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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
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(54) Title: METHOD OF REDUCING SWELLING OF EXPANSIVE SOILS REINFORCED WITH GRANULAR PILE

(57) Abstract: Present invention relates to method of reducing swelling of expansive soils of expansive soils by granular pile technique. Besides initial moisture content. W_i, the spacing between the piles (expressed by s/d ratio; s = spacing between the piles and d = diameter of a pile) and the relative density of granular pile forming material were the variables of the study. Three initial moisture content 15%, 17% and 20%, three s/d ratio values 2, 3, and 4 and two relative densities of the sand (D_r) 50% and 70% were selected. Granular piles of different diameters were installed in prepared clay beds in model cylindrical moulds. Reduction in swelling of expansive soils due to installation of pile, depends on W_i, s/d ratio and the relative density (D_r) of the granular pile material.

METHOD OF REDUCING SWELLING OF EXPANSIVE SOILS REINFORCED WITH GRANULAR PILE

FIELD OF THE INVENTION

The present invention relates to method of reducing swelling of expansive soils without and with granular pile.

BACKGROUND OF THE INVENTION

Expansive soil deposits occur in the arid and semi arid region of the world and are problematic to engineering structures because of their tendency to heave during wet season and shrink during dry season. These soils are prone to increase in volume on absorption of water, resulting in great volume expansion and reduction in strength (Holtz and Gibbs 1956; Grim 1968; Jones and Holtz 1973; Chen 1988). Several nations in the world face construction problems associated with expansive grounds (Gourley et al. 1993; Puppala and Cerato 2009; John and Ian 2012). Light structures such as highways, railroads, runways, and other lifeline structures, constructed over such soils often get severely damaged due to high swell-shrinkage behaviour and loss of strength owing to fluctuating water content (Zheng et al. 2009). Due to the above reasons construction on or using expansive soils is considered to be unsafe.

The traditional techniques of ground improvement, like cohesive non-swelling soil layer, sand cushion method, chemical stabilization, deep soil mixing method, mixing of different cementitious and non-cementitious materials like lime, cement, fly ash, stone dust etc. (Katti et al. 1983; Satyanarayana 1969; Estabragh et al. 2014; Madhyannapu et al. 2009; Cokca 2001; Zha et.al 2008; Mathur et al. 2012; Phanikumar and Sharma 2004; Sridharan et al. 2006; Eme et al. 2016) etc. are available. These have difficult of mixing the stabilizer to the soil properly and limited to treat the soil to shallow depth only. Hence the search for developing a new technique for expansive soil improvement still remains alive and relevant.

The technique of soft soil improvement by installation of granular piles (also known as stone columns) is popular to marshy lands, marine clays, loose sand, silty or clayey sand, and compressible soils. Granular piles not only strengthen the load bearing capacity of the ground but reduce the settlement, improve the drainage and overall stability. They are most effective in clayey soils having undrained shear strength ranging from 7-50 kPa (IS: 15284 (Part-I):2003).

Many investigators have reported that installation of granular pile in expansive soils have positive effect in enhancing the load carrying capacity (Hughes and Withers 1974; Priebe 1995; Black et al. 2006; Guetif et al. 2007; Stuedlein and Holtz 2012; Hanna 2013; Zhang et al. 2013; Rangeard et al. 2016). However, detailed and systematic invention on the influence of granular pile on swelling of the expansive soil has needs to be carried out.

Rao and Padmavathi (2010) studied heave behaviour of expansive clay reinforced with granular pile anchors (GPA). In that, the foundation was anchored to a mild steel plate provided at the bottom of the granular pile. That became tension – resistant and prevented the particulate medium from getting sheared away by the swelling soil surrounding it. The various forces acted on the granular pile-anchor is shown in Fig.1. The swelling potential of the untreated soil with an initial moisture content of 14% at dry unit weights γ_d of 13.0, 14.0 and 15.0 kN/m^3 were found to be 6%, 9% and 14% respectively. The swelling potential of the soil was increased with an increase in its dry unit weight. This is because, as γ_d is high, the number of particles in the expansive soil is more. Greater surface area was thus available which gives greater scope for accumulation of water around the soil particles and a consequential increase in swelling.

