n} \sigma_{0i}^2 + a_2 \sum_{i=1}^{n} \sigma_{0i}^3 + \sum_{i=1}^{n} s_i \cdot \sigma_{0i}$$

$$a_0 \sum_{i=1}^{n} \sigma_{0i}^2 + a_1 \sum_{i=1}^{n} \sigma_{0i}^3 + a_2 \sum_{i=1}^{n} \sigma_{0i}^4 + \sum_{i=1}^{n} s_i \cdot \sigma_{0i}^2$$

Here n=6

$6a_0+1.26a_1+0.382a_2=9.470$	$a_0=$	1.1413617
$1.26a_0+0.382a_1+0.13a_2=2.247$	$a_1=$	1.7813866
$0.382a_0+0.13a_1+0.047a_2=0.714$	$a_2=$	0.98764986

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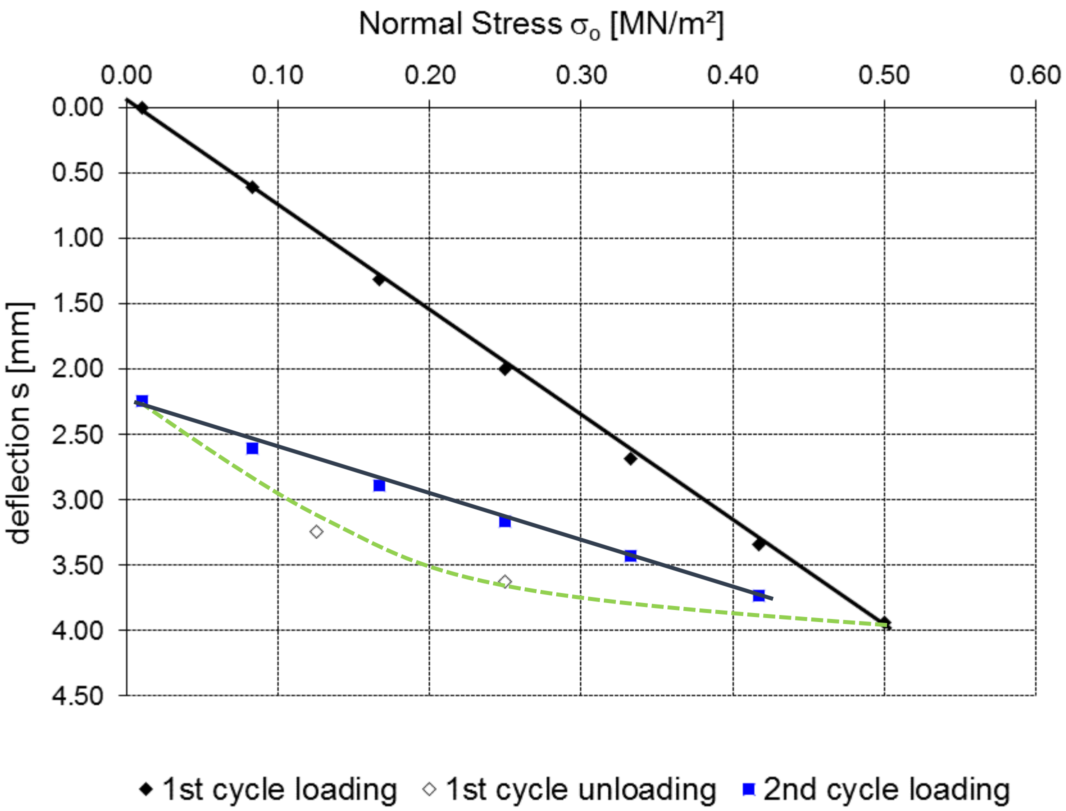
$$EV_2 = 1.5.r \frac{1}{a_1 + a_2 .\ \sigma_0 max}$$

$$= 1.5 * 300 \frac{1}{1.7814 + 0.98765 * 0.50}$$

=98.89 Mpa

Strain modulus (EV_2) value has been found as 98.89 Mpa as above. It is observed that first loading cycle, unloading cycle and unloading cycles form almost straight lines because of good homogeneity, good structure and good consolidation of soil as much time has elapsed since its deposit/formation.

