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DESIGN PARAMETERS FOR GEOTEXTILE-REINFORCED UNPAVED ROAD BY APPLYING DIMENSIONAL ANALYSIS

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Abstract

Soil swelling in road layer is the complex phenomenon. The paper aims to derive a concise expression for two challenging design parameters when the subgrade layer is expansive in geotextile-reinforced unpaved road. The design parameters considered in the present study are the mobilized bearing capacity and swelling pressure for expansive soil. Herein the dimensional analysis via Buckingham's π method is applied to derive the design parameters by forming the dimensionless group for prototype and model system. The model testing for the swelling pressure and mobilized bearing capacity are carried out in the laboratory by using consolidometer ring and CBR set up. The test results reveal the swelling pressure of 22.03kN/m^2 for the soil sample having 76% as degree of saturation. A linear relation is observed between swelling pressure and degree of saturation and becomes equal upon surcharge. The mobilized bearing capacity for the expansive soil sample is 0.47kg/cm^2. The failure pattern observed during testing is general shear failure in unsoaked condition and punching soil failure in soaked condition. The paper provides geometric ratio of 1:6 for model and prototype and also suggests modification in Giroud and Han generic equation by including the developed dimensionless group.

Keywords:

Dimensionless group; Giroud and Han approach; Mobilized bearing capacity; Pavement design parameters; Swelling pressure.

1 Introduction

The present paper aims to apply dimensional analysis, which reduces a large group of variables involved in the unpaved geotextile road to a small group with minimal variables by aiding in designing laboratory experiments and diminishing the complexity. The swelling pressure in the expansive subgrade and the mobilized bearing capacity of the subgrade are considered in the present work for which the dimensionless group is developed using Buckingham's π method. The generic Giroud and Han equation for unpaved roads is modified with the developed dimensionless group. The laboratory testing is performed to validate the concepts and identify the lab model's geometric ratio to the required prototype.

Dimensional analysis is generally followed by Buckingham's π method, a conventional approach [1]. The possible dimensionless groups can be developed for any specific engineering problem. Since pavement design problems involve dynamics and complex geometry, properties concerned with many pavement design parameters are very tricky. The experiments may be small-scale models, medium-scale models, or prototypes. Prototyping specific structures like pavement is complex, costly, and time-consuming. Dimensional analysis is a tool to reduce the scale effect and allows the output of a small-scale model to be applied to a prototype with a particular modification. The dimensional analysis has three significant similarities, i.e., geometry, kinematic and dynamic. If the three similarities match the model and prototype, then the results determined in the model with a specific relation to the dimensionless group can be applied to the prototype. The swelling in the soil is complex, and with dimensionless analysis, it was predicted with influencing factors like initial water content, initial dry unit weight, and vertical stress and validated with data from a one-dimensional swelling test [2]. The dimensionless models for swelling soil also consider the influencing parameters like void ratio and degree of saturation, with boundary conditions like sample dimension, soil structure, and stress path [3]. Recently, a new framework and math were proposed where the user need not select the repeating variable to arrive at the new set of dimensionless groups for problems in a different field [4]. The moisture variation is observed in soil properties pre and post-monsoon, which governs the magnitude of swelling pressure developed in expansive soil [5].

2 Description of the dimensional approach

The methodology description includes the basic dimensional analysis formulation, the dimensionless group using Buckingham's π method, and the unpaved road design parameters categorized based on the dimensionless similarity property to identify the variables involved in developing the dimensionless group.

2.1 Formulation for dimensional analysis approach

The basic formulation adapted to illustrate dimensional analysis is based on the variables concerned with the problem. The variables are categorized as the dependent and independent variables of the system. Examples of dependent quantities are displacement, stress, bending moment, and independent quantities like a specific system's size, density, and mass [1, 6]. The minimum number of dimensionless groups for a specific problem is represented by the basic equation (1) as per Buckingham's π method of 1914 analysis.

$$N_g = n - m_d \tag{1}$$

Where:
N_g - minimum number of a dimensionless group,
n - list of variables $\{V_1, V_2 \ldots V_n\}$,
m_d - independent primary dimensions or combinations called secondary dimensions $\{D_1, D_2 \ldots D_n\}$ e.g., mass, length, time, temperature.