Aparna et al. (2014) have observed reduction in swelling of black cotton soil by using granular pile/sand column at different water content. The black cotton soil used was CH, i.e. clay of high plasticity and compressibility, having following properties: Clay and silt content= 95%, LL=54, PL=29, PI=25, G=2.64, OMC = 23.5%, MDD =15kN/m^3, Differential free swell =40%. Diameters of sand columns were of 25mm, 37.5mm, 50mm respectively used and mould size was used 100mmX125mm. The test beds were prepared at different water contents 14, 18, 22, 26,30,36,40 and 44%. The results indicated that higher diameter of sand column reduced more swelling as compare to lower diameter. Soil with high initial moisture content showed less swelling than that with low initial moisture content. At 44% water content, no swelling was observed in the soil.

Granular pile technique

A vertical sub-structural element, installed in-situ by ground improvement techniques (replacement, displacement, and/or mixture with chemical agents), that carries the load of the super-structure or earth structure with surrounding soil and transmits it to geo-media around *and/or below, through compression, shear or rotation (Han 2015). It is known as granular* piles or stone columns. Granular piles are the most natural and ecologically neutral foundation system in existence. Granular piles consist natural material like river sand, gravel, stone or stone chips with sand etc.

Installation of Granular Pile

The construction of granular pile is done by two methods namely displacement method, in which the soil is laterally pushed or shifted while making the hole and the non- displacement method in which the in place soil is taken out during boring to make the hole. The non displacement method is also known as replacement method. These methods have been discussed in IS 15284(Part-I): 2003.

The improvement of a soft soil with granular pile or stone column can be accomplished using various excavation, replacement and compaction techniques. Some of these techniques have proved their applicability whereas others have yet to confirm so. Vibroflotation (Greenwood and Krisch 1983), rammed stone column (Datye and Nagaraju 1981) and simple boring technique (Ranjan and Rao 1983) are some of these common techniques.

Unit Cell Concept

Granular piles should be installed preferably in an equilateral triangular pattern which gives the densest packing, although a square pattern may also be used. A typical layout in an equilateral triangular pattern and square pattern are shown in Fig. 2, IS 15284(Part-I):2003.

For an equilateral triangular pattern of granular piles the equivalent circle has an effective diameter of D_e =1.05 s and similarly for a square grid D_e =1.13 s where "s" is the spacing of granular piles IS 15284(Part-I): 2003.

SUMMARY OF THE INVENTION

In this method it has been found that for a particular *s/d* ratio; increase in initial water content, and relative density of pile material, the swelling of expansive soils decreases.

BRIEF DESCRIPTION OF THE ACCOMPANIYING DRAWINGS

The subject matter is better understood when read in conjunction with the accompanying drawings in which:

Fig. 1 is Concept of granular pile anchor and forces acting on a granular pile anchor (After Rao and Padmavathi 2010)

Fig. 2 is Arrangements of granular piles (After IS 15284(Part-I):2003)

Fig. 3 is Experimental setup of without pile

Fig. 4 is Experimental setup of with granular pile

DETAILED DESCRIPTION OF THE INVENTION

Swelling is governed by various factors such as variation in moisture content, type of soil, type of clay mineral, dry density etc. Granular pile may be construct in any season at field. The variable parameters were: (i) Initial moisture content in soft soil (W_i) (ii) s/d ratio ('s' is the spacing between piles, and 'd' is the effective influence diameter of the granular pile) (iii) Relative density of the granular soil (D_r).

There are six expansive soils used for determination of swelling and sand used as pile material.

(i)Sand: Properties of sand is presented in Table 1.