Graphical presentation of load v/s settlement for tests performed on trial bed of virgin clayey soil of various thicknesses is below:



Load-Settlement Curve of Virgin Clayey Soil for 150mm Layer

Figure No.8

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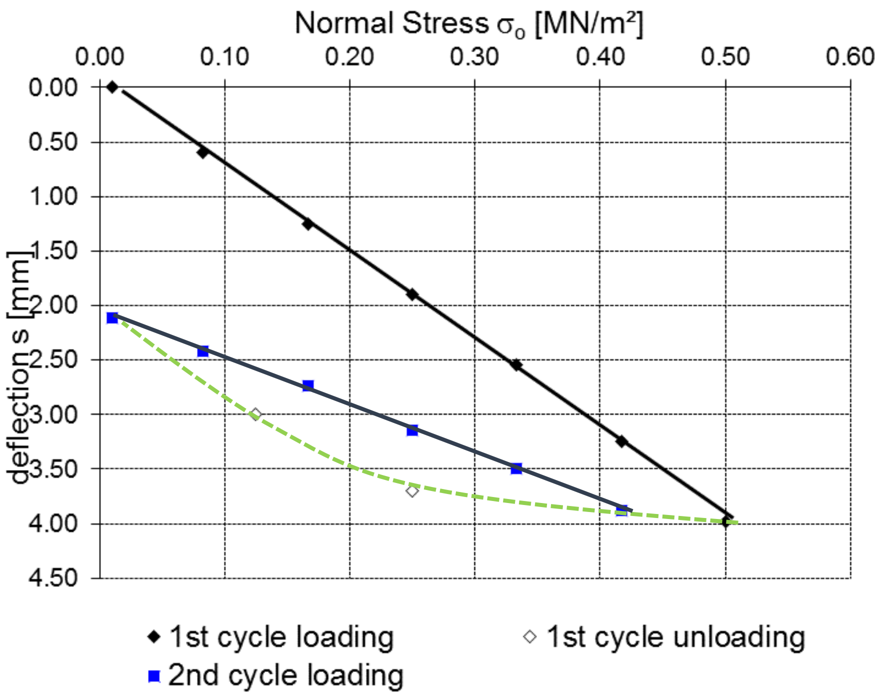
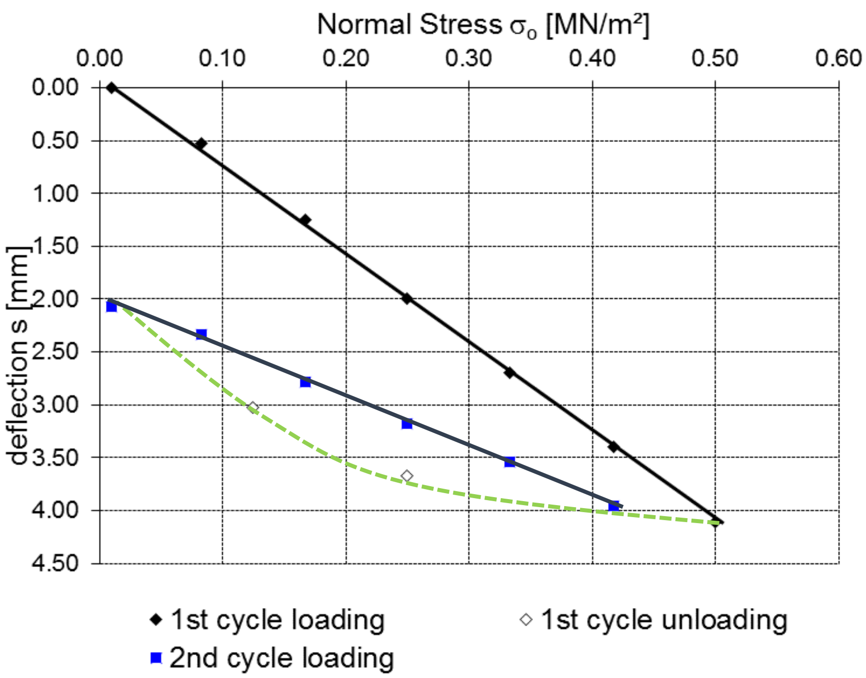


