Evaluation of resilient and permanent deformations of geogrid reinforced pavements

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ABSTRACT

Geosynthetics have long been used for reinforcing unbound base/subbase layers in paved and unpaved roads for improving its performance and carrying more loads. Field applications demonstrated that geosynthetic reinforcement can help reduce various types of distresses and extend the service life of pavement structures. Geogrid, a two dimensional planar geosynthetic is used in unpaved roads to to carry the superimposed load such as traffic load and to well distribute the load safety to the subgrade. In the current paper experimental studies are conducted on geogrid reinforced Granular Sub Base to see the effectiveness of reinforcement in the field by allowing the load for very large number of repetitions. The performance of the reinforcement is monitored by studying the plastic and elastic deformation and then comparing it with the unreinforced cases. The results showed that geogrid reinforces the unbound aggregate thus reducing the deformation along with the reduction in the required thickness of the aggregate layer of unpaved roads. The amount of reduction of permanent deformation was more for reinforced layer with higher thickness.

Keywords: Resilient deformation, plastic deformation, geogrids, load deformation response

1 INTRODUCTION

The performance of highway pavements is influenced by the strength and stiffness of the pavement layers. The cost and duration of construction depends on the availability of aggregate used in laying pavement construction. In India, there is a high demand for good aggregates and the availability of aggregate resources is limited to certain areas. There is a need for development of sustainable construction methods which can handle aggregate requirements with least available resources and provide good performance. Hence it is imperative to strive for alternatives to achieve improved quality of pavements using supplementary and potential materials. The use of geogrids in aggregate layers provides the reinforcing application and promotes sustainable Geotechnics.

The paper presents the results of load – deformation behavior of geogrid reinforced pavements in terms of resilient deformations and plastic deformations. The use of geogrids improves the performance of pavements in terms of reduced deformations is presented and discussed, results also showed a lesser granular sub base layer thickness, thus resulting in reduction of aggregate required for construction.

2 LITERATURE REVIEW

Shin et al. (1993) conducted laboratory model tests on a surface strip foundation, supported by geogrid-reinforced saturated clay to obtain the critical parameters required to derive the maximum ultimate bearing capacity for a given clay-geogrid combination. Similarly Das and Shin (1994) also conducted laboratory model tests to determine the permanent settlement of a surface strip foundation supported by geogrid-reinforced saturated clay which was subjected to a combination of static and dynamic load of slow-frequency. The results showed that maximum permanent settlement increases with the increase in the intensity of the static load for a given amplitude of the cyclic load intensity. Raymond and Komos (1978) derived the relationship between foundation settlement and the number of load cycles by conducting the model tests on strip surface foundations supported by sand. Shin et al. (2002) conducted large-scale laboratory model tests to determine the permanent settlement due to cyclic load on a rail road bed for a proposed high-speed train route extending from Seoul to Pusan in South Korea. They evaluated that the permanent settlement of the rail road bed is constant after the application of $10^5$ numbers of cycles. They made one conclusion that the settlement reduction is more effective when the geogrid is placed in between the interface of subgrade and sub base. Khodaii and Fallah (2009) investigated the permanent accumulation of permanent deformation on the top of the crack in the asphalt pavement. They conducted a series of experiments with and without geogrid reinforcement. It was shown that by using geosynthetic materials, specimens exhibited resistance to develop cracking. Moghadas Tafreshi and Khalaj (2008) performed an experimental study on a small-diameter pipes buried in reinforced sand subjected to repeated loads. They concluded that, as the number of cycles increased the
deformation of the pipe and the settlement of the soil surface increased respectively. All the above studies indicated that geogrids are effective under repeated loading conditions. The resilient deformation behavior of granular sub base with and without reinforcement, with variation in the depth of granular sub base is a useful input in design of pavements and needs to be studied. The paper presents the results of experiments and analysis of the results to understand the behavior of geogrid reinforced granular sub base during cyclic loading.

3 EXPERIMENTAL STUDIES

3.1 Materials Used

3.1.1 Sand and granular sub base material

In these experimental studies, sand and granular sub base were used. The sand and granular sub base were properly cleaned and then engineering tests were conducted. Grain size distribution curves of sand and granular sub base are shown in Fig.1. The properties of the sand and granular sub base were determined in the laboratory by performing several tests as per ASTM standards. Index parameters of sand and granular sub base are presented in Tables 1 and 2.

![Grain size distribution of materials.](image)

**Table 1: Index properties of sand**

| Parameter       | Value       |
|-----------------|-------------|
| D<sub>10</sub>  | 0.082       |
| D<sub>60</sub>  | 0.3         |
| Coefficient of curvature (C<sub>c</sub>) | 1.17         |
| Coefficient of uniformity (C<sub>u</sub>) | 3.66         |
| Maximum dry density of sand | 20.6 kN/m<sup>3</sup> |
| Minimum dry density of sand | 14.3 kN/m<sup>3</sup> |
| Internal Friction angle (Φ) | 31          |
| CBR             | 10          |

The granular sub base was placed over the sand as a base course material and geogrid was placed in granular sub base to investigate the improvement of load carrying capacity of the pavement in the presence of geogrid reinforcement.