The usual approach for dimension m = {M, L, T} as {mass, length, time}. Buckingham's π method's usual representation for a set of variables is V and D, which can be lessened to a minimum set $\{D_{min}\}$ in problems concerning dimensional analysis, which can define all components of variable V. The function 'f ' is formulated using general proofs developed without explicit assumptions [7]. The repeating variables must be chosen based on geometry, kinematic, and dynamic properties. The repeating variable should not be a dimensionless group. The fundamental dimensions in the repeating variable must be the same. Any two repeating variables must not have the same dimensional formula. If all the influencing factors accounting for a design parameter, if considered, require extensive experimental programs and multivariable regression, which is cumbersome to apply in practice [3]. Dimensionless analysis is the best alternative to overcome cumbersome experimentation with broad applications in fluid, machines, and economics [3, 8].

2.2 Pavement design parameter based on dimensional similarity properties

Table 1: Summary of geometric, kinematic, and dynamic properties involved in pavement design.

Geometric Property	Kinematic property	Dynamic property
Width of the road	Modulus ratio	California bearing ratio
Radius of the tire contact area	Resilient Modulus [12]	Unit weight [2]
Layer thickness [9,10]	Anchorage	Load
Rut depth [11]	Geotextile Stiffness [13]	Stress [9,10]
Location of reinforcement [13]	Interface friction	Shear Strength
	Time (For loading repetition)	Tensile Strength
	Cohesion	Swelling Pressure
	Moisture	
	Bulk Density	
	Traffic Count [9,10]	
	Degree of saturation [2]	
	Water content [2]	

Table 1 categorizes the pavement design parameters in terms of geometric, kinematic, and dynamic properties. The design parameters involved in pavement design are classified into geometric, kinematic, and dynamic properties to derive solutions from dimensional analysis. Generally, the pavement design is for layer design thickness by Giroud and Han approach [9, 10], which depends on the required performance and serviceability criteria and varies based on the design period and estimated traffic flow. The kinematics property is categorized for the movement without considering the forces involved, and dynamics is the movement where force is the cause. The geometric property is regarding the road layer dimensions and the layer characterization. Rut depth is the critical geometric property that acts as serviceability criteria with a permissible value of 50mm [11] and a severe rutting failure [12]. The tensile property of geosynthetics falls under the dynamic category, whose benefits are based on the elongation rate of geosynthetics [13]. The parameters include the early design approach proposed in 1981 [14] for geosynthetic reinforced unpaved roads to recent mechanistic design methods [15] and subgrade soil properties.

3 Methodology of dimensional approach

The sequence of work methodology includes developing a dimensionless group for design parameters and the lab testing and its interpretation.

3.1 Dimensional analysis for design parameter 1: Swelling pressure

The illustration determines swelling pressure for the expansive soil in the pavement subgrade layer. In this example, Buckingham's π method procedure is adapted to reveal the dimensionless group for swelling pressure. The Swelling pressure in expansive soil is not a unique parameter and is influenced by initial moisture, initial dry density, compaction method, confinement surcharge, and soil specimen thickness [2]. Swelling pressure is directly proportional to the height of the specimen and the surcharge load, as the load restricts the volume change in the subgrade and generates more swelling pressure. The volume of the aggregate layer thickness above the subgrade behaves as a surcharge to expansive soil. The performance of the structures built on expansive soil is enhanced with an improved design and new construction material [16]. The use of geotextile in roads improves the strength, controls swell to stabilize the expansive subgrade road layer [17], increases the rutting resistance [18], and is cost-effective [19]. The variables listed in Table 2 include independent and dependent variables in finding the dimensionless group for swelling pressure.

Table 2: Variable listed to develop group for swelling pressure (p_s) using dimensional analysis.