Table 1 Properties of sand

Properties	Value	IS code used
Coefficient of uniformity, C_u	2.50	IS :1498
Coefficient of curvature, C_c	1.29	
Specific gravity, G	2.70	IS: 2720(Part III/Sec1)
Minimum dry unit weight (γ_{dmin}), (kN/m^3)	14.73	IS: 2720 (Part 14)
Maximum dry unit weight (γ_{dmax}), (kN/m^3)	17.88	

(ii)Soil: Six expansive soils i.e. black cotton soil (natural soil) and others are artificial soils were used. The artificial soils have made by mixing of black cotton (BC) soil and different percentage of bentonite (BT) clay shown in Table 2.

Table 2 Designation of Expansive soils

S.N.	Soil samples	Combination	Type of Soil
1.	*SS1*	BC Soil	Natural
2.	*SS2*	BC soil+ 15% BT	Prepared
3.	*SS3*	BC soil+ 25% BT	Prepared
4.	*SS4*	BC soil+ 35% BT	Prepared
5.	*SS5*	BC soil+ 45% BT	Prepared
6.	*SS6*	BC soil+ 55% BT	Prepared

The basic properties of the expansive soils are determined by conducting following tests as per relevant IS codes and given in Table 3. All expansive soils were classified, CH i.e. clay of high plasticity and compressibility group, as per (IS: 1498-1970).

Table 3 Properties of the Soils

Properties	*SS1*	*SS2*	*SS3*	*SS4*	*SS5*	*SS6*	IS code used
Sand Content (%)	2.0	2.0	1.8	1.4	1.2	1.2	
Silt Content (%)	69.0	67.0	61.2	57.6	51.8	48.8	IS: 2720 (Part 4)
Clay Content (%)	29.0	31.0	37.0	41.0	47.0	50.0	
Liquid Limit (%)	51	53	58	64	73	84	
Plastic Limit (%)	22	27	30	33	35	39	IS: 2720 (Part 5
Plasticity Index (%)	29	26	28	31	38	45	
Specific gravity	2.65	2.61	2.57	2.55	2.52	2.50	IS: 2720 (Part III/Sec)
FSI (%)	49	52	71	99	145	179	IS 2720-PartXL
OMC (%)	20.0	20.9	21.5	23.8	25.0	25.9	IS: 2720 (Part VII)
MDD (kN/m^3)	15.5	15.1	14.8	14.5	14.1	14.0	

Where,

FSI= Free Swell Index, OMC= Optimum Moisture Content, MDD= Maximum Dry Density

Test Moulds

Three moulds have been used to prepare granular piles of different diameters accordingly the requirement of mould diameter for different *s/d* ratio for these pile sizes are as given in Table 4.

Table 4 Requirement of mould diameter for different *s/d* ratio

Mould Designation	*s/d* ratio	Pile diameter (mm)	Mould diameter (mm)	Mould Height (mm)
TM_1	2	48	100	240
TM_2	3	32	100	160
TM_3	4	25	105	125

The height of a mould was fixed as 5 d (d=diameter of the pile) to satisfy the critical length criteria. As per IS: 15284 (Part-I)-2003, a granular pile should have length equal to or more than critical length for developing full limiting axial stress in it and as per this code this value should be nearly 4 d (d=diameter of the pile).

Preparation of Clay Bed

Quantity of soil was taken corresponding to initial moisture content i.e. 15%, 17% and 20%, and their dry unit weight for different expansive soils as given in Table 5.

Table 5 Dry unit weight of expansive soils at different moulding moisture contents

Soil designation	Dry unit weight (kN/m^3) to be achieved for the moisture content of		
	15%	17%	20%
SS1	15.3	15.4	15.5
SS2	14.3	14.8	15.0
SS3	14.2	14.5	14.7
SS4	13.9	14.2	14.4
SS5	13.5	13.8	14.0
SS6	13.1	13.4	13.6

A thin coat of grease was applied along the inner surface of mould wall. Water was mixed to the soil and fill into the mould. Soil was compacted uniformly in three layers by using steel rammer. Test set up for without pile and with granular pile were shown in Fig. 3 and Fig. 4.