3.1.2 Geogrid

Biaxial geogrid is used as reinforcement in granular sub base and its parameters are given in Table.3.

**Table 3: Geogrid parameters**

| Polymer          | Polypropylene |
|------------------|---------------|
| Aperture size (MD, XMD) | 30mm, 30mm   |
| Ultimate tensile strength (kN/m) | 20           |
| Mass per unit area (g/m<sup>2</sup>) | 200         |
| Shape of the aperture opening | Square |

Each layer is compacted with the help of a hammer to achieve the required density. The depth of granular sub base (D) varied from 150mm to 300mm from the subgrade. A circular model plate, with a diameter of 150mm was used. Model plate was placed on the pre-determined alignment at the top surface of the granular sub base. Linear Variable Differential Transformer (LVDT) is used for measuring the settlement of plate during experiments. The least count of the LVDT is 0.1mm and the maximum value is 50mm.

3.2 Experimental setup

The experiments were conducted in the test tank of size (1500mm x 1500mm x 1000mm) made up of cast iron. The tank was fitted to the loading frame which is connected to the automated operating system. A circular steel plate with 15 mm thickness and 150 mm diameter was used as the model plate. The load cell was placed between the plate and actuator to measure the imposed load. Subgrade and granular sub base layer was separated using a thin geotextile throughout the experiments. Schematic representation of test setup is shown in Fig.2.

3.3 Testing procedures

Using precise measurements, the plate was placed exactly at the centre of the test tank in order to avoid the eccentric loading. Four LVDTs were placed on
either side of the centerline of the circular plate to record the plate settlement. During experimental study, cyclic loading was carried out for all the depths of granular sub base. Cyclic loading was applied in load increments of 19.62kN, 24.52 kN and 29.43kN. The magnitude of the load and settlement were recorded using automatic data acquisition system.

3.4 Experimental programme

The details of the testing program are summarized in Table.4. The geogrid was used in square shape and width of geogrid (b) is three times the width of the plate (B), and is kept constant throughout the experiments. The density of granular sub base, size of plate, relative density of the sand bed, geogrid size and width of geogrid were kept constant in all the tests. Plate was placed on the surface of the granular sub base. In reinforced tests, the geogrid reinforcement was placed at a depth of 50mm below the loading plate, as shown in the Fig.2.

Table.4 Testing programme details for granular sub base bed

| Test Series | Variable parameters | Constant parameters |
|-------------|---------------------|---------------------|
| A           | Type of reinforcement: Unreinforced, geogrid reinforced (granular sub base 200mm) | b/B=3 |
| B           | Unreinforced condition | b/B=3 |
|             | D = 250mm, 300mm |
| C           | Geogrid reinforced | b/B=3 |
|             | D = 250mm, 300mm |

Haversine loading pattern is used for the application of cyclic loading, and for every 1000 cycles, loads in the range of 19.62kN, 24.52kN and 29.43kN on 15 cm dia plate were applied. These correspond to 1110 kPa, 1387 kPa and 1665 kPa.

During cyclic loading, granular sub base experiences the elastic and plastic deformation. Fig.6 (a), represents the approach followed in the evaluation of elastic and plastic deformation of granular sub base. The resilient and plastic deformation determined from total deformation is shown separately in Fig.6 (b). In case of geogrid reinforced granular sub base, the resilient deformation is less compared to the unreinforced base and is attributed to the contribution of tensile behavior of geogrid reinforcement.
To understand the response of sections under large number of load repetitions, stresses are increased in relation to the stress corresponding to the standard stress (550 kPa). These stresses are 1110 kPa, 1387 kPa and 1665 kPa.

Hence corrected number of cycles and settlement is determined by using the equation (1) given in Sivakumar Babu (2006) wherein it is suggested that, if the loading is expressed in terms of a number of passes of an axle load other than the standard axle load, then it can be converted into an equivalent number of standard axle load passes using equation.

\[
\frac{N}{N'} = \left( \frac{P}{P'} \right)^{1.93}
\]

Where, \(N'\) = number of passes, \(N\) = standard number of passes, \(P\) = standard axle load, \(P'\) = axle load.

From Fig.7, it is observed that, the resilient deformation of geogrid reinforced granular sub base is increased by 23% as compared to unreinforced granular sub base. Fig.8 shows the response of total deformation versus standard number of passes. For 10^7 (one million) cycles, the 41% of reduction in total deformation was observed that by providing the geogrid reinforcement in granular sub base.

5 CONCLUSIONS

From experimental studies it was concluded that, the resilient and permanent deformation of the granular sub base increased with the increase in number of cyclic loading. Fig.7 and Fig.8 show that, reduction in resilient deformation is up to 23% and the total deformation of the reinforced granular sub base reduces by about 35 to 41% with the provision of geogrid in granular sub base.

ACKNOWLEDGEMENTS

The work reported in this paper is a part of the work carried out in the project sponsored by the Department of Science and Technology, Government of India New Delhi. The authors thank the DST for the financial assistance in the project.

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