International Journal of Scientific & Engineering Research, Volume 4, Issue 6, June-2013 574
ISSN 2229-5518

Procedure of Achieving High Range Elastic Properties of Soilmass for Creation of Better Foundation soil

Gokul k Bayan

Abstract— Improvement of properties of weak soil mass by treating them with hard inclusions is the objective of this study. In general, constitutive behavior of soil mass is normally measured in-terms-of its nature of particle size density together with the existence of water quantity. Achieving the best behavior in-term-of elastic properties is always desirable for construction of better foundation of structures on soil mass. However, elasticity range of soil mass is quite small at its untreated stage, in comparison to other building materials. Hence, it reveals less allowance in every directions of its behavioral expression. Of many, settlement is the principal criterion to put attention for achieving the best safety performance. To achieve the above goal some laboratory model tests were performed. In consistence, three series of R&D works were carried out in a model plate load machine by using three types of soil mass under various field conditions treated with hard inclusions. The results reveal high range elastic properties of the treated soil mass to be used for road and building foundations. In conclusion, it is found that - utilization of such achievements generates a system of surface foundation in reality with the targeted properties.

Index Terms— Elastic properties, foundation, honey-comb-cell, hard inclusion, improvement, settlement, Soil mass

1 Introduction

SOIL mass is a disintegrated geomaterials which express its naturally bonded behavior with its water content. Constitutive particles of soil mass perform individual activities within its stage of micro action phenomenon. Integrated result of such micro action leads to development of macro action. Finally the integrated macro action yields physical behaviour of the soil mass. Such behaviour is found in three different categories. Accordingly, such behaviour of soil mass is termed as elastic, plastic or brittle material. In which way micro actions lead to generate macro action and ultimately reveal behaviour, exactly in that way it bears the witness regarding its entity of geological origin in nature. Profoundly, the three forms of behaviors pertaining to elastic or plastic or brittle nature bearing presence of density variation of different particles coexist with water content indicates its utility expressing its aspect of geological origin. Study reveals that such behaviour of geologic origin do not express wide range of variation of properties as and when it is placed for utilization in a remolded state.

To obtain high range elasticity of a structural soil mass is the prime objectives of this study for yielding the best performed structures like construction of road and building foundations to be placed at surface level. Accordingly, three series of R&D works carried out in a model Plate Load Test (PLT) by using three types of soil mass under various field conditions comprising special form of hard inclusions. Obviously, for soil mass, hard inclusions are more rigid material and it is made either of PVC or Steel. Therefore, counting of their individual behaviors with the loading intensity is beyond scope of this study.

• *Principal Scientist, North East Institute of Science & Technology (CSIR- Govt. of India), Jorhat; CSIR – NEIST Branch Laboratory, Itanagar, Arunachal Pradesh, Pin-791 110, Email: gokul_kb_ctk@yahoo.com*

In broad sense, field condition comprises two phases. Treated and untreated phase as the field condition implies. Physically treated phase includes engineering development of soil mass with hard inclusion to soil mass for generating confined environment of structural soil. It is achieved through development of inner and outer confinements. The complete confined situation created through such stages is known as fully treated structural soil mass (FTSM). Preparation and field placement of such FTSM is the ultimate goal to achieve which yields high range of elastic properties. Thus it reveals the concept of developing surface foundation for both road and building.

In this contexture, Table 1 gives various geotechnical properties of the structural soil used for conducting three series of constitutive model test to explore their engineering behaviours in the laboratory.

