New Technology Initiatives in Rural Roads and Use of Marginal Materials

Design of Flexible Pavements for LVR Reinforced with Geosynthetics

National Rural Infrastructure Development Agency

Ministry of Rural Development

National Institute of Technology

Warangal, Hyderabad

Lecture 6

Design of Flexible Pavements for LVR Reinforced with Geosynthetics

Presentation Outline

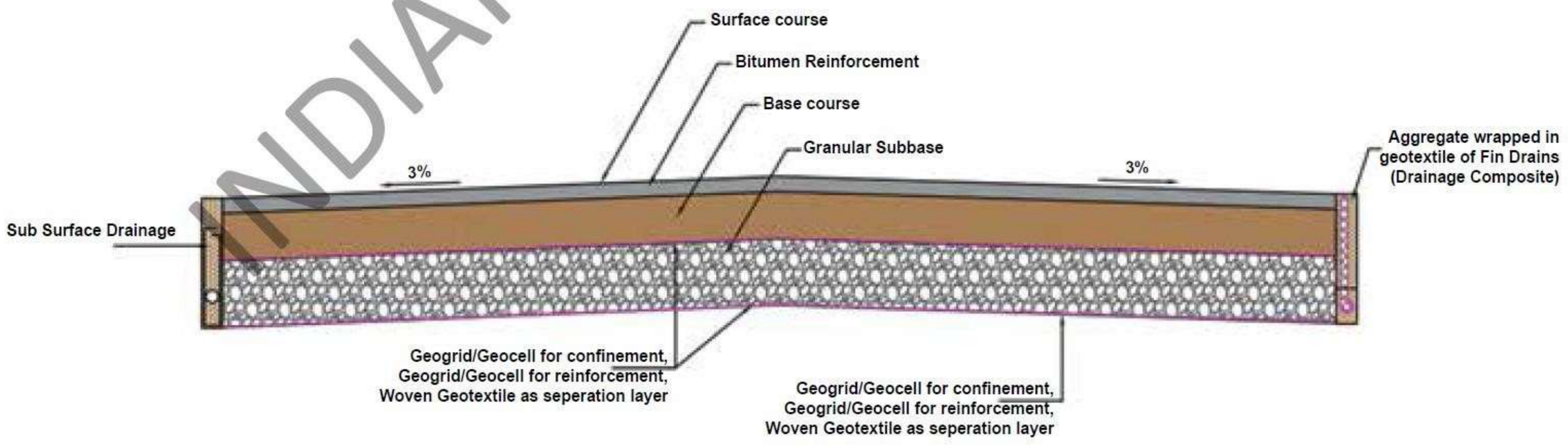
- Introduction
- Classification and Functions
- Test Methods for Geosynthetics
- Design Methodologies
- Flexible Pavement Design-Numerical!

Introduction

- The production and application of geosynthetics started in China-1970s
- Development was slow in 1980s and by 1990s Growth witnessed
- 1998-China-heavy floods the adoption of GSM for dam repair etc.
- Over past 3 decades engineers shown interest in geosynthetics-Globally!
- Sustainable development- Investments and reduce the carbon footprint!
- Geosynthetics added to the traditional list of construction materials.
- IRC:SP:59-2019, addressed the following applications
  - Stabilization and reinforcing of pavement layers
  - Separation and filtration
  - Subsurface and surface drainage and Erosion control

Applications of Geosynthetics

- Stabilization and reinforcing of pavement layers
- Separation and filtration
- Subsurface and surface drainage
- Erosion control of road embankments



