INVESTIGATION AND STABILITY ANALYSIS OF EMBANKMENT BUND

V.K. Kanaujia¹, A.K. Sinha², V.G. Havanagi³, U.K. Guruvittal⁴

ABSTRACT

Considering the rapid development of residential area in and around district Ghaziabad (Uttar Pradesh), widening of bund road from one lane two way road to two lane divided road was carried out. This bund is connecting road between NH-24 to NH-58 and running parallel to Hindan river. The height of embankment is varying from 3 to 5 m and side slope is 2H:1V. The carriageway width of the existing bund road is 5.5 m (two way). The top surface and side slope of the existing bund is badly damaged due to poor maintenance and plying of traffic from the nearby residing people/builders activities. The existing embankment bund road was widened by increasing the top width to 11m and the slope of the embankment was restricted to 1.5H:1V due to unavailability of land width. The width of carriageway way is increased from 5.5 m to 7.5 m and shoulder of 0.75 m on both sides with median. Field investigation was carried out to examine the in-situ density of embankment and sub soil material. Geotechnical characterization was carried out on borrow soil which was used in the construction of embankment and sub grade. Slope stability analysis was carried out using computer software on the existing and new (proposed) embankments of different heights under traffic loading and different water saturation conditions. Factor of safety was determined considering the slope and global stability of the embankment. The research paper discusses the result of geotechnical characterization of in-situ and borrow soils. It was observed that borrow soil may be used for the construction of embankment and sub grade layer of road. Slope stability analysis reveals that new slope is stable and factor of safety was observed to be more than 1.5. Based on the result of laboratory investigation and expected traffic, design of pavement was also carried out as per IRC 37 (2012).

Keywords: Bund, embankment, slope, stability, soil, investigation

¹Kanaujia V. K., Sr. Technical Officer, CSIR-Central Road Research Institute, New Delhi, India, Email-vkk.crri@nic.in
²Sinha, A. K., Sr. Scientist, CSIR-Central Road Research Institute, New Delhi, India, Email-sinha.crri@nic.in
³Havanagi V. G., Sr. Principal Scientist, CSIR-Central Road Research Institute, New Delhi, India, Email-vasant.crri@nic.in
⁴Guruvittal U. K., Chief Scientist, CSIR-Central Road Research Institute, New Delhi, India, Email-vittal.crri@nic.in
INVESTIGATION AND STABILITY ANALYSIS OF EMBANKMENT BUND

V. K. Kanaujia, Sr. Technical Officer, CSIR-Central Road Research Institute, New Delhi, Email-vkk.crri@nic.in
A. K. Sinha, Sr. Scientist, CSIR-Central Road Research Institute, New Delhi, Email- sinha.crri@nic.in
V.G. Havanagi, Principal Scientist, CSIR-Central Road Research Institute, New Delhi, Email- vasant.crri@nic.in
U. K. Guruvittal, Chief Scientist, CSIR-Central Road Research Institute, New Delhi, Email-vittal.crri@nic.in

ABSTRACT: Considering the rapid development of residential area in and around district Ghaziabad (Uttar Pradesh), widening of bund road from one lane two way road to two lane divided road was carried out. This bund is connecting road between NH-24 to NH-58 and running parallel to Hindan river. The height of embankment is varying from 3 to 5 m and side slope is 2H:1V. The carriageway width of the existing bund road is 5.5 m (two way). The top surface and side slope of the existing bund is badly damaged due to poor maintenance and plying of traffic from the nearby residing people/builders activities. The existing embankment bund road was widened by increasing the top width to 11m and the slope of the embankment was restricted to 1.5H:1V due to unavailability of land width. The width of carriage way is increased from 5.5 m to 7.5 m and shoulder of 0.75 m on both sides with median. Field investigation was carried out to examine the in-situ density of embankment and sub soil material. Geotechnical characterization was carried out on borrow soil which was used in the construction of embankment and sub grade. Slope stability analysis was carried out using computer software on the existing and new (proposed) embankments of different heights under traffic loading and different water saturation conditions. Factor of safety was determined considering the slope and global stability of the embankment. The research paper discusses the result of geotechnical characterization of in-situ and borrow soils. It was observed that borrow soil may be used for the construction of embankment and sub grade layer of road. Slope stability analysis reveals that new slope is stable and factor of safety was observed to be more than 1.5. Based on the result of laboratory investigation and expected traffic, design of pavement was also carried out as per IRC 37 (2012).