2 Procedure for Experimental Evaluation of Elastic Behaviour of Soil mass

2.1 Procedure for arrangement of soil layer

A good number of constitutive model tests in the laboratory were carried out keeping the field condition representative such that observed behaviors shall be materialized. In this regard, preparation of treated soil mass is equally important as that of their placement in location. In reality at the field, for achieving the best performed foundation soil mass, the in-situ subsoil is treated with desired inclusion at that state, as and when the water content of the preparing soil mass is closely lower than its optimum moisture content (OMC). The moisture closely below the OMC is the criterion to fix its inclusions for development of its engineering properties. At this stage of treated soil mass reveals more elastic behavior. After such development of the structural soil mass with special rigid inclusions, which are termed as inner skirt or outer skirt to the soil mass, it is found that the water absorption capacity of those treated soil particles is turning to about stagnant situation. Hence, the chances of attaining its worst situation comprising cent percent saturation stage become zero. Under influence of this stage, because of the applied load on the treated soil mass, particularly at this intermediate state of water content with confinement made of impervious rigid material, the soil mass never try to freely achieve its plastic limit stage which is the aim to achieve through these efforts.

In consistence to the above, a thin layer of soil mass, the thickness of which is equal to height of the outer skirt adopted, is taken, created with treatment of hard inclusions arranged in honey comb cell pattern and placed just below loading plate to carryout the series of tests, which is shown in Fig. 1 in detail.

Table 1. Properties of structural soil used for conduction of different tests in various condition

Broad division of soil (BDS), their geological origin and physical description of soil samples used	Soil grains as p.c. passing Grain size in (mm)					Basic properties of soil (i.e. Consistency limits) in %			Classification of soil as per IS:1498	Result of Standard Proctor Test		Result of Direct shear Test from LB-DST*		SBC of ground from PLT* in (kN/m^2)
	10.0	4.75	1.18	0.15	0.075	W_L	W_P	I_P	Group Symbol	OMC	DD in kN/m^3	'C' in N/mm^2	'ϕ' in degree	
(1) BDS-1. Laterite soil of upper tertiary deposit in local lake; Reddish brown to pale yellowish brown color in wet condition; Inorganic sandy-silt of low compressibility with angular-rounded grains														
(1.1) Reddish brown color soil	93.6	87.3	73.2	35.3	21.8	None-plastic			SM	11.6	18.7	0.6	33.2^0	156
(1.2)***Pale brown color soil***	84.2	90.9	69.3	25.9	16.4	None-plastic			SM	10.5	19.4	1.5	35.0	107
(2) BDS-2. Alluvial soil of recent deposit in local lake; yellowish to blackish grey color in wet condition; Inorganic or organic silty-clay of low compressibility with rounded grains														
(2.1) Yellowish grey color soil	100	100	100	98.7	97.9	32.7	23.4	9.3	CL	18.3	17.8	1.0	29.5^0	69.7
(2.2) Blackish grey color soil	100	100	100	97.1	91.5	27.0	21.9	5.1	ML-OL	16.0	18.2	1.1	27.0^0	67.7
BDS-3. Colluvial soil of quaternary deposit in local lake; bluish grey to pale grey color in wet condition; Inorganic or organic sandy-silt of low compressibility with angular grains														
(3.1) Pale bluish grey color soil	88.5	81.3	64.5	32.8	24.3	None-plastic			SM	7.25	19.6	0.3	34.99	346

Note: LB-DST* implies Large Box Direct Shear Test & PLT* implies model Plate Load Test carried out in the laboratory