Application and functions of Geosynthetics in Roadway Systems

Application	Function(s)	Subgrade Strength	Qualifier
Separator	Separation Secondary: filtration*	2000 psf $\le c_u \le$ 5000 psf (90 kPa $\le c_u \le$ 240 kPa) $3 \le$ CBR ≤ 8 4500 psi $\le M_R \ge$ 11,600 psi (30 MPa $\le M_R \ge$ 80 MPa)	Soils containing high fines (SC, CL, CH, ML, MH, SM, SC, GM, GC)
Stabilization	Separation, filtration and some reinforcement (especially CBR <1) Secondary: Transmission	$c_u <$ 2000 psf (90 kPa) CBR < 3 $M_R <$ 4500 psi (30 MPa)	Wet, saturated fine grained soils (i.e., silt, clay and organic soils)
Base Reinforcement	Reinforcement Secondary: separation	600 psf $\le c_u \le$ 5000 psf (30 kPa $\le c_u \le$ 240 kPa) $3 \le$ CBR ≤ 8 1500 psi $\le M_R \ge$ 11,600 psi (10 MPa $\le M_R \ge$ 80 MPa)	All subgrade conditions. Reinforcement located within 6 to 12 in. (150 to 300 mm) of pavement
Drainage	Transmission and filtration Secondary: separation	not applicable	Poorly draining subgrade

*always evaluate filtration requirements

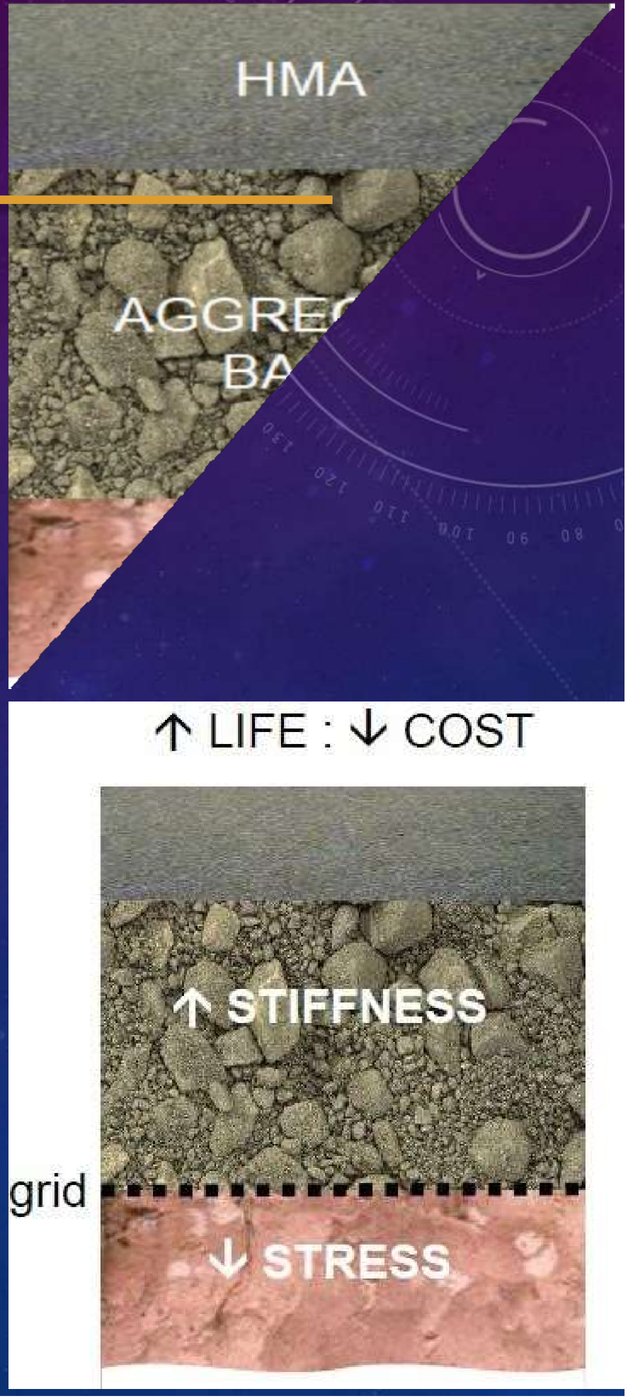
Geogrid Reinforcement

❖ Subgrade Improvement

- Undercut reduction in soft soils
- Construction platform for road construction
- Protection of sensitive subgrade soils