Keywords: Bund, embankment, slope, stability, soil, investigation

1. INTRODUCTION
The widening of bund road from Km. 13.175 to 17.000, connecting NH-24 to Hindan Barrage is being taken up by Irrigation Construction Division, Ghaziabad (Uttar Pradesh), considering the rapid development of residential area in and around this bund and increase in road traffic. The bund road would also be part of road connectivity plan of Ghaziabad Development Authority, between NH-24 and NH-58. The existing top width of bund is 5.5 m and side slope is 2H:1V. The available width of land is 28m. The width of bund and side slope is observed to be disturbed due to residing people/builders activities on the downstream side. This bund would also be used as inspection road and way for flood relief items in rainy seasons. The existing embankment bund road has been planned to be widened by increasing the top width to 11m with side slope of 1.5H:1V. The width of carriage way will be increased to 7.5 m with shoulder of 0.75 m on both sides.

2. SCOPES AND OBJECTIVES
The scopes and objectives of the study are given below.

a. Geotechnical characterization of existing embankment soil, sub soil and borrow soil materials
b. Design and Slope stability analysis of embankment
c. Design of pavement layers

3. MATERIALS
Samples were collected from existing embankment soil, sub soil and borrow soil at Ghaziabad, (U.P.).
4. LABORATORY INVESTIGATIONS
Geotechnical characterization of collected sample were carried out which includes Proctor compaction, Direct shear test, and California Bearing Ratio test. The details of laboratory tests carried out are given below:

4.1 Grain Size Analysis
Grain size analyses of materials were carried out as per bureau of Indian standard procedure. Grain size distribution curves (embankment, sub soil and borrow soil) are shown in the Fig. 1. The existing embankment, sub soil and borrow soils were observed to be fine grained material.

![Grain size distribution curves](embankment, sub soil and borrow soil)

4.2 Proctor Compaction Test
Modified Proctor compaction test was carried out as per bureau of Indian standard procedure. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were observed to be 18.60 kN/m$^3$ and 11.4 % for existing embankment soil, 18.50 kN/m$^3$ and 10.4 % for sub soil and 18.47 kN/m$^3$ and 14.65% for borrow soil respectively. From the above result, it was observed that all three materials (embankment soil, sub soil and borrow soil) have similar compaction characteristics.

4.3 California Bearing Ratio Test
CBR test was carried out on existing embankment soil sample, borrow soil as per bureau of Indian standard procedure. Three specimens were prepared by compacting the soil sample at 97 % of their respective MDD/OMC. The specimens were then soaked for 4 days in potable water before testing. The specimens were then sheared at the rate of 1.25 mm/min. The average value of CBR is determined as 6.0 % under soaked condition.

4.4 Direct Shear test
Direct Shear test was carried out on sub soil sample of size 6 cm x 6 cm x 2.5 cm as bureau of Indian standard procedure. The test was carried out on a soil sample compacted at 95% of its maximum dry density and its optimum moisture content. The sample was tested under the saturated condition. The normal stress was varied in the range of 50 to 150 kN/m$^2$. The soil sample was sheared at the rate of 0.625 mm/min. Sub soil sample was found to have Cohesion (c) of 15 kPa and angle of internal friction ($\phi$) of 25$^0$.

5. STABILITY ANALYSIS OF EMBANKMENT BUND
Design and stability analysis of widened embankment was carried out. Factor of safety of critical slip circle was evaluated for different heights of embankment viz. 3m, 4m, and 5m. The stability analysis was carried out for different conditions viz. (a) Partially saturated (Embankment compacted at MDD/OMC (2) Fully saturation up to H.F.L and (3) Sudden draw down. The traffic and other live loads are considered as 24 kN/m$^2$. Analysis was carried out for both earthquake and without earthquake conditions. The earthquake factors viz. $\alpha_h= 0.05$ (horizontal coefficient), $\alpha_v= 0.025$ (vertical coefficient) were used during the analysis. The factor of safety calculated under different saturated conditions is shown in Table 1.