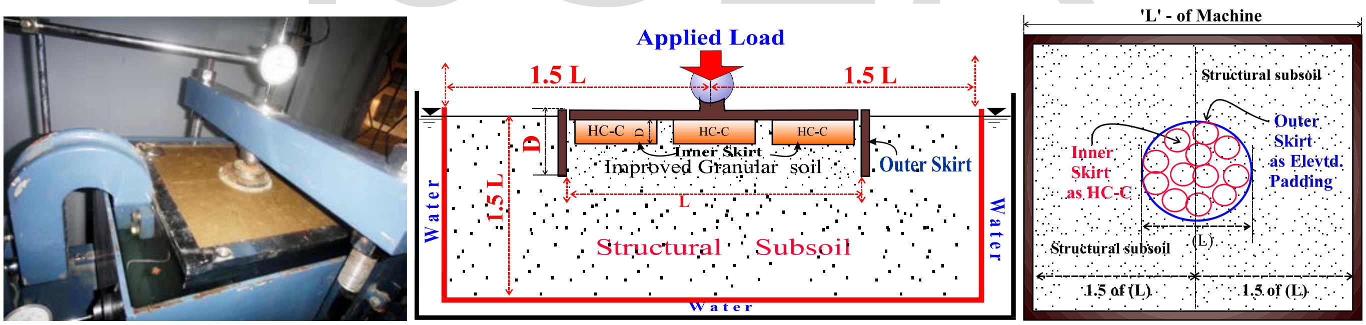

Fig. 1.a Photograph of PLT in LB-DST

Fig. 1.b PLT arrangement in longitudinal section

Fig.1.c shows the PLT in Plan

Figure 1 Arrangement for conduction of numerical model plate load tests

2.2 Procedure for preparation of hard inclusions into soil mass and generation of site conditions

The treated soil layer described above is named after their process of treatment engaged to generate improved field condition. Thus, the process involved is consisting of developing the following –

(i) Inner confining skirt of circular shape placed as honey comb cell type mass particle and
(ii) Outer confining skirt used as elevated Padding.

Both the skirts are filled with soil materials (Fig. 1).

Further, filling materials may also vary in two ways as –

(i) Soil that of site available nature (weak or strong) used as structural soil below foundation level, and
(ii) Soil that of borrowing improved quality granular soil-mass (IQGrS) for filling the layer.

The overall process having the best situation involved consisting of development of inner confining ring as open cell type mass particle and outer skirt in combination as shown in Fig. 1. Similarly, the treated layers so placed are as 1st layer, filling with insitu soil materials and 2nd layer filling with IQGrS below which is the site original massive subsoil (Fig. 1).

ISSN 2229-5518

Both inner skirt, which is known as micro *cell particle* to the system and outer skirt, which is known as *skirt padding* are defined by their characteristics ratio (CR). In this regard for all model PLT, the depth (D) implies to the total used length of the ring type structural inclusion and the length (L) implies to the outer diameter of the ring type inclusion. Thus the ratio of depth (D) to length (L) is termed as CR, or RR particularly for inner cell particles. Similarly, the same ratio for outer skirt is termed as SR i.e. skirt ratio. Such confined soil cell particle of RR is arranged as honey comb cell (HC-C) manner (Fig. 1) placed in a same plane treated with confined pressure of outer skirt which is placed as elevated skirt padding with SR value or untreated with outer skirt condition. In this regards, Table 2 gives some characteristics account of such hard inclusions used for conducting the series of tests as model PLT.

Table 2. Characteristics properties of hard inclusions used in the series of tests

Particulars of items and their materials used to conduct the tests	Dimensions in (mm)			Characteristics Ratio (CR) = Depth to Length	Area within skirts used as individual/group in (mm^2)	
	Outside Diameter (Length)	Inside Diameter	Depth		For PLT & K-value test: As individual/ group inclusion without soil	For CBR-value test: Used in CBR mould during penetration
1. Outer Skirt of Steel (Sk-1)	115	107	32	0.278	Area of 1 Sk 10386.9	Area (1- Sk) 10386.9
2. Outer Skirt of Steel (Sk-2)	60	54	23	0.383	Area of 1 Sk = 2827.4	Area (1 Sk) 2827.4
3. Inner skirt (HC-C) as cell of PVC						
3(a) PVC-1	40	36	5	0.125	Area of 4 Sk 5026.5	Area (4 Sk), 5026.5
3(b) PVC-2	25	22	5	0.200	Area of 4 Sk 1963.5	Area (4-Sk), 3712.2
3(c) PVC-3	23.5	21	11	0.468	Area of 4 Sk 1828.4	Area (4-Sk), 3712.2
3(d) PVC-4	23.5	21	20	0.851	Area of 4 Sk 1828.4	-
3(e) PVC-3	23.5	21	32	1.36	Area of 4 Sk 1828.4	-
4. Inner skirt HC-C of Steel (STL)	19	17	19	1.000	Area of 7 Sk 1984.7	Area (7-Sk), 3237.1
-Do-	19	17	32	1.68	Area of 7 Sk 1984.7	--

For different series of tests carried out with various type of soil with different values of CR or RR, such values are fixed with many trials, which become the desired value, e.g. 0.125, 0.20, 0.468, 0.851, 1, 1.36 & 1.68 (Table 2).

