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Technical Note

Laboratory investigation of bearing capacity behaviour of strip footing on reinforced flyash slope

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ABSTRACT

The paper presents the results of laboratory model tests on bearing capacity behaviour of a strip footing resting on the top of a geogrid reinforced flyash slope. A series of model footing tests covering a wide range of boundary conditions, including unreinforced cases were conducted by varying parameters such as location and depth of embedment of single geogrid layer, number of geogrid layers, location of footing relative to the slope crest, slope angles and width of footing. The results of the investigation indicate that both the pressure–settlement behaviour and the ultimate bearing capacity of footing resting on the top of a flyash slope can be enhanced by the presence of reinforcing layers. However the efficiency of flyash geogrid system increases with the increasing number of geogrid layers and edge distance of footing from the slope. Based on experimental results critical values of geogrid parameters for maximum reinforcing effects are established. *Experimental results obtained from a series of model tests have been presented and discussed in the paper.*

1. Introduction

Use of polymeric reinforcements to improve load-bearing capacity of foundation has been extensively reported by researchers by using different foundation material. These investigations have demonstrated that both the ultimate bearing capacity and settlement characteristics of the foundation can be improved by the inclusion of reinforcements within the fill. In reality, there are many situations where foundations need to be located either on the top of a slope or on the slope itself (Foundation of a bridge abutment or foundations constructed on hill slopes). When a footing is constructed on sloping ground, the bearing capacity of the footing may be significantly reduced depending upon the location of the footing with respect to slope. The improvement of load carrying capacity of such loaded slopes is therefore one of the very important aspects of geotechnical engineering practice as such structures are liable to be unsafe due to slope failure. One of the possible solutions to improve the bearing capacity would be to reinforce the sloped fill with the layers of geogrid. To design a footing on a reinforced sloped fill requires a thorough understanding of both the bearing capacity behaviour of the footing and mechanical behaviour of the reinforced slope. Few studies on bearing capacity behaviour of strip footings on a reinforced slope have been reported in the literature (Selvadurai and Gnanendran, 1989; Huang et al., 1994; Lee and Manjunath, 2000; Yoo, 2001, El Sawwaf, 2007 and Mittal et al., 2009) where the investigations were conducted with granular soil having single slope angle ranging in between 20° and 35°. In any major geotechnical project the volume of soil involved is enormous and if good quality soil is not available locally than transportation of soil from far off borrow areas itself may incur a good amount of project cost. Even when the borrow soil is transported, the contractor has to ensure that the properties of the soil must remain consistent and if it is fine grained soil than the moisture adjustment is also necessary to avoid construction progress. In case the soil used is plastic then an additional problem of dimensional instability may be encountered. The decreasing availability of good construction site has led to the increased use of low lying areas filled up with industrial wastes whose bearing capacity is low. In-situ treatment of such industrial waste fills; in order to improve their bearing capacity with reinforcements is a good alternative to other conventional methods of stabilization. Many a times the industrial wastes (flyash, blast furnace slag, etc.) also termed as an artificial soil, if available locally and found suitable can reduce the construction cost significantly apart from encouraging the sustainable development and reducing the environmental problems (Kamon and Nontananandh, 1991). Therefore any possibility of using these industrial wastes as

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Nomenclature

φ	angle of internal friction
φ_{μ}	tie-soil friction angle
c	apparent cohesion
G	shear modulus of soil
L_r	length of reinforcement
B	width of footing
L	length of footing
L_3	length of loading beam
D_e	edge distance from slope crest
H	slope height
Z	embedment depth
N	number of reinforcing layers
β	slope angle
q	pressure
q'	effective pressure at a depth $B/2$
E	elastic modulus of soil
μ	Poisson's ratio
δ	settlement ratio
w	footing settlement
q_R	footing ultimate pressure for reinforced slope
q_o	footing ultimate pressure for unreinforced slope
γ	unit weight of soil
N_{cq}, $N_{\gamma q}$	resultant bearing capacity factors
F_{cc} and $F_{\gamma c}$	soil compressibility factors

