Finite Element Analysis of Embankment using Tire Crumb Rubber

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ABSTRACT: Organized highway networks contribute vital role for the nation by economic development. In India, more roads are needed for connecting all villages to urban areas for transportation. To fulfil the demand of materials for the roads, more construction materials are required for making new roads. The shortage of natural aggregate and cost of construction material is a big problem for any construction project. Scrap rubber tires are fire hazards kind of waste, and the quantity of this waste is increasing annually. The utilisation of shredded tire waste rubber is to combine or mix with soil as lightweight embankment fill material. The current study is based on stability analysis of reinforced highway embankment on soft soil by using finite element based software PLAXIS 3D. The numerical model study has done on the embankment reinforced with geogrids. The effect of stiffness of reinforcement and embankment fill has been presented in this paper.

Keywords: Crumb rubber; embankment; FEM; geogrid

1. Introduction

Every year millions of tires are disposed or dumped in large amount stockpiles in India. These stockpiles of tires cause environmental pollution when it burnt and provided mosquito-breeding places. In India due to the infrastructure development and industrialisation in the rural or urban area, the means of transportation are increased on the roads. As increasing the infrastructure development in India, conventional materials such as sand, aggregate and gravel, etc. are depleting. Therefore, there is a need for searching alternative materials for civil engineering activities. Tyre crumb rubber has drawn the attention of highway engineers due to their properties of lightweight, excellent shock absorbance and high resilience. The cost of tire chips is approximately Rs 700/- to Rs 2000/- per cubic meter depending on the quality and size. Various names according to their sizes referred to the ASTM D 6270-98 “Standard practice of use scrap tires in civil engineering. The size of rubber less than 12 mm used in this study called “granulated or ground rubber.” Studies on soil-tire mixtures by (Bosscher et al. 1992) discussed the improved frictional resistance, increased resistance to dynamic loading and improved drainage characteristics of the soil. The engineering properties of sand-rubber mixtures were studied by several researchers for application in the geotechnical related engineering field as a lightweight backfill material (Humphrey et.al.1997; Lee et al. 1999; Yang et al. 2002). The performance of a test embankments constructed of sand-tyre shred mixture as fill material was reported (Borssscher et al. 1997; Yoon et al. 2006). The influence of tire crumb and buffing inclusion on the shear strength was reported (Edincliler et al. 2010). The model simulation and validation by using finite element method were used as an alternative tool to investigate the behaviour of the reinforced embankment with the different waste material. The finite element 2D analysis has been used to simulate the behaviour of the embankment with lightweight fill material on soft soil (Tanchaisawat et al. 2008). The most of the research work has been done, using finite element 2D plane strain conditions on the full model test. This paper presents the predictions and numerical simulations of the performance of full-scale embankment test overlying on soft soil using lightweight material made of crumb rubber and sand with geogrid reinforcement. The PLAXIS 3D finite element program was used to analyse the performance of embankment.

2. Methodology

2.1 Materials

The materials were used in this study consisted of river sand, crumb rubber, and geogrid. The size of crumb rubber was found from 2 mm to 3 mm. The percentage of crumb rubber adopted 10 % by weight of sand. Particle size analysis test was carried out according to IS: 2720(Part 4)-1985(reaffirmed 2006). Both materials classified to poorly graded soil according to Indian standard soil classification system. The biaxial geogrid material was used as a reinforcement.

Fig. 1 sand-tire crumb rubber
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Fig. 2 Grain size distribution curve for sand-crumb rubber

2.2 Material testing
The shear strength characteristics of sand–tire crumb rubber mixtures were measured using triaxial apparatus. Triaxial consolidated drained tests were conducted for obtaining the Modulus of elasticity of mixed sample of sand-tire crumb rubber. A sample size of 75 mm diameter by 150 mm length was tested consolidated drained conditions. The sand-tire crumb rubber mixture was prepared at four different percentage 5%, 10%, and 15% by weight of sand. The procedure for mixing of sand–tire crumb rubber was adopted (Bali reddy 2015). Triaxial CD test conducted at two different confining pressures of 25 kDa and 50 kDa.