In consistence to the above, the IQGrS when made confined or treated with outer skirt is generating another characteristic ratio which is termed as improved granular soil ratio (IGSR). This ratio is also found out as L/D of the Skirt. However, the D is defined as – total thickness of compacted granular mass inside the skirt.

For the whole series of tests conducted under the present study, the IGSR value considered is mostly one i.e. 0.278 in stead of many. The reason is: it is revealed after putting many efforts by evaluated opinion on the use of their IGSR aspects that, this value may be holding better yielding optimum behavior in our present study. Alternately, in general case, the depth of such outer skirt should not exceed the largest diameter of the inner skirted ring use to develop HC-C which is placing in single, double or triple layers within the SR.

Finally, the permutation and combination of such criteria having RR, SR and IGSR generates many categories of treated soil conditions. Of the many, the treated skirt condition having HC-C process filling with IQGrS is termed as FTSM which is found the best. Out of many trials of FTSM with different RR values of HC-C, the combination bearing CR value 1.0 is found to be the best suitable process for obtaining high range elastic properties.

Of course, following engineered conditions were created and are availed to conduct the series of tests:

- Untreated condition – implies PLT without inclusion of CR, SR and IGSR.
- Treated condition – implies PLT with inclusion of CR or SR or IGSR, or combination of both or all with variation of their individual values as under:
  - SRB-SF – implies padding & HC-C ring base surface foundation layer with different values of CR e.g. CR=0.125, 0.468, 0.851, 1; etc.
  - SLRB-SF – implies Skirtless but HC-C ring base surface foundation layer with different values of CR e.g. 0.125, 0.468, 0.851, 1; etc.
  - SGrB-SF – implies skirted granular soil but without HC-C ring base surface foundation layer with different values of IGSR e.g. 0.299; 0.187; etc.
  - SRGrB-SF – implies skirt & HC-C ring with improved granular soil filled base surface foundation layer with different values of CR & of IGSR e.g. CR-0.468 & IGSR-0.299; etc.

In reality, the combination of this CR, SR and IGSR as a thin engineered layer to this method of soil improvement governing the process of development of surface foundation for

ISSN 2229-5518

Road [2,3] and low rise buildings upto 12 storey height [1,2,3,4,5&6]. However, such treatment is extensively differing by principle and practice as and when the subsoil ground is treated with granular piles or stone columns [7].

2.3 Conduction of test and value achieved

In the above series of tests so carried out under model PLT set up that placed in a LB-DST machine (Fig. 1), it was tried to maintain the above mentioned field situation for each tests so conducted. The preparation of the tests with selective undisturbed and remolded soil mass (Table 1) is done meticulously to achieve targeted field condition and moisture situation. For the remolded soil, standard compaction procedures were followed and soil layers are placed at moisture content closely lower to OMC. Additional moisture content is allowed to increase by absorption from bottom of the testing soil mass through machine system after setting of all loading and measuring devices (Fig. 1). After a few hours of absorption i.e. approximately crossing about 45% saturation, load versus settlement tests were commenced for every trial tests as per relevant IS: Code of practices to conduct the PLT.

About 30 number of different model tests were conducted and carriedout on different diameters and lengths of HC-C under various field conditions to study the overall settlement behaviours and increase in bearing capacity. Yielding improved bearing capacity with less amount of settlement proclaims the possession of high elastic properties of the treated soil layer than the untreated one. To establish this fact and to provide a comprehensive understanding of the present study, for instance let us take one series of PLT test carriedout with one type of soil (Table 1), the results of which is tabulated in tabular form and are given in Table 3.