a structural fill material reinforced with geogrid layer, if found effective may ensure bulk utilization of such wastes including the reduction in construction cost and environmental hazards. Disposal of flyash, an industrial waste coming out of the thermal power plants (TPPs) is a major concern and requires a large land area. Acquiring open lands for disposal in developing countries like India is difficult due to small land-to-population ratio. Flyash produced by Indian coal based TPPs is around 90×10^6 tonnes per year requiring an area of 265 km^2 as ash pond (Das and Yudhbir, 2005) for safe disposal and presently less than five percent of this flyash is being gainfully utilized. Flyash when used in structural fills or embankments offers several advantages over borrow soils. It is light in weight, exerts less pressure on subgrade as a fill material and a well compacted embankment made of flyash would exert only 50% of the pressure on a soft subgrade as a fill of equivalent height using coarse granular borrow and again the compaction curve of flyash is relatively flat, thus implying that construction is less sensitive to compaction-moisture content than that of the fine grained soils commonly used as structural fill (Martin et al., 1990). Flyash being non-plastic will also solve the problem of dimensional instability as exhibited by plastic soils. Further properties of flyash from a given source are likely to be more consistent as compared to the soil from natural borrow areas. Studies on bearing capacity of shallow foundation on a level flyash ground have been reported by Pusadkar and Ramasamy (2005), Trivedi and Sud (2005) and Bera et al. (2007). However, there is very limited information (Choudhary and Verma, 2001) on the integrity, deformation and bearing capacity behaviour of reinforced flyash slopes when subjected to a vertical load applied to a strip footing positioned close to the slope crest. Therefore reinforced flyash sloped fill is one of the possible promising areas for bulk utilization of flyash in geotechnical applications where the flyash will provide the bulk of the mass in the fill and the reinforcement may provide the necessary strength to the mass of the geotechnical system and if found effective, can provide an economically viable solution particularly for the road and railway embankments. But prior to prototype use it is essential to establish at least experimentally the influence of reinforcement in enhancing the behaviour of footing located near the crest of a flyash sloped fill. In view of the limited information available on the aforementioned problem, the present investigation aims at the comprehensive investigation relating to the behaviour of a loaded strip footing resting on the top of a reinforced flyash embankment. The aim of present investigation is to find out the efficacy of a single geogrid layer in terms of its location and depth of embedment as well as multiple layers of geogrid at certain specified vertical spacing when incorporated within the body of a model flyash embankment and loaded at its top surface through the footing. Various other aspects, which can influence the behaviour of footings resting on the top of a slope like edge distance, slope angle, width of footing have also been studied for unreinforced and reinforced cases.

2. Laboratory model tests

2.1. Materials

Flyash procured from electrostatic precipitators of TISCO (Tata Iron and Steel Company Limited, Jamshedpur, India) was used throughout the investigation. Particle size distribution of the flyash is shown in Fig. 1. The measured standard proctor density and the corresponding optimum moisture content (OMC) were 9.34 kN/m^3 and 48% respectively. The value of apparent cohesion (c) and angle of internal friction (φ) were 20 kPa and 14° respectively. Commercially available polypropylene model geogrids 0.27 mm thick and 300 mm wide having an average tensile strength of 4.0 kN/m and tie-soil friction angle (φ_{μ}) equal to 35° were used as reinforcing elements.

2.2. Test tank

The model tests were conducted in an open ended masonry tank having dimensions of 2400 mm × 310 mm in plan and 1200 mm in depth. The tank was fitted with a 12 mm thick perspex sheet on front side to observe the failure mechanism during the tests. Horizontal and vertical lines were also marked on the perspex sheet forming a grid to measure and record the coordinates of failure surface of the slope. The tank was built sufficiently rigid to

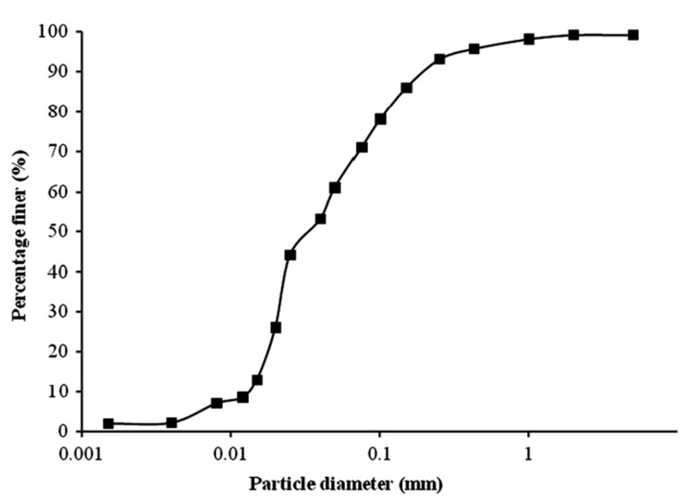

Fig. 1. Particle size distribution of flyash.