Variable	Symbol	SI Unit	Mass system	Dependent variable	Repeating variable
Swelling pressure	p_s	N/m^2	M/(LT^2)	✓	x
Thickness of subgrade	h_{sg}	Meter	L	x	✓
Thickness of macadam	h_{bc}	Meter	L	x	x
Density of the subgrade	ρ_{sg}	Kg/m^3	M/L^3	x	✓
Degree of saturation for subgrade	S_r	m^3/m^3	-	✓	x
Unit weight of aggregate	Υ_{bc}	N/m^3	M/(L^{2}T^2)	✓	✓

The variables decided based on the concepts of swelling properties help in developing meaningful π terms. From Table 3, the total number of variables governing dimensional analysis is 6, and the number of fundamental dimensions is 3.

3.1.1 Dimensional group for swelling pressure

As per Buckingham's π method 1914 analysis, from equation (1), the minimum number of dimensionless groups is 3 π terms for deriving swelling pressure, and the functional relationship with the variables involved may be written as equation (2).

$$f_1\left(h_{sg}, \rho_{sg}, \Upsilon_{bc}, h_{bc}, S_r, p_s\right) = 0 \tag{2}$$

The dimensionless group for swelling pressure makes the process easier for real-time application with only two parameters, moisture causing the degree of saturation and surcharge load, apart from the other geometrical dimensions. The surcharge load is the known data in the real-time application; hence, moisture needs to be measured at different time zones to measure the degree of saturation and other geometry of the subgrade layer to obtain the precise values of the swelling pressure of the expansive soil. Finally, the resultant expression for swelling pressure of subgrade soil in terms of the dimensionless group is given in equation (3), which is dimensionally homogeneous. Giroud and Han's comprehensive equation for determining the aggregate layer thickness is modified for swelling pressure by including equation (3), which becomes equation (4).

$$p_s = \Upsilon_{bc} * S_r * h_{bc} \tag{3}$$

$$p_s = (\Upsilon_{bc} * S_r)\left[\frac{0.868+\left(0.661-1.006J^2\right)\left(\frac{r}{h}\right)^{1.5}\log N}{1+0.204[R_E-1]}\left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{fs}\right)\left[1-0.9e^{-\left(\frac{r}{h}\right)^2}\right]N_c f_c CBR_{sg}}}-1\right]r\right] \tag{4}$$

Where:
P - wheel load (kN),
N - design traffic of standard axle load,
J - geogrid aperture stability modulus (J as 0 for geotextile reinforced and unreinforced state),
r - radius of equivalent tire contact area, R_E is limited modulus ratio for base and subgrade layer,
s - allowable rut depth (mm),
f_S - factor equal to 75 mm,
N_c - bearing capacity factor,
CBR_{sg} - subgrade CBR.

Swelling pressure depends on the properties of both the aggregate and subgrade layers. Giroud and Han's approach [9, 10] considers only the wheel load 'P' as the applied load, which is half the total axle load and does not account for the self-weight of the aggregate layer above the interface. But the developed group in equation (4) considers the additional parameter, which is the aggregate layer's unit weight, the product of Υ_{bc} and h_{bc}, that adds value and matches the conceptual fact. The degree of saturation S_r depends on the subgrade layer's void ratio and specific gravity and can vary from a dry state to a fully saturated state, from 0% to 100%. The generic Giroud and Han equation is modified to estimate the corrected layer thickness $h_{bc\ (modified)}$ in equation (5) by including the expected swelling pressure in the pavement subgrade layer.

$$h_{bc(modified)} = \frac{p_s}{\Upsilon_{bc} * S_r} \quad (5)$$

3.1.2 Model test for swelling pressure

The black cotton soil, which is expansive and prone to swelling, is used in the model test. The consolidometer ring apparatus is used in the laboratory, as shown in Fig. 1, by following the constant volume method [17] for measuring the swelling pressure of soil sample #1.

Fig. 1: Laboratory set up for the swelling pressure test.