Load-Settlement Curve of Virgin Clayey Soil for 300mm Layer

Figure No.9



Load-Settlement Curve of Virgin Clayey Soil for 450mm Layer

Figure No.10

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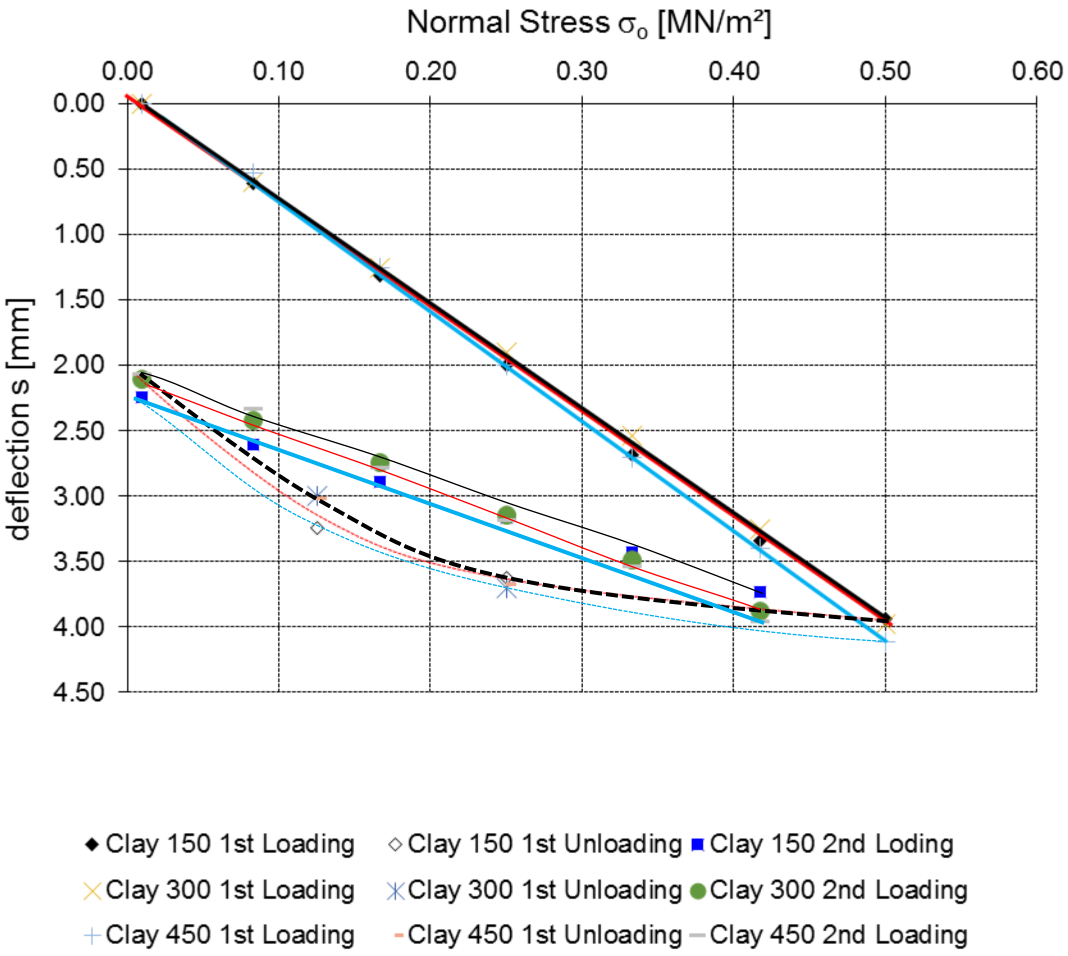

Load-Settlement Curve of Virgin Clayey Soil for all thicknesses

Figure No.11

Strain modulus values for all the above and balance tests have been found in the same fashion as explained above in case of original ground and detailed calculations not being produced. Strain modulus (EV_2) values have been found as 64.88 Mpa, 49.75 Mpa and 46.19Mpa for 150mm,300mm and 450 mm thicknesses of clayey bed respectively. It is observed that first loading cycle and second loading cycles form almost straight lines in this case also because of low rate of consolidation in clayey soils because complete consolidation of clayey soil takes years together. Rate of consolidation is very slow in clayey soils because of low rate of dissipation of pore water as clay particles have tendency to attract water molecules and continue to hold it till much surcharge load is given to the soil or length of drainage path is reduced with provision of sand drains or sand blanket etc.

Graphical presentation of load v/s settlement for tests performed on trial bed of mixed soil of proportion of virgin clayey soil:sandy soil :: 60 :40 of various thicknesses has been done as below.