3 Test Results and Discussion for High Elastic Property

In total 30 number of model PLT were carried out with three kinds of soil given in Table 1. It is not felt necessary to state all the results one by one. However, for comprehensive understanding and for scientific discussion regarding how it is achieving which fulfilling the aim and objective of the study, a few number of test results carried out with soil type BDS-1(1.2 of Table 1) i.e. pale brown color soil of laterite origin are presented here in Fig. 2. For illustrative purposes, Fig. 2 shows a series of PLT results which are representative by nature of all series of tests conducted under various field conditions with different soil materials.

Fig. 2 demonstrating all about seven kinds of test results which represent seven varieties of applied field conditions for a single type of soil. In general, the PLT curve reveals loading intensity (i.e. stress), settlement (i.e. strain) and ultimate elastic stress which is utilized for finding factor of safety (FoS) from geological point of view and final safe bearing capacity (SBC) of the soil used to carry out the PLT. Hence, yield stress is an important expression of soil behaviour which is the maximum elastic stress point of the tested soil mass. Since it is known as critical stress point i.e. end point of elastic behavior of soil mass, therefore, the execution of plastic behavior begins beyond this point. Such critical point is illustrated and marked on curve no. 1 in Fig. 2.

Table 3. Result of one series of Model PLT with laterite soil used for both layers

<table>
<tr><td colspan="12">Basic data
Type of soil used: Laterite soil of gravelly silty sand (Table 1) compacted at closer to its OMC.
Size of loading plate used: Circular steel plate of 98.6 mm diameter & 7635 mm^2 area.
Outer skirt of steel ring : Length as OD =115 mm & Depth as used length of ring = 32 mm
Inner skirt of PVC ring forming HC-C : Length as OD =23.5 mm & Depth as used length of ring = 20 mm</td></tr>
<tr><td colspan="3">Particulars about remoulded soil</td><td colspan="5">Field conditions applied in PLT</td><td colspan="3">Details of Model Plate Load Test</td><td rowspan="4">Improvement of treated SBC over untreated</td></tr>
<tr><td colspan="3">Properties of soil used</td><td colspan="3">Characteristics of hard inclusion</td><td rowspan="3">Layer-1 i.e. Foundation subsoil</td><td rowspan="3">Layer -2 i.e. Engineered soil</td><td rowspan="3">Load in Kg/cm^2</td><td rowspan="3">Total settlement in mm</td><td rowspan="3">SBC in t/Sq.m</td></tr>
<tr><td rowspan="2">Parameters</td><td rowspan="2">Layer-1 forming base</td><td rowspan="2">Layer-2</td><td colspan="3"></td></tr>
<tr><td>IGSR</td><td>CR</td><td>Quantity</td></tr>
<tr><td rowspan="2">Density in gm/cc</td><td rowspan="2">1.88</td><td rowspan="2">Nil</td><td rowspan="5">Nil</td><td rowspan="5">Nil</td><td rowspan="5">Nil</td><td rowspan="5">Field subsoil with gravel 60 – 12 mm</td><td rowspan="5">No 2nd layer</td><td>0.811</td><td>0.38</td><td rowspan="5">11.7</td><td rowspan="5">Remain same at surface level</td></tr>
<tr><td>1.094</td><td>0.49</td></tr>
<tr><td rowspan="3">Moisture content in %</td><td rowspan="3">14.95</td><td rowspan="3">Nil</td><td>1.658</td><td>0.80</td></tr>
<tr><td>2.364</td><td>1.45</td></tr>
<tr><td>3.704</td><td>4.75</td></tr>
<tr><td rowspan="4">Density in gm/cc</td><td rowspan="4">1.88</td><td rowspan="4">2.0</td><td rowspan="8">0.174 for 20 mm thick granular soil for Layer-2</td><td rowspan="8">0.851</td><td rowspan="8">12 no. within outer Skirt</td><td rowspan="8">Field subsoil with gravel 60 – 12 mm</td><td rowspan="8">Field subsoil after passing 10 mm Sieve</td><td>0.822</td><td>0.39</td><td rowspan="8">36.0</td><td rowspan="8">208 % at surface level</td></tr>
<tr><td>1.244</td><td>0.70</td></tr>
<tr><td>1.455</td><td>0.88</td></tr>
<tr><td>1.913</td><td>1.22</td></tr>
<tr><td rowspan="4">Moisture content in %</td><td rowspan="4">14.95</td><td rowspan="4">14.95</td><td>2.512</td><td>1.61</td></tr>
<tr><td>3.111</td><td>2.08</td></tr>
<tr><td>3.710</td><td>2.75</td></tr>
<tr><td>5.083</td><td>9.23</td></tr>
</table>