The percentage of compaction achieved during the model test is 93%. The strain dial reading is measured by allowing the soil sample in the ring to swell with continuous water supply under constant volume for 5 days. The model test results are summarized in Table 3.

Table 3: Model test results summary for swelling pressure.

Variable	Lab parameter for swelling property	Unit	Lab test value
OMC	Optimum moisture content	%	27
MDD	Maximum dry density	g/cc	1.4
G_s	Specific gravity	-	2.72
d	Diameter of the soil specimen	cm	6
$h = h_{bc}$	Compacted depth of the soil specimen	cm	2.1
Υ_w	Unit weight of water	g/cc	1
V	Volume of the sample	cc	59.35
W1	Weight of ring and sample	g	307.78
W2	Weight of sample	g	104.54
w	Water content of the sample	%	27.4
ρ_d	Bulk density	g/cc	1.76
$\rho_d = \Upsilon_{bc}$	Dry density	g/cc	1.38
e	Void ratio	-	0.97
S_r	Degree of saturation	%	76

The model test results are applied in the dimensionless group of equation (3) to arrive at the swelling pressure of the soil. The degree of saturation achieved at OMC is 76%. Considering the field condition as the OMC may be varied by +- 5%, here the degree of saturation is varied from 71% to 81%, and the swelling pressure estimated is plotted in Fig.2, which shows the variation is linear. Hence, as the volume of water increases, the degree of saturation increases, increasing the swelling pressure in the soil. The degree of saturation is equal to swelling pressure upon the surcharge, as observed from the dimensionless group. In general, the degree of saturation, swelling pressure, and inclination angle are linear, as shown in Fig.2, and vary with the layer thicknesses, soil type, and soil property. The expected intensity of swelling pressure can be achieved in pavement layers by choosing the appropriate degree of saturation after deriving a relation similar to Fig. 2 for the selected soil type in the pavement design.

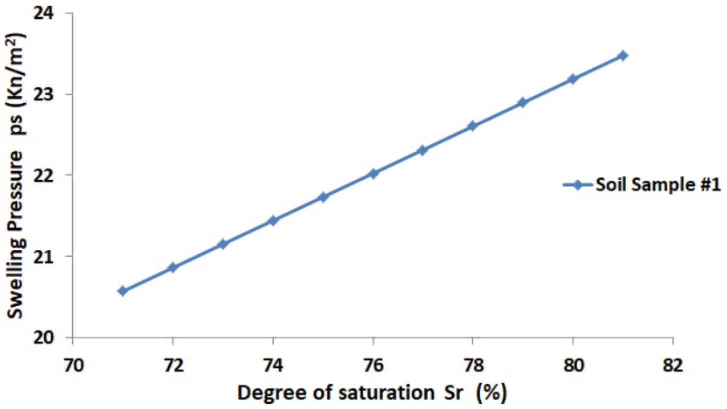

Fig. 2: Relationship between the degree of saturation and swelling pressure.

3.2 Dimensional analysis for design parameter 2: Mobilized bearing capacity

In pavement design, the required aggregate layer thickness needs to meet the bearing capacity of the subgrade. The mobilized bearing capacity relates to the subgrade bearing capacity [20], which primarily relates to the wheel load distribution angle, the vertical stress intensity, and the modulus of the pavement layers, which is related to the aggregate and subgrade layer CBR. The angle of stress distribution is a critical design parameter that is complicated to quantify in pavement layers. Geotextile reinforcement enhances the modulus of pavement layers compared to the unreinforced state and significantly reduces rut [21]. The magnitude of geotextile strain depends on its stiffness property when it gets stretched upon the applied loading and diminishes the stress transmission to the weak subgrade layer. Hence, geotextile stiffness adds up to the mobilization of bearing capacity. The stress distribution is often helpful in quantifying the performance of unpaved, unreinforced, reinforced roads with geotextile fabric at the interface. In geotextile reinforced roads, the stress is spread to a wider angle and minimizes the intensity of vertical stress ingress into the subgrade [22]. Thus, wider stress distribution prevents the development and growth of the local shear zone at the pavement layer interface and improves the bearing capacity.