Construction of Granular Pile

After the clay soil bed was prepared, a casing pipe having an outer diameter equal to the diameter of the granular pile and an auger were used to install the granular pile at the center of top surface by replacement method. Thin open-ended seamless steel pipes of 25mm, 32mm, and 48mm outer diameters were used. While inserting the auger or pipe the disturbance should not be caused in the clay bed. Outer surface of the pipe and auger was lubricated by applying a thin layer of grease for easy withdrawal without any significant disturbance to the surrounding soil. Granular material i.e. sand is filled into the hole in layers in measured quantities and then compacted by tamping rod. It resulted in to a dry unit weight of 16.15 kN/m^3 and 16.80 kN/m^3, the value corresponding to 50% and 70% relative density of the sand (D_r). The porous plate with a filter paper placed above and below the soil sample.

TEST PROCEDURE

After preparing soil sample, collar fitted to top of the mould and placed into water tank. The heave stake was placed on the top of porous plate and a dial gauge was fixed on the top of the heave stake to measure the swelling. The dial gauge was set on zero. Then water was added in water tank to submerge the mould. Swelling was monitored continuously by taking the dial gauge readings from time to time till its reading ceases to change. The total reading of dial gauge gives swelling value.

Tests were conducted for all the test mould prepared with different water contents, *s/d* ratio and relative densities of the granular material.

TEST RESULTS

Three test series were conducted for swelling of expansive soils reinforced with granular pile. These are TS1, TS2 and TS3 for *s/d* values of 2, 3 and 4 respectively.

Test Series TS1:

In Test series TS1, *s/d* ratio = 2, swelling for six expansive soils was determined as given in Table 6.

Table 6 Swelling of soils for *s/d* = 2

Soil Type	Initial water content	Swelling (mm)		
		without pile	with pile	
			D_r =50%	D_r =70%
SS1	15%	4	3	2
	17%	3	2	2
	20%	2	2	1
SS2	15%	6	3	2
	17%	5	3	2
	20%	4	3	2
SS3	15%	8	4	3
	17%	7	4	4
	20%	5	3	2
SS4	15%	12	6	4
	17%	10	5	5
	20%	6	4	3
SS5	15%	15	8	6
	17%	14	8	7
	20%	9	5	5
SS6	15%	19	10	9
	17%	17	10	9
	20%	11	7	5

Test Series TS2:

The *s/d* ratio in this test series was 3 and result was shown in Table 7.

Table 7 Swelling of expansive soils for $s/d = 3$

Soil Type	Initial water content	Swelling (mm)		
		without pile	with pile	
			D_r =50%	D_r = 70%
SS1	15%	5	4	3
	17%	5	4	3
	20%	3	2	2
SS2	15%	7	5	4
	17%	5	4	3
	20%	4	2	2
SS3	15%	9	7	6
	17%	8	6	4
	20%	5	3	3
SS4	15%	13	9	8
	17%	11	7	6
	20%	7	4	5
SS5	15%	17	10	9
	17%	15	9	8
	20%	10	6	7
SS6	15%	20	12	11
	17%	18	10	10
	20%	14	7	9

Test Series TS3:

In this test series *s/d* ratio was 4 and swelling of expansive soils is given Table 8.