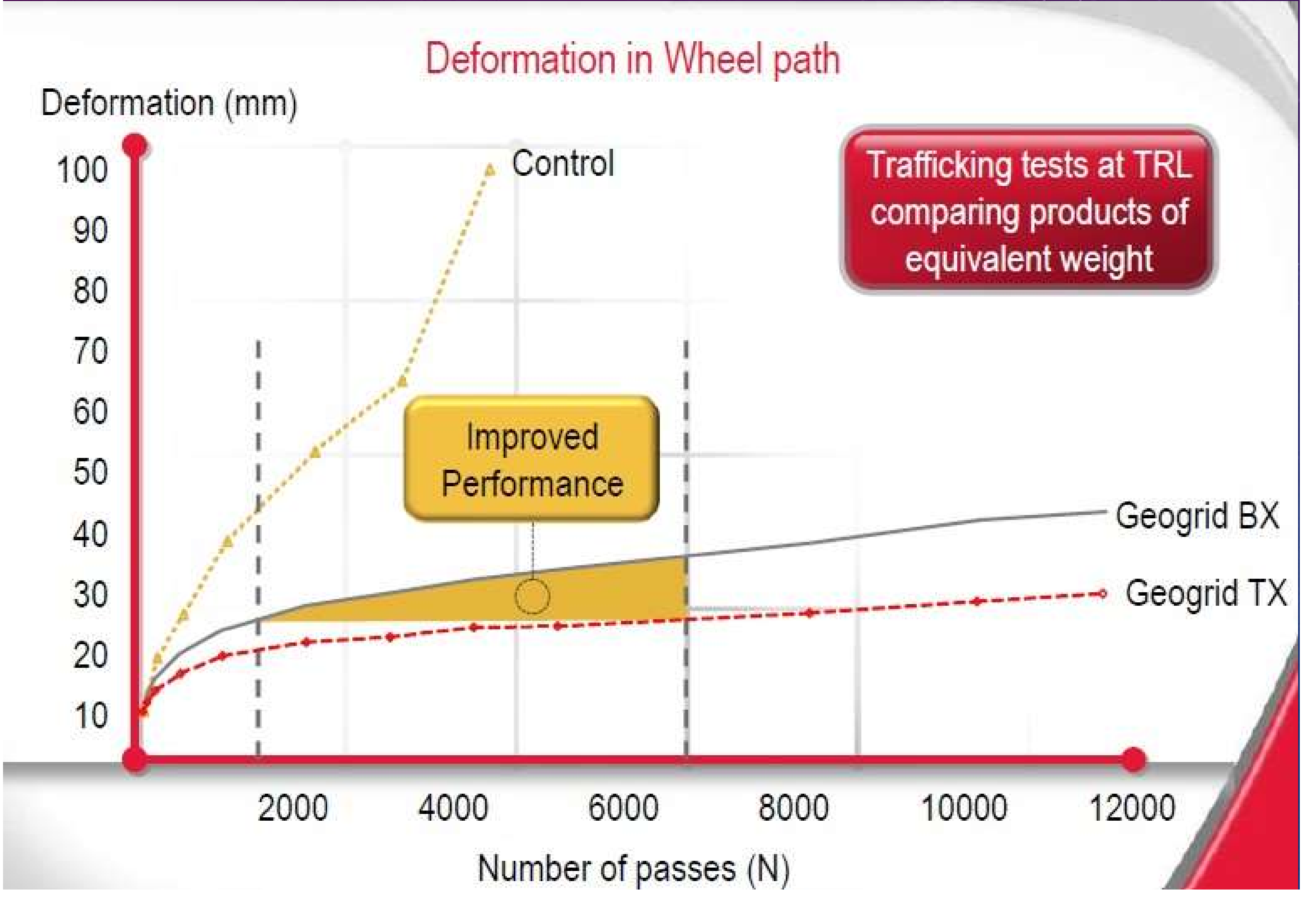
❖ Pavement Base Reinforcement

- Stiffening of base aggregate layer
- Reduction of pavement section
- Extended life of pavement