<table>
<thead>
<tr>
<th>Height of Embankment &amp; E.Q Conditions</th>
<th>Moisture conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Partially Saturated</td>
</tr>
<tr>
<td>H=3 m With E.Q.</td>
<td>2.90</td>
</tr>
<tr>
<td>Without E.Q.</td>
<td>3.16</td>
</tr>
<tr>
<td>H=4 m With E.Q.</td>
<td>2.68</td>
</tr>
<tr>
<td>Without E.Q.</td>
<td>2.90</td>
</tr>
<tr>
<td>H=5 m With E.Q.</td>
<td>2.50</td>
</tr>
<tr>
<td>Without E.Q.</td>
<td>2.70</td>
</tr>
</tbody>
</table>

![Fig. 1 Grain size distribution curves](embankment, sub soil and borrow soil)
It was observed that factor of safety values ranged between 2.5 to 2.06 for the most critical condition (sudden draw down with earthquake factors) for different embankment heights of embankment. So it was concluded that the embankment is safe for construction.

6. DESIGN OF PAVEMENT LAYERS
Design of pavement layers was carried out for typical traffic data. The proposed thickness of different layers of pavement are as given below.
G.S.B = 300mm, W.M.M = 300mm, D.B.M = 100 mm and B.C = 50 mm.
Analysis of design was carried out by considering the value of sub grade CBR, Traffic data, assumed Vehicle Damage Factor (VDF) and critical strain analysis as per IRC-37 (2012).

6.1 Sub Grade and Traffic Data for Design
Traffic data supplied by UP Irrigation department is given in Table 2.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Delhi to GZB</th>
<th>GZB to Delhi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two wheeler</td>
<td>1513</td>
<td>1490</td>
</tr>
<tr>
<td>Auto rickshaw</td>
<td>443</td>
<td>425</td>
</tr>
<tr>
<td>Car/jeep</td>
<td>3614</td>
<td>3852</td>
</tr>
<tr>
<td>Van/tempo</td>
<td>508</td>
<td>369</td>
</tr>
<tr>
<td>Mini bus</td>
<td>57</td>
<td>85</td>
</tr>
<tr>
<td>Standard bus</td>
<td>631</td>
<td>540</td>
</tr>
<tr>
<td>LCV</td>
<td>1385</td>
<td>1215</td>
</tr>
<tr>
<td>Two axle rigid truck</td>
<td>3862</td>
<td>2850</td>
</tr>
<tr>
<td>Three axle rigid truck</td>
<td>646</td>
<td>585</td>
</tr>
<tr>
<td>Four to six axle</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>Tractor</td>
<td>65</td>
<td>74</td>
</tr>
<tr>
<td>Tractor Trailer</td>
<td>41</td>
<td>38</td>
</tr>
<tr>
<td>Animal/hand drawn</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Cycles</td>
<td>166</td>
<td>175</td>
</tr>
<tr>
<td><strong>Total vehicles</strong></td>
<td><strong>12979</strong></td>
<td><strong>11745</strong></td>
</tr>
</tbody>
</table>

From above Average Daily Traffic (ADT), Commercial vehicles include; Standard bus, LCV, Trucks (Two, Three, Four to Six axles), Tractor and Tractor trailer.

Total Commercial vehicle for both directions = 11,992

It was assumed that 25% of total commercial vehicle will pass through Bund road. Hence, Commercial Vehicle per day (CVPD) = 11,992 x 0.25 = 2,998

As per IRC-37-2012, the cumulative number of standard axles to be carried during the design life is given by

\[ N = 365 \frac{[(1+r)^n-1]}{r} \times A \times D \times F \]  

Where,  
N = Cumulative number of standard axles;  
r = Growth rate (Assumed as 5%);  
n = Design life considered as 10 years.  
A = Commercial vehicle per day in the year of completion of construction;  
D = Lane distribution factor (Assumed as 0.5)  
F = Vehicle damage factor (Assumed as 10, based on the available data with CRRI as per the year 2008 ,VDF=8.3).

\[ N_f = 365 \frac{[(1+0.05)^{10}-1]}{0.05} \times 2998 \times 0.5 \times 10 \]

= 68.8 million standard axles (msa)

6.2 Computation of Allowable Strain at Critical Locations for the above Traffic as per IRC 37 (2012 ).
Fatigue and rutting are two failure criteria of flexible pavement.