ISSN 2229-5518

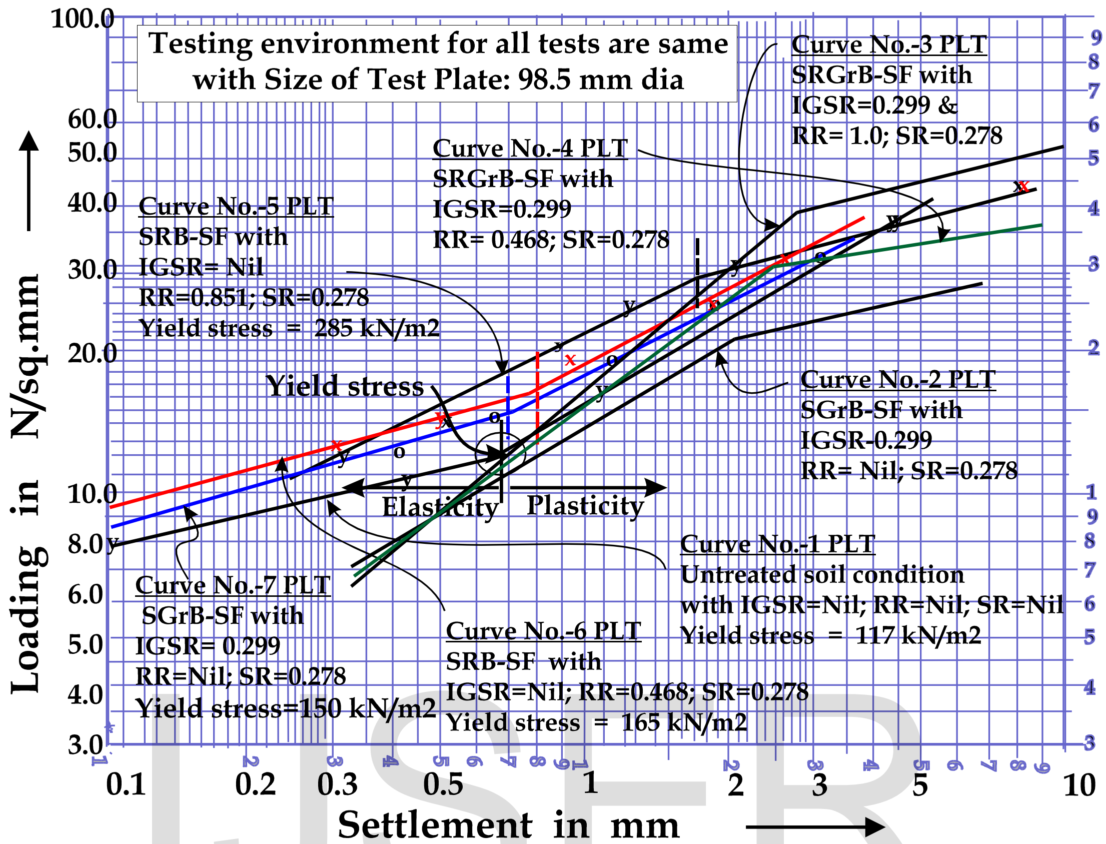

Fig. 2 Load Vs settlement curves representing results of a single type structural soil mass namely Laterite soil of pale brown color.