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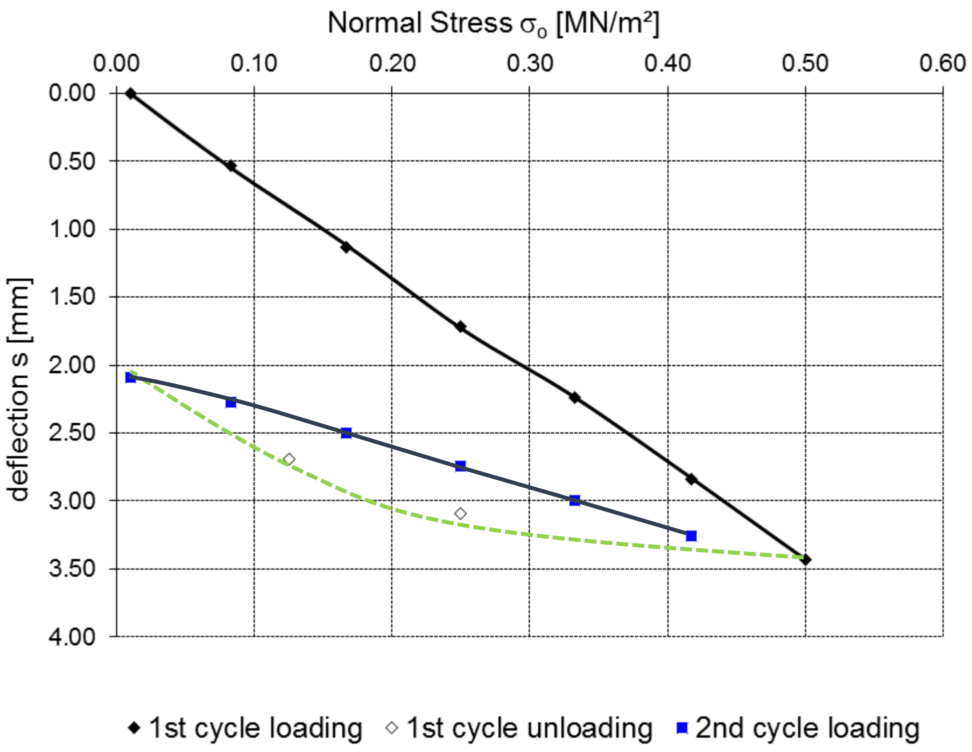
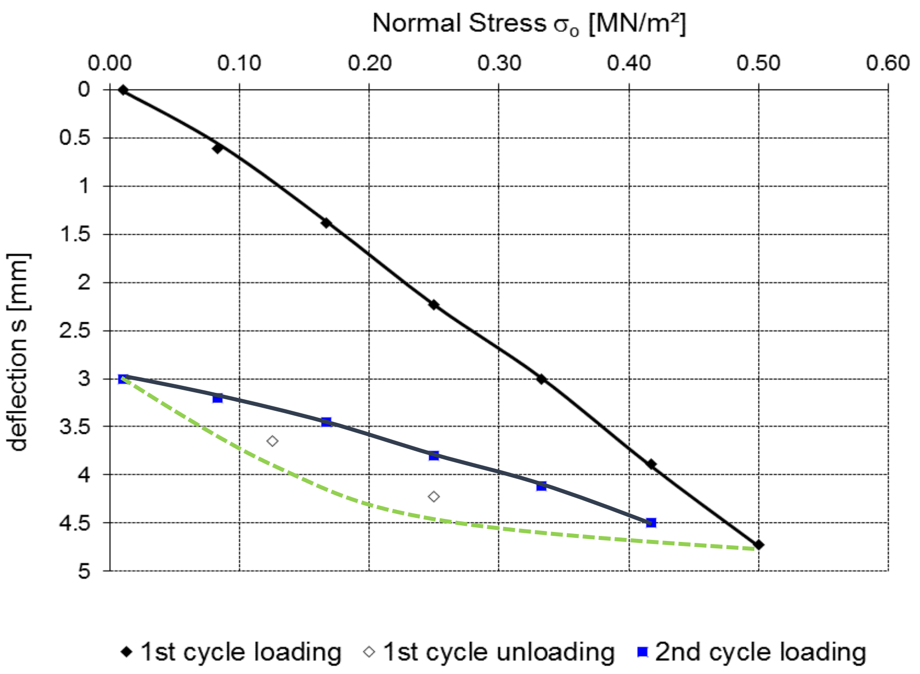