The bearing capacity in cohesive soil is given by CN_c, where C is the cohesion in N/m^2 and N_c is the dimensionless bearing capacity factor. Giroud and Han's approach [9,10] for pavement design considers 3.14 for N_c in unreinforced conditions and 5.14 for geotextile reinforced conditions, and the mobilization coefficient depends on r, h, and s/fs. Where r is the radius of the equivalent tyre contact area, h is the required thickness of base course in unpaved road, s is the allowable rut depth, and fs is the factor equal to 75mm rut depth.

Giroud and Han [9,10] introduced s/fs to account for serviceability criteria other than 75mm. The mobilization coefficient occurs when the aggregate layer of a certain thickness is placed above the subgrade, and the interface deflection decreases. In pavement layers, the moduli of the upper layer are higher than the lower. From the Burmister correlation, as the modulus ratio increases, the magnitude of vertical stress at the interface decreases due to the broader distribution of stress in the upper layer of higher moduli, bringing the angle for stress distribution to a high value to improve the serviceability of the road [14, 23]. The parameters concerning the moduli of the pavement layer are the CBR and density of the layer. The interdependent design parameters are vertical stress at the interface and stress distribution angle.

To avoid pavement failure, the stress at the interface should not increase above the bearing capacity of the pavement layers [9, 10]. Due to traffic, the aggregate layer rearrangement or slipping takes place, which is controlled, and the intactness of the aggregate is improved when reinforced with geotextile. When the traffic increases, the accumulation of stress and the intermixing of layers occur at the interface for the unreinforced state, which further reduces the modulus ratio of pavement layers.

Table 4: List of variables to develop a dimensionless group for mobilized bearing capacity (q_{msg}).

Variable	Symbol	SI Unit	Mass system	Dependent variable	Repeating variable
Undrained cohesion	C_u	N/ m^2	M/LT^2	✓	x
Aggregate layer thickness	h_{bc}	Meter (m)	L	x	✓
Geotextile stiffness	g_s	N/m	MT^{-2}	✓	x
Wheel load	P	N	ML/ T^2	x	✓
Stress distribution angle	α	Degree or Radian	$M^0L^0T^0$	✓	x
Limited modulus ratio	$R_E = \min(\frac{Ebc}{Esg}, 5)$	No dimension	$M^0L^0T^0$	✓	x
Traffic count	N	Constant value	$M^0L^0T^0$	✓	x
Mobilized Bearing capacity	$q_{msg} = m(cN_c)$	N/ m^2	M/LT^2	✓	x
Deflection at the interface	I_d	Meter (m)	L	✓	x
Density of the subgrade layer	ρ_{sg}	Kg/m^3	M/L^3	x	✓
Radius of equivalent tyre contact	r	Meter (m)	L	x	x
Bearing capacity factor	N_c	Constant value	$M^0L^0T^0$	✓	x
Swelling pressure of soil	p_s	N/m^2	M/(LT^2)	✓	x

Table 4 summarizes sufficient variables listed under dependent, repeating category and their mass system for determining the mobilized bearing capacity of subgrade (q_{msg}) using dimensional analysis.

3.2.1 Dimensional group for mobilized bearing capacity

The minimum number of dimensionless groups is 10 π terms for deriving the mobilized bearing capacity of subgrade in pavement layers as given in equation (6). Mathematically, the functional relationship of mobilized bearing capacity of the subgrade (q_{msg}) may be written as equation (7).

$$f_1(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7, \pi_8, \pi_9, \pi_{10}) = 0 \quad (6)$$

$$f_1(q_{msg}, h_{bc}, \rho_{sg}, P, r, C_u, g_s, p_s, I_d, R_E, N, N_c, \propto) = 0 \quad (7)$$

Hence the resultant expression for the mobilized bearing capacity of the subgrade (q_{msg}) for geotextile reinforced condition in pavement design in terms of the dimensionless group is given in equation (8). Where q_{msg} = m (CN_c) and traffic count N relates to the CBR_{sg}. The expression for 'm', the mobilization coefficient, is given by equation (9).