Curve no.1 represents the untreated normal ground and hence, it expresses the geologic original range of elasticity of the soil mass which is prevailing in nature without treatment. The range of elasticity expressed through elastic settlement Vs corresponding stress is the shortest range, which reveals a lower most yielding stress. On the other hand, the higher most range of elasticity expresses by curve no. 3 among the present results in Fig. 2. The field condition represented by curve no. 3 is evidently for SRGrB-SF with all form of possible combination described earlier. However, the determining criteria like IGSR, SR & RR for the present study imply to value given are 0.299, 0.278 & 1.0 respectively. This is the best combined process known as FTSM of soil mass development for construction of surface foundation layer built as Bi-layer footing foundation system [4,5,6] for building and road foundation [3] with high range elasticity.

Study reveals that the achievement of high range elastic behavior of such FTSM developed with various types of soil (Table 1) are varied extensively but always reveals many times more that the untreated site ground (Curve No. 1), which is given in Table 3.

4 CONCLUSIONS

Present study carried out for achieving high range elastic properties of soil mass to be used as road and building foundations reveals the following:

- It is possible to enhance the elastic property of naturally occurs soil mass many times (Fig. 2) by treating them with hard inclusion with their characteristics ratio (Table-2) pertaining to RR, SR and IGSR placing them as one thin layer to Bi-layer SF system which reveals stable and durable structures.
- It is concluded that FTSM with the highest combination of various field conditions generates the highest elastic property layer to bi-layer foundation system comprising surface foundation, which can be used as shallow foundation for multistorey building as well as road foundation as express way.
- Present study carried out as Model PLT as an innovative work attracts more meticulous study with prototype results in future to achieve more benefit for human developments.

5 Acknowledgement

The author extends his thanks gratefully to Dr. R.C. Baruah, Acting Director, North east Institute of Science and Technology (CSIR), Jorhat, Assam; (formerly RRL-J), for his kind permission to publish this paper.

6 References

[1] Gokul K Bayan: Improved Bearing Capacity for 2nd Layer of Foundation Subsoil in Bi-layer Footing Foundation System– A Concept of Surface Foundation. Phoon, K. K., Chua T. S., Yang, H. B. & Cham, W. M. (eds); Proc. Volume of International Symposium on Advances in Foundation Engineering (ISAFE 2013), 5-6 December 2013, Singapore (Accepted for publication).

[2] Gokul K Bayan: Achieving High Range Elastic Properties of Soil mass for more Stable and Durable Geostructure; Q. Yang et al (Eds): Constitutive modeling of geomaterials, SSGG; Beijing, China [© Springer-Verlin Heiberg, 2013], October, 2012, pp 391-397.

[3] Gokul K. Bayan : Road foundation – a new avenue for its stable and everlasting aspect. B. Indraratna, C. Rujikiatkamjorn and J S Vinod (eds.), Book on "Int. Conference on Ground Improvement and Ground Control". 2012, University of Wollongong, Australia. Publisher: Research Publishing Service, ISBN: 978-981-07-3560-9; pp 1639 – 1647.

[4] Gokul K Bayan : Introduction of bi-layer footing foundation for multistorey RCC building in weak subsoil of lower Himalayan region in India–A case study; Geotechnics for Sustainable Development– Geotech Hanoi 2011; Phung (Edt.); Construction Publishing House (ISBN 978-604-82-000-8); Vietnam; pp 387-398.

[5] Gokul K Bayan: Design & Detailing of (G+6)-Storeys rcc Building of Er. Ayung Nabam, with Bi-layer Footing Foundation System at Doimukh; M/S Design-Tech Pvt. Ltd, Report No. Report No.DgT/ Nabam/ rcc Building/ 7s 2011 July; Naharlagun; Arunachal Pradesh; India pp 1-166.

[6] Gokul K Bayan : Failure of a 4-storey RCC Building and its Retrofitting with bi-layer footing foundation under Eq Zone V – A Case study; IGC-11 Proc. of IGS & Cochin University of Science and Technology, Dec., 2011..Kochi, Kerala, pp 999 – 1002

[7] Gokul K Bayan : Behaviour of Weak soil Foundations Treated with Granular Piles. Proc. 12th Asian Regional Conference, ISSGE (International Society for Soil Mechanics and Geotechnical Engineering), Aug.2003. Singapore pp 443-447.