Table 8 Swelling of expansive soils for $s/d = 4$

Soil Type	Initial water content	Swelling (mm)		
		without pile	with pile	
			D_r =50%	D_r = 70%
SS1	15%	6	4	3
	17%	5	3	2
	20%	4	2	2
SS2	15%	8	5	5

	17%	6	3	4
	20%	4	3	3
SS3	15%	12	7	9
	17%	10	5	6
	20%	6	5	4
SS4	15%	13	10	11
	17%	11	9	8
	20%	8	7	6
SS5	15%	18	13	13
	17%	16	12	10
	20%	13	8	8
SS6	15%	25	15	15
	17%	22	13	13
	20%	19	10	11

From test results, the effects of variables of present invention on swelling of expansive soils are discussed below:

Effect of Variables on Swelling of expansive soils

In order to study the influence of installing granular pile on swelling of expansive soils, the test variable related to soil was (a) initial moisture content and those related to pile were (b) *s/d* ratio, and (c) relative density of pile material. The swelling of plain soil test bed or the composite material i.e. the soil reinforced with granular pile was noted by replacement method. The discussion on the results of the tests is presented in following manner:

(a) Effect of initial moisture content on swelling of expansive soils
(b) Effect of *s/d* ratio of pile on swelling of expansive soils
(c) Effect of relative density of pile material on swelling of expansive soils

(a) Effect of initial moisture content on swelling of expansive soils

It is observed that for test beds without granular pile and those with granular pile; the swelling is found decreased as the initial moisture content in the soil increased. This is observed for all soils and mould sizes. Because dry or partial saturated soil has water absorption capacity more than fully saturated soil.

(b) Effect of *s/d* ratio of pile on swelling of expansive soils

For given moisture content, as *s/d* ratio increases, swelling of raw soil increases but inclusion of granular pile lowers the swelling.

The reason for reduction in swelling may be attributed to

(a) removal of some of expansive soil and replacement of it, by granular material and,

(b) friction between the expansive clay and the granular material.

(c) Effect of relative density of pile material on swelling of expansive soils

Under a given case of W_i and s/d ratio, D_r of sand affect the reduction in swelling of expansive soils. The granular pile at high D_r, produces more reduction in swelling than that at low D_r. It may be explained due to the fact that sand of higher relative density develops, large friction with the surrounding soil than that of the lower relative density.

On comparing the results of different soils, i.e. from soil *SS1* to soil *SS6*, it may be noted that

1. All the expansive soils exhibit reduction in swelling due to the inclusion of pile.
2. The trend of variation of swelling with s/d ratio or with W_i or with D_r is similar for all soils *SS1*, *SS2*, *SS3*, *SS4*, *SS5*, and *SS6*.
3. The percentage decease in swelling is different for different soils.

CONTRIBUTION FROM THE INVENTION

Recent invention revealed that installation of granular piles in expansive soils reduces swelling of the composite ground. However, no systematic study on the influence of pile installation on swelling of expansive soil was known. Swelling of expansive soils is serious concern to the field engineers as many lightly loaded structures, building components, roads etc. constructed on expansive soils fail due to significant up lift pressure exerted by the soil. Present invention has clearly established that swelling reduces significantly by the installation of granular piles. Under different initial moisture conditions, spacing between the piles and densities of the pile material; a soil bed reinforced with granular pile reduces swelling; the magnitude of which may depend on soil and pile characteristics. Thus the results of the present invention will build confidence in practicing engineers and researchers to use and recommend the technique of granular piles to mitigate the problems associated with construction in expansive soil areas.

I CLAIM:

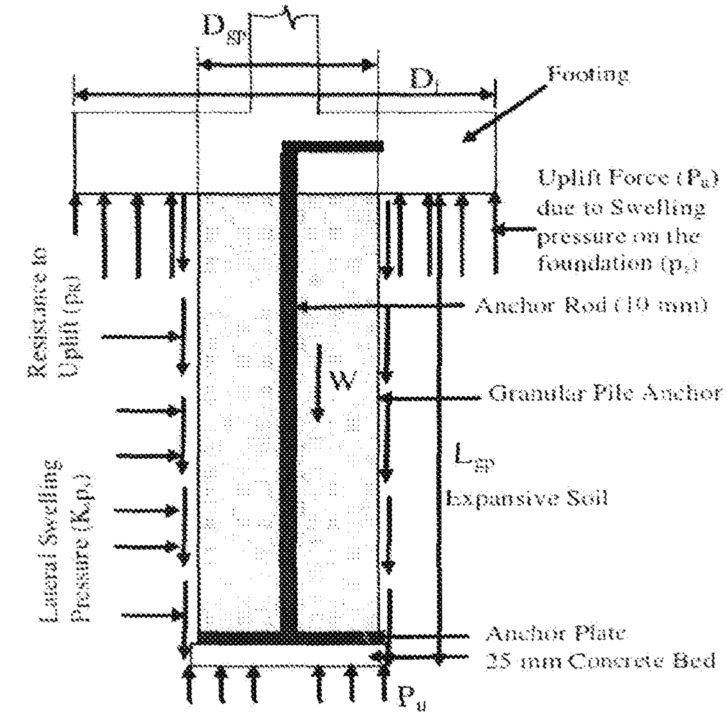
1. A method of reducing the swelling of expansive soils by constructing granular pile of sand. The relative density of sand, gradation of granular material, length and diameter of pile, spacing, pattern and method of installation of pile varied to obtain desired reduction in swelling of expansive soils. The initial moisture content in the soil influences the reduction in swelling of expansive soils due to installation of the granular piles.

2. A method as claimed in claim 1 where in initial moisture content with respect to saturation moisture content affect the swelling of the expansive soil, that is the soil mainly containing clays of high plasticity.

3. A method as claimed in any of the preceding claim where in diameter and length of the granular pile affect the swelling of the expansive soils. The length of granular pile should be the five times of diameter of pile.

4. A method as claimed in any of the preceding claim where in gradation and relative density of granular material affect the swelling expansive soil. The relative density of the granular material should be 50% to 70%.

5. A method as claimed in any of the preceding claim where in the *s/d* ratio of the granular pile should lie between 2 to 4 for effective reduction in swelling. '*s*' is the center to center spacing between granular piles and '*d*' is the diameter of the pile.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D_f
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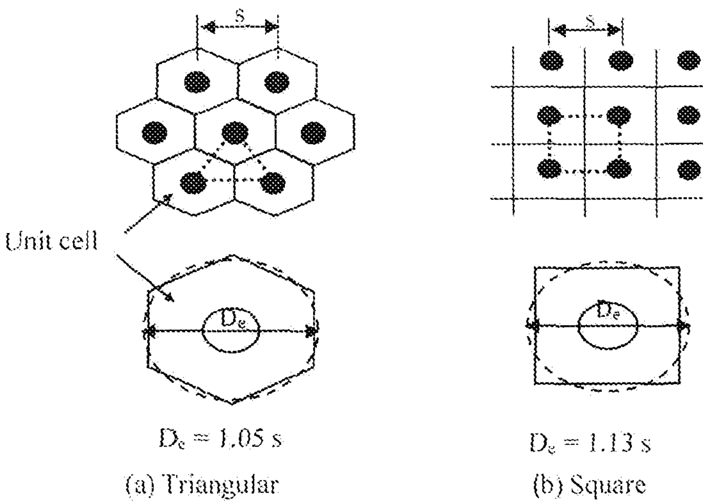
due to Swelling
pressure on the
foundation (p_s)
Resistance to
Uplift (p_R)
Anchor Rod (10 mm)
W
Granular Pile Anchor
L_gp
Expansive Soil
Lateral Swelling
Pressure (K_s p_s)
Anchor Plate
25 mm Concrete Bed
P_u

Fig.1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s
Unit cell
De
De
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(a) Triangular
De = 1.13 s
(b) Square