$$q_{msg} = \left[\frac{I_d h_{bc} g_s P}{p_s^2 r^5} N \propto R_E\right] C_u N_c \quad (8)$$

$$m = \left[\frac{I_d h_{bc} g_s P}{p_s^2 r^5} N \propto R_E\right] \ (or) \left[\frac{I_d g_s P}{h_{bc} S_r^2 \Upsilon_{bc}{}^2 r^5} N \propto R_E\right] \quad (9)$$

Equation (8) can derive the maximum value for q_{msg} or be lesser but not higher than the maximum to avoid failure. The group for swelling pressure from equation (3) is substituted to find the mobilization coefficient for expansive soil, which is given in equation (9), and in the case of unreinforced conditions, g_s = 0, and for non-expansive soil, p_s = 0.

3.2.2 Model test for mobilized bearing capacity

The laboratory model test for bearing capacity is performed for expansive soil sample #2. The laboratory model test for bearing capacity is performed for expansive soil sample #2. The reinforcement needs for the subgrade soil with less than 5% CBR [9, 10, 24, 25]. Hence, the soil condition during testing is soaked to account for the worst condition. The model test is continuous and not a static or intermittent test. The strain rate is at the lower limit of 1.25mm/min to observe the load and settlement and simulate the prototype's parking speed. The CBR mould is 150mm with a plunger of 50mm, and the space on either side is also 50mm. The confinement is observed at 50mm on either side in the case of

CBR mould. The test is carried out to a maximum of 25mm settlement. In the model test, the soil sample is compacted using the tamping rod with a round edge to carry out kneading to match the prototype. Giroud and Han [9, 10] say the mobilization is for zero base course thickness. In the model test for unsoaked and soaked conditions, there is no need for a surcharge while determining the expansive soil's bearing capacity. The settlement of the plunger is to be measured with the strain gauge with 0.01mm accuracy. Fig. 3 shows the set up using CBR mould for the model test performed in the laboratory for mobilized bearing capacity.

Fig. 3: Laboratory set up for the mobilized bearing capacity test.

Upon increasing the load, excessive deformation may indicate soil failure. The profile can be determined by placing the gauges at the edges of the sample. The test ends when the deformation is exorbitant and may not visualize the pattern of failure.

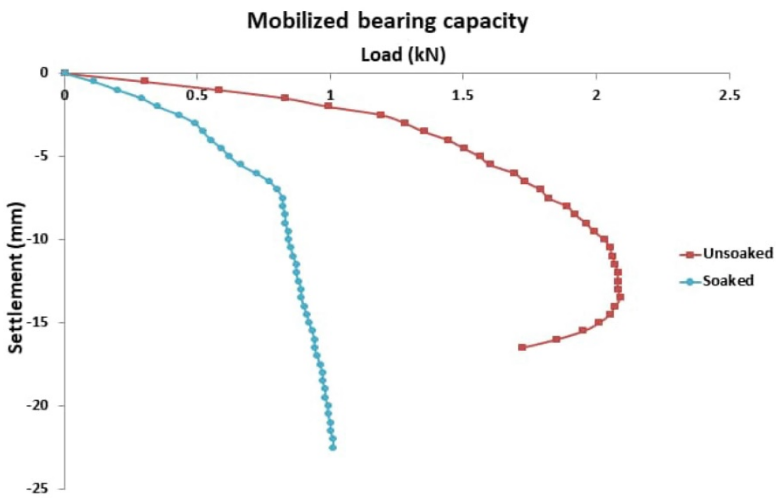

Fig. 4: Variation in settlement with load for the soaked and unsoaked condition.

In Fig. 4, the unsoaked graph shows a general shear failure pattern; in the soaked soil state, the failure pattern shows a punching type. The test results in soaked condition show closer values representing the ultimate load at 7.5mm settlement. The load value at 7.5mm settlement is 83.59 kg, showing that the mobilized bearing capacity of the tested soil sample #2 is 0.47kg/cm^2, and the sample cross-sectional area is 176.625 cm^2. Compared to the test results obtained from the unconfined compression test, the values match about 80% with the laboratory test carried out for mobilized bearing capacity for sample #2.