6.2.1 Allowable tensile strain under fatigue criteria
For fatigue criteria, 80% reliability criteria has been considered for estimating allowable tensile strain for the design traffic;

\[ N_f = 2.21 \times 10^{-4} \times \left( \frac{1}{\varepsilon_{uf}} \right)^{3.89} \times \left( \frac{1}{N_r} \right)^{0.854} \]

\( \varepsilon_t \) = Allowable tensile strain at the bottom of bituminous layer;
$M_r = \text{Resilient modulus of Bituminous layer (assumed as 1700MPa, VG30 @ temp. 35^0C)}$

By substituting these values in the equation (2).

$$68.8 \times 10^6 = 2.21 \times 10^{-4} \times \left( \frac{1}{E_r} \right)^{3.85} \times \left( \frac{1}{1700} \right)^{0.854}$$

Allowable value of tensile strain at the bottom of bituminous layer;

$$\varepsilon_t = 216.96 \times 10^{-6}$$

### 6.2.2 Allowable vertical compressive strain on sub grade under rutting criteria

Allowable vertical compressive strain for the design traffic on the sub grade may be computed by rutting criteria as given below;

$$N_v = 1.41 \times 10^{-8} \times \left( \frac{1}{E_v} \right)^{4.5337}$$

$C_v = \text{Allowable vertical compressive strain on sub grade.}$

By substituting the value of design traffic;

$$68.8 \times 10^6 = 1.41 \times 10^{-8} \times \left( \frac{1}{E_v} \right)^{4.5337}$$

Allowable value of vertical compressive strain on sub grade computed as, $C_v = 346.43 \times 10^{-6}$

### 6.3 Computation of Induced Strain at Critical Locations for Total Repetition of Load as per IITPAVE, IRC-37 (2012)

#### 6.3.1 Material properties and their input

CBR value of sub grade soil = 6 %

Modulus value of sub grade,

$$M = 17.6 \times \text{CBR}^{0.64}$$

(4)

Modulus value of subbase and base course (granular layers)

$$M = 0.2 \times \text{sub grade modulus} \times h^{0.45}$$

(5)

Where, $h$ is the thickness of granular layer

No. of layers for analysis: 3

(i.e B.C+DBM (VG30@temp.35°C), WMM+GSB and Sub grade layer)

**Loading Configuration**

Dual tire single axle load with single tire load of $20.5 \text{kN}$ with tire pressure of $0.56 \text{MPa}$.

The determined values of modulus and assumed values of Poisson's ratio are given in Table 3.

#### Table 3 Values of modulus and Poisson ratio

<table>
<thead>
<tr>
<th>Type of layers</th>
<th>Proposed thickness (mm)</th>
<th>Modulus Value (MPa)</th>
<th>Poisson’s value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC+DBM</td>
<td>150</td>
<td>1700</td>
<td>0.35</td>
</tr>
<tr>
<td>GSB+WMM</td>
<td>600</td>
<td>195</td>
<td>0.40</td>
</tr>
<tr>
<td>Sub grade</td>
<td>500</td>
<td>55</td>
<td>0.40</td>
</tr>
</tbody>
</table>

#### 6.3.2 Analysis for proposed thickness of different layer

By substituting input parameters for different layers like modulus value, Poisson’s ratio, thickness and loading pattern, the induced stress at critical locations i.e., tensile strain at bottom of bituminous layer and vertical compressive strain on sub grade is calculated using IITPAVE. The computed induced strains are given in Table 4.

**Table 4 Comparison of allowable and induced strains at critical locations**

<table>
<thead>
<tr>
<th>On sub grade</th>
<th>Allowable vertical compressive strain</th>
<th>Induced vertical compressive strain</th>
<th>At the bottom of bituminous layer</th>
<th>Allowable tensile strain</th>
<th>Induced tensile strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>346.43 x 10^{-6}</td>
<td>276.9 x 10^{-6}</td>
<td>216.96 x 10^{-6}</td>
<td>255.3 x 10^{-6}</td>
<td></td>
</tr>
</tbody>
</table>

Induced vertical compressive strain on sub grade is less than allowable value of vertical compressive strain on sub grade. Hence safe.