APT Full Scale TRL

Small Scale APTF



Deformation in Wheel path
Deformation (mm)
100
90
80
70
60
50
40
30
20
10
Control
Trafficking tests at TRL comparing products of equivalent weight
Improved Performance
Geogrid BX
Geogrid TX
2000
4000
6000
8000
10000
12000
Number of passes (N)

Aggregate Rutting Profiles

Unreinforced

3,000 axle passes

Geogrid BX

10,000 axle passes

Geogrid TX

10,000 axle passes

Subgrade Rutting-Profile

Unreinforced

3,000 axle passes

Geogrid BX

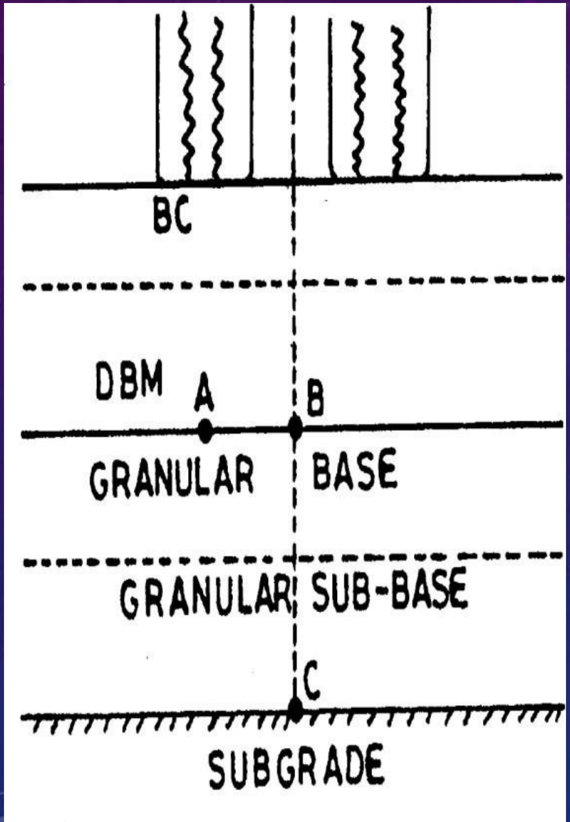
10,000 axle passes

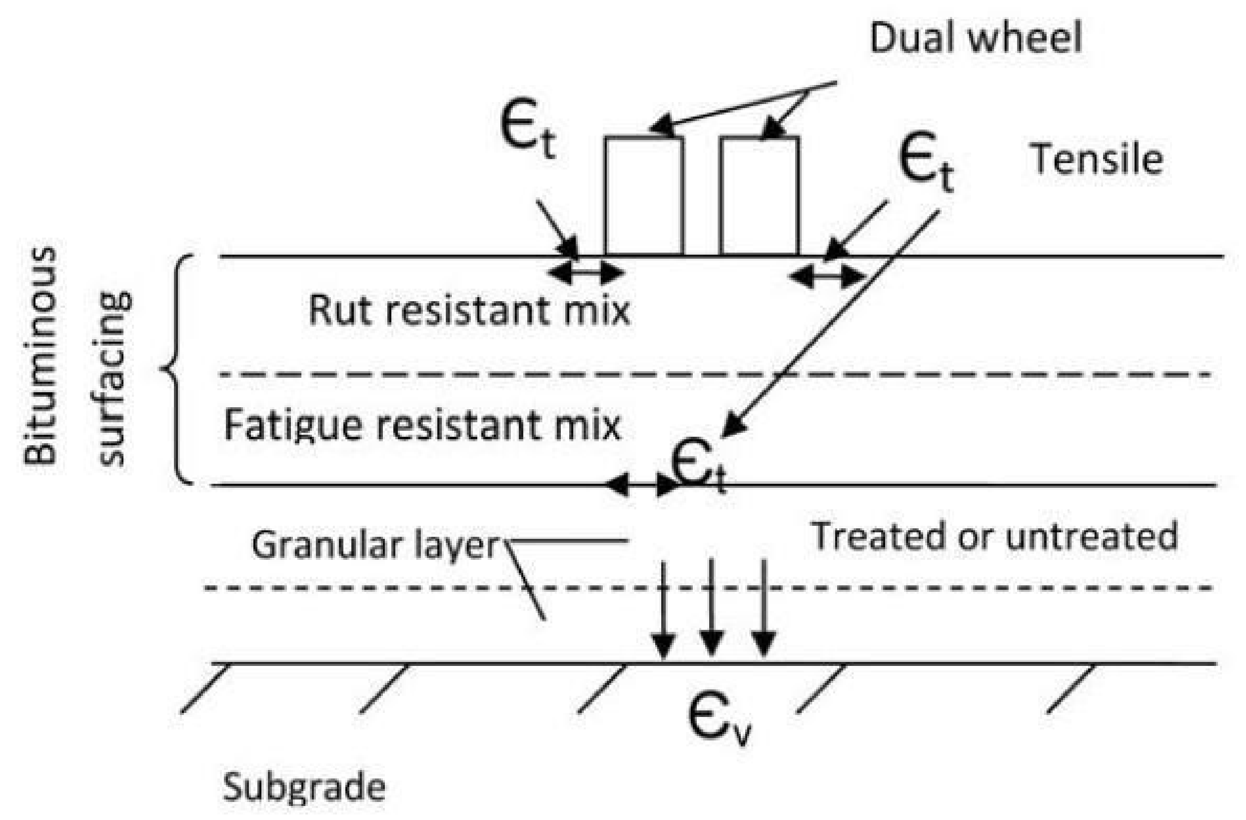
Geogrid TX

10,000 axle passes

Subgrae Stabilization

IRC:37-2018
Guidelines for the Design of Flexible Pavements





Design Methodologies:

Empirical Design Method of Giroud and Han (2004)

- Serviceability Criterion Based on Rut Depth
- Characterization of Geogrid Reinforcement
- Bearing Capacity Factors
- Equation for Required Thickness of Base Course.

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

where:

$(0.661\text{-}1.006\,J^2) > 0$

h = required base course thickness (in. or m)

J = aperture stability modulus in metric units (N-m/degree)