4 Modified Giroud and Han equation with dimensionless groups

The generic equation of Giroud and Han is modified by including the developed dimensionless group for 'm' and 'p_s', and equation (10) is achieved. Equation (10) requires an iterative methodology to solve for the required aggregate thickness. The swelling pressure parameter and the interface rut depend on the geotextile stiffness in the case of the reinforced condition. Since the parameter for geotextile stiffness is considered in the dimensionless group, there is no need for the model testing with geotextile.

$$h_{bc(modified)} = \left[\frac{0.868+\left(0.661-1.006J^2\right)\left(\frac{r}{h}\right)^{1.5}\log N}{1+0.204[R_E-1]}\left[\sqrt{\frac{p_s^2 r^3}{s\pi h_{bc} g_s N\alpha R_E N_c f_c CBR_{sg}}}-1\right]r\right] \tag{10}$$

The parameters in equation (10) are already described, while the previous chapter states equation (4).

5 Concluding remarks

From the above results, the concluding remarks are as follows:

- Using dimensional analysis to derive design parameters in pavement engineering is relatively accurate and efficient.
- The proposed dimensionless group for swelling pressure includes the variable weight of the aggregate layer, and mobilized bearing capacity includes the variable swelling, which is not accounted for in the Giroud and Han generic equation for pavement design.
- The group developed using dimensional analysis is homogeneous and matches the properties with the variables considered in the approach.
- The model test results reveal the swelling pressure of 22.03kN/$m^{2,}$ and the mobilized bearing capacity for the expansive soil sample is 0.47kg/cm^2.
- The observed linear relation between swelling pressure and degree of saturation from the model test is prudent that as the volume of water increases, the degree of saturation increases, raising the swelling pressure.
- The test result reveals that the punching failure is observed for unreinforced samples, and the failure pattern gets transferred from punching to local for reinforced conditions.
- The geometric ratio is 1:6 for the model and prototype, with the wheel diameter of 300mm in the prototype as the plunger diameter in the present model test is 50mm.
- One of the limitations is the calibration of the proposed modified equation, which requires a certain number of experimental data from the prototype.

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References

[1] BUTTERFIELD, R.: Dimensional analysis for geotechnical engineers. Geotechnique, Vol. 49, Iss. 3, 1999, pp. 357–366.
[2] BUZZI, O. - GIACOMINI, A. - FITYUS, S.: Towards a dimensional description of soil swelling behavior. Geotechnique, Vol. 61, Iss. 3, 2011, pp. 271–277.
[3] ADEM, H. H. - VANAPALLI, S. K.: Elasticity moduli of expansive soils from dimensional analysis. Geotechnical Research, Vol. 1, Iss. 2, 2014, pp. 60–72.
[4] KARAM, M. - SAAD, T.: Buckingham Py: A Python software for dimensional analysis. SoftwareX, 2021, pp.16.
[5] GUPTA. - SANJAY. - RAVI SUNDARAM. - SORABH GUPTA.: Seasonal Variations in Properties of Expansive Soils along a Railway Corridor in Western India. In Geotechnics for Transportation Infrastructure, Springer, Singapore, 2019, pp. 3-14.
[6] ZHANG, J. A. M. - TANG, Y.: Dimensional Analysis of Soil-Foundation-Structure System Subjected to Near Fault Ground Motions. In Geotechnical Earthquake Engineering and Soil Dynamics, Vol. IV, 2008, pp. 1-10.