Fig. 2

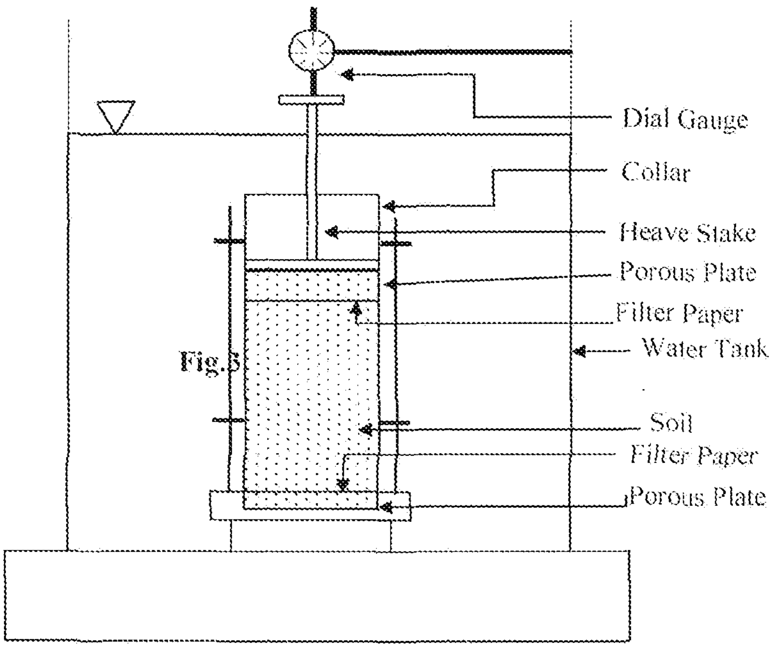
Dial Gauge
Collar
Heave Stake
Porous Plate
Filter Paper
Water Tank
Fig.3
Soil
Filter Paper
Porous Plate

Fig.3

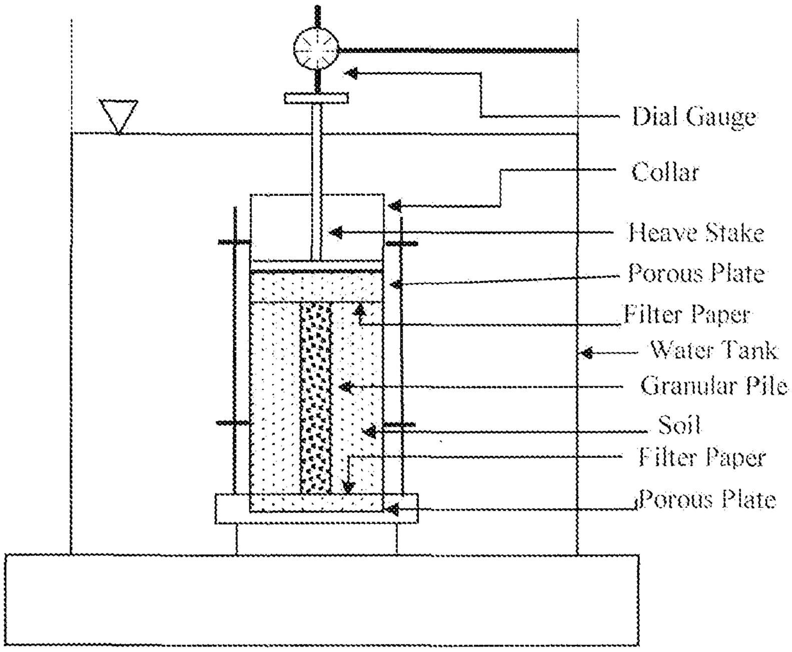
Dial Gauge
Collar
Heave Stake
Porous Plate
Filter Paper
Water Tank
Granular Pile
Soil
Filter Paper
Porous Plate

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2019/000037

A. CLASSIFICATION OF SUBJECT MATTER

E02D3/08 Version=2020.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

TotalPatent One, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO2018116313A1 (MESHRAM Kundan & JAIN Pradeep) 28 June 2018 (28.06.2018) Abstract, Claims 1-5 & No Family	1-5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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