2.3 Material models
The finite element model PLAXIS 3D was used for the embankment using geogrid reinforcement. The 10 noded triangular elements was used in the model simulation. The soft soil model was used for soft clay foundation. The Mohr-coulomb failure criterion was used to simulate the behaviour of the sand and lightweight fill material. Geosynthetic reinforcement was modelled using the geogrid elements, which has tensile resistance only, in plaxis. Hence, the only property required for the geogrid material is its axial stiffness, EA. The normal stiffness of 100 kN/m to 2500 kN/m was used for geogrid material. The width of embankment 16 m and side slope of two horizontal to one vertical and height of the embankment 4 m used for FEM analysis. A surcharge weight on the embankment is considered 24 kPa, which is equivalent to traffic and dead weight of pavement. Stability of embankment was analyzed with and without geogrid at the various elastic stiffness of reinforcement. The finite element analysis in this paper is based on the two types embankment fill material one is natural fill material sand and other sand-tire crumb rubber mix. The properties of embankment fill material and soft soil are given in Table-1.

Table-1 Material Model properties of embankment fill and foundation soil

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sand–crumb rubber mix</th>
<th>Sand</th>
<th>Soft soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material model</td>
<td>Mohr-coulomb</td>
<td>Mohr-coulomb</td>
<td>Soft soil model</td>
</tr>
<tr>
<td>Drainage condition</td>
<td>Drained</td>
<td>Drained</td>
<td>Undrained</td>
</tr>
<tr>
<td>Unsaturated density (kN/m³)</td>
<td>13.20</td>
<td>14.16</td>
<td>14.02</td>
</tr>
<tr>
<td>Saturated density (kN/m³)</td>
<td>15.33</td>
<td>16.55</td>
<td>16.10</td>
</tr>
<tr>
<td>Elastic modulus (E₅₀) (kN/m²)</td>
<td>5000-8000</td>
<td>15000</td>
<td>-</td>
</tr>
<tr>
<td>Poisson’s ratio(µ)</td>
<td>0.38</td>
<td>0.35</td>
<td>0.33</td>
</tr>
<tr>
<td>Cohesion (kN/m²)</td>
<td>1.0</td>
<td>1.0</td>
<td>10</td>
</tr>
<tr>
<td>Friction angle(ϕ₀)</td>
<td>35</td>
<td>38</td>
<td>5</td>
</tr>
<tr>
<td>Dilation angle(Ψ)</td>
<td>5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Interface strength (Rₛₛ)</td>
<td>0.90</td>
<td>0.96</td>
<td>0.60</td>
</tr>
</tbody>
</table>

3. Results and Discussion
The results of finite element analysis of horizontal and vertical deformation in embankment reinforced with the various proportion of crumb rubber are illustrated in figure 3 and 4. It is observed from the figures, the deformation in vertical and horizontal direction decreases with increases percentage of crumb rubber content in the sand. In addition to a percentage of the crumb rubber in the sand the vertical and horizontal deformation found less as compared to zero percent of crumb rubber. Since rubber has some tensile stiffness, which provides the additional reinforcing effect in the sand. The vertical and horizontal deformation decreases due to densification and interlocking effect between sand and rubber particles. The shear strength also increases with increasing content.
4. Conclusions
This article presents the finite element analysis of the embankment using lightweight fill material made of sand-tire crumb rubber. The reinforcement effect of crumb rubber has been investigating using PLAXIS 3D software. From the laboratory test and earlier published results, the specific gravity of tire crumb rubber has found less than sand. In addition, of crumb rubber in the sand reduces the bulk unit weight of lightweight material (sand-crumb rubber) and due to the reduction in overburden pressure, the footing settlement reduced on soft soil. Vertical and horizontal deformations in the embankment reinforced with geogrids are less as compared to the unreinforced embankment. The beneficial effect of geogrid in terms of axial stiffness observed at 2500 kN/m. No further reduction has been observed after increasing the axial stiffness of geogrid.

References


IS 2720 (Part 4) (1985) Methods of Test for Soils: Grain Size Analysis, Bureau of Indian Standards, New Delhi, India.