Load-Settlement Curve of Mixed Soil for 150mm Layer

Figure No.12



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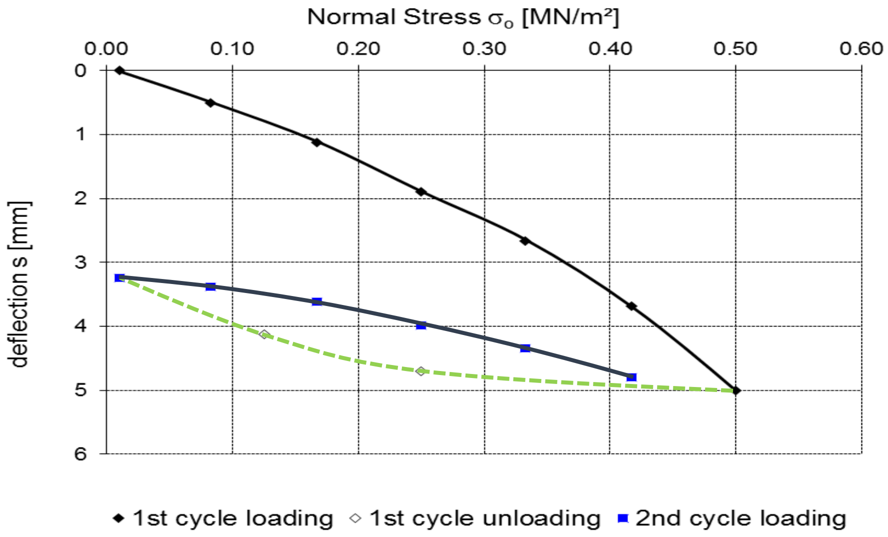
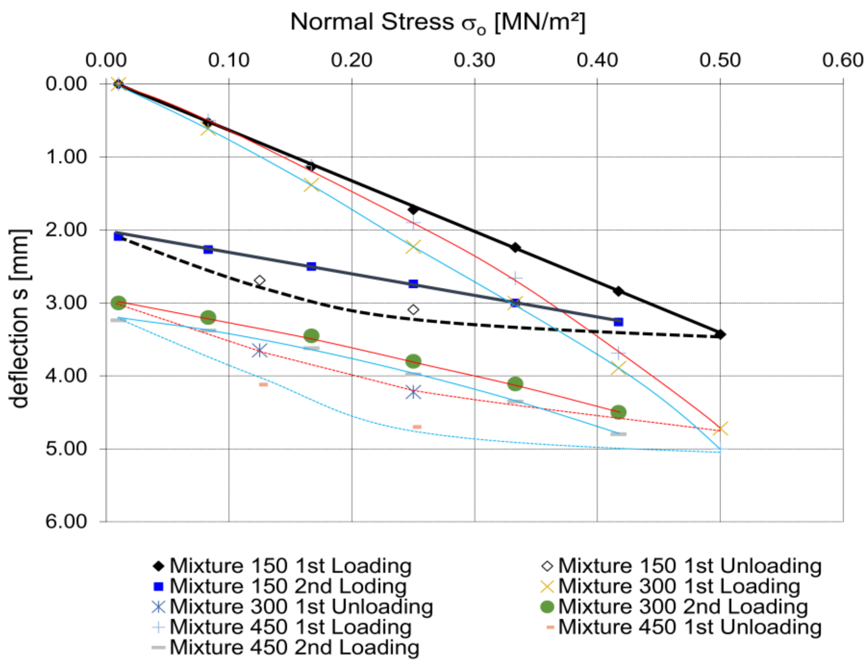
Load-Settlement Curve of Mixed Soil for 300mm Layer

Figue No.13



Load-Settlement Curve of Mixed Soil for 450mm Layer

Figure No.14



Load-Settlement Curve of Mixed Soil for all thicknesses
Figure No.15

Strain modulus values for all the above tests have been found in the same fashion as explained above in case of original ground and detailed calculations not being produced.