However, the Induced tensile strain is more than allowable tensile strain at the bottom of bituminous layer.

The bituminous layer would fail in fatigue and hence will not perform its intended service for whole design life. There is a need to increase the thickness of bituminous layer. Trials and error methods were carried out by increasing the thickness of bituminous layer, especially DBM for reevaluating the induced and allowable strains.

#### 6.3.3 Trial 1. Increasing the Thickness of DBM 20 mm

Induced vertical compressive strain on top of sub grade and Induced tensile strain at the bottom of bituminous layer decreases as given in Table 5.

However, Induced tensile strain at the bottom of bituminous layer is more than allowable strain. Therefore, the increase of bituminous layer thickness by 20mm is not sufficient.
6.3.4 Trial 2. Increasing the thickness of DBM 30 mm.
Induced vertical compressive strain on top of sub grade and Induced tensile strain at the bottom of bituminous layer decreases as given in Table 6.

**Table 5** Induced vertical compressive and tensile strains (trial 1)

<table>
<thead>
<tr>
<th>On sub grade</th>
<th>Allowable vertical compressive strain</th>
<th>346.43 x 10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Induced vertical compressive strain</td>
<td>256 x 10^-6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>At the bottom of bituminous layer</th>
<th>Allowable tensile strain</th>
<th>216.96 x10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Induced tensile strain</td>
<td>224 x 10^-6</td>
</tr>
</tbody>
</table>

**Table 6** Induced vertical compressive and tensile strains (trial 2)

<table>
<thead>
<tr>
<th>On sub grade</th>
<th>Allowable vertical compressive strain</th>
<th>346.43 x 10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Induced vertical compressive strain</td>
<td>246 x 10^-6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>At the bottom of bituminous layer</th>
<th>Allowable tensile strain</th>
<th>216.96 x10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Induced tensile strain</td>
<td>211 x 10^-6</td>
</tr>
</tbody>
</table>

Here, induced tensile strain at the bottom of bituminous layer is less than allowable tensile strain (216.96 x 10^-6). Hence safe.

**RECOMMENDATION**
The thickness of DBM needs to be increased by 30mm for performing its intended service for whole design life. The DBM may be laid in two layers of 65mm each (Total thickness of 130 mm).

**CONCLUSIONS**
The widening of bund road from km. 13.175 to km.17.000, connecting NH-24 to Hindan Barrage is being taken up by UP Irrigation Construction Division, Ghaziabad (Uttar Pradesh). The existing embankment bund road proposed to be widened by increasing the top width to 11m with side slope of 1.5H:1V. For this, detailed laboratory investigation to analyze the safety of embankment bund was carried out along with design of pavement layers. Brief conclusions are given below.

1. The Maximum dry density and Optimum moisture content of different materials like existing embankment soil, borrow soil and sub soil have almost equal values. The average CBR value was determined as 6%.
2. The estimated shear strength parameter of the sub soil was determined as Cohesion (c) of 15 kPa and angle of internal friction (ϕ) of 25°.
3. Factor of safety of different heights of widened embankment was observed in the range of 2.06 to 3.09 under different saturation and seismic factors.
4. Analysis of pavement with proposed specifications indicate that the induced tensile strain at the bottom of bituminous layer was more than the allowable strain. Hence, it is proposed to increase the thickness of DBM by 30mm for performing its intended service for whole design life.

**ACKNOWLEDGEMENT**
The authors are thankful to the Director, CSIR-Central Road Research Institute, New Delhi for giving permission to publish the paper.

**REFERENCES:**
1. IRC:37-2012 "Guidelines for the Design of Flexible Pavements"(Third Revision) Published by Indian Road Congress, 2012
2. MORTH (2013) “Specifications for road and bridge works”, "(Fifth Revision)” Published by Ministry of Road and Highway Transport, New Delhi, India.