[7] CHRISTOPHE, F. - SELL, R. - COATANEA, E.: Conceptual design framework supported by dimensional analysis and system modelling language. Estonian Journal of Engineering, Vol. 14, Iss. 4, 2008, pp. 303–316.
[8] LONGO. - SANDRO, G.: Principles and applications of dimensional analysis and similarity. Springer International Publishing, 2021.
[9] GIROUD, J. P. - HAN, J.: Design method for geogrid-reinforced unpaved roads. I. Development of design method. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, Iss. 8, 2004, pp. 775–786.
[10] GIROUD, J. P. - HAN, J.: Design Method for Geogrid-Reinforced Unpaved Roads. II. Calibration and Applications. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, Iss. 8, 2004, pp. 787-797.
[11] IRC: SP 72.: Guidelines for the design of flexible pavement for low volume rural roads. The Indian Road Congress, New Delhi, 2015.
[12] AASHTO.: Guide for Design of Pavement Structures. American Association of State Highway and Transportation Official USA, 1993.
[13] GIROUD, J. P. - AH-LINE, C. - BONAPARTE, R.: Design of unpaved roads and trafficked areas with geogrids. In Polymer grid reinforcement, Thomas Telford Publishing, 1984, pp. 116-127.
[14] GIROUD. - JEAN-PIERRE. - LAURE NOIRAY.: Geotextile-reinforced unpaved road design. Journal of the Geotechnical Engineering Division, Vol. 107, Iss. 9, 1981, pp. 1233-1254.
[15] PERKINS, S. W.: Mechanical response of geosynthetic-reinforced flexible pavements. Geosynthetics international, Vol. 6, Iss. 5, 1999, pp. 347-382.
[16] PUPPALA, J. A.: Performance evaluation of infrastructure on problematic expansive soils: Characterization challenges, innovative stabilization designs, and monitoring methods. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 147, Iss. 8, 2021.
[17] TIWARI. - NITIN. - NEELIMA SATYAM. - ANAND J. P.: Effect of synthetic geotextile on stabilization of expansive subgrades: experimental study. Journal of Materials in Civil Engineering, Vol. 33, Iss. 10, 2021.
[18] SINGH MEENAKSHI. - ASHUTOSH TRIVEDI. - SANJAY KUMAR SHUKLA.: Evaluation of geosynthetic reinforcement in unpaved road using moving wheel load test. Geotextiles and Geomembranes, Vol. 50, Iss. 4, 2022, pp. 581-589.
[19] PALMEIRA, E. M. - ANTUNES, L. G.: Large scale tests on geosynthetic reinforced unpaved roads subjected to surface maintenance. Geotextiles and Geomembranes, Vol. 28, Iss. 6, 2012, pp. 547-558.
[20] VANDEN BERGE. - DANIEL, R. - EMILY, C. R. - RUIDONG, LI.: Mobilized Bearing Capacity Analysis of Global Stability for Walls Supported by Aggregate Piers. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 147, Iss. 6, 2021.
[21] MUTYALA. - PRUDVIRAJ. - MENA, I. - SOULIMAN. - KARTHIKEYAN LOGANATHAN.: Quantifying the Influence of Geosynthetics on Pavement Performance against Rutting. In Airfield and Highway Pavements, 2023, pp. 406-415.
[22] KEVIN, L. C. - JONATHAN FANNIN.: A comparison of two design methods for unpaved roads reinforced with geogrids. Canadian geotechnical journal, Vol. 43, Iss. 12, 2006, pp. 1389-1394.
[23] BURMISTER, D. M.: Evaluation of Pavement Systems of the WASHO Road Test by Layered System Methods. Highway Research Board Bulletin, Highway Research Board (HRB), Vol. 177, 1958, pp. 26-54.
[24] JAYALAKSHMI DHEIVEEKAN. - BHOSALE, S. S.: Laboratory investigation to identify subgrade soil in Maharashtra to satisfy reinforcement need for pavement design. Materials Today: Proceedings, Vol. 85, 2023, pp. 127-133.
[25] INGLE, G. S. - BHOSALE, S. S.: Development of full-scale laboratory accelerated pavement testing facility: a step toward performance assessment of geosynthetics reinforced pavement. Innovative Infrastructure Solutions, Vol. 4, Iss. 1, 2019, pp. 1-12.