Strain modulus (Ev_2) values have been found as 74.9 Mpa, 56.86 Mpa and 52.13Mpa for 150mm,300mm and 450 mm thicknesses of mixed soil bed of proportion of clayey soil:sandy soil::60:40 respectively as above. It is observed that first loading cycle, unloading cycle and unloading cycles are curvilinear in this case which is due to immediate settlement effects of sandy soil which constitute 40% of total soil mass. Rate of settlement is high in sandy soils because of possessing high permeability which leads to high rate of dissipation of pore water.

Strain Modulus Results of Virgin Clayey Soil and Mixed Soil for various thicknesses have been presented at a glance as below:

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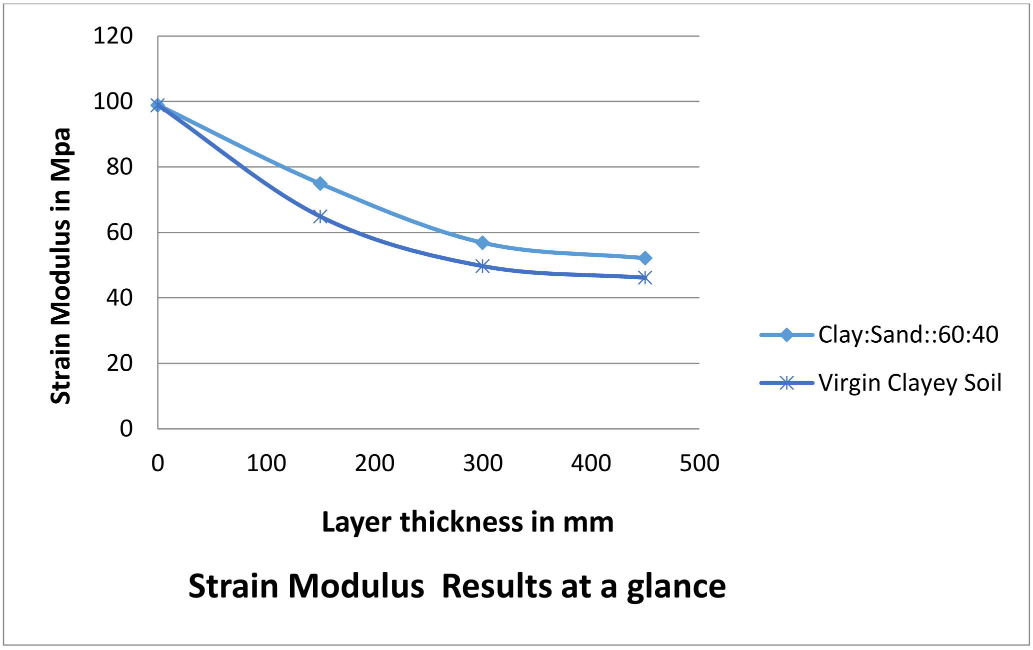

Figure No.16

From table 3 & figure 16 above, it is seen that Strain Modulus (EV_2) of mixed soil has increased by 15.46%, 14.29% & 12.85% for layer thickness of 150mm, 300mm & 450mm respectively. Small variations in %age increase for layers of different thicknesses is due to the effect of underlying consolidated natural ground where maximum EV_2 value has been observed. In case of 150mm prepared bed layer, stresses are transferred to natural ground to a depth of about 300mm i.e. 1.5 times of diameter of loading plate. Lesser stresses are transferred to the natural ground as we go on increasing the thickness of prepared bed because of shifting of stress influence zone to prepared bed from natural ground.

It is seen that strain modulus for all the thicknesses of mixed soil i.e. clayey soil: sandy soil:: 60:40 has increased as above. This is due to improvement in gradation of mixed soil wherein voids in sandy soil have been filled up with clayey soil. This is also due to sand particles having more crushing strength than clay particles. Cycling loading has brought clay and sand particles closer and increased overall denseness of soil mass. Sand particles have thus increased the load carrying capacity of mixed soil and decreased net settlement, this has lead to sharpening of stress strain curve and resulted in increase of strain modulus value .

Strain modulus (EV_2) of mixed soil has increased by 15.46%, 14.29% & 12.85% for layer thickness of 150mm, 300mm & 450mm respectively.

4. CONCLUSION

Strain modulus (EV_2) of mixed soil of proportion clayey soil : sandy soil :: 60:40 has increased by 15.46%, 14.29% & 12.85% for layer thickness of 150mm, 300mm & 450mm respectively and it is concluded that blending of sandy soil to clayey soil has positive effect on overall basis.

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