P = wheel load (lbs or kN)

r = radius of tire print (in. or m)

N = number of axle passes

R_E = modulus ratio = $E_{bc}/E_{sg} = 3.28\ CBR_{bc}^{0.3} / CBR_{sg} \leq 5$

E_{bc} = base course resilient modulus (psi or MPa})

E_{sg} = subgrade soil resilient modulus (psi or MPa)

CBR_{bc} = aggregate CBR

CBR_{sg} = subgrade CBR

f_s = rut depth factor

s = maximum rut depth (in. or m)

N_c = bearing capacity factor
= 3.14 for unreinforced roads
= 5.14 for geotextile reinforced roads
= 5.71 for geogrid reinforced roads

f_c = factor relating subgrade CBR to undrained cohesion, c_u = 4.3 psi (30 kPa)

Design Procedure…..

SteP1: **Preliminary calculations**

SteP2: **Check capacity of subgrade soil without reinforcement**

$$P_{h=0,unreinf} = \left(\frac{s}{f_s}\right)\pi r^2 N_c c_u$$

where:

- P_h = support capacity of subgrade *(lb or kN)*
- s = the allowable rut depth (in. or mm)
- f_s = 3 in. (75 mm)
- r = radius of tire contact (in. or m)
- N_c = 3.14 bearing capacity factor for unreinforced case
- c_u = subgrade undrained shear strength (psi or kN/m^2)

If $P < P_{h=0,\ unreinf}$ the subgrade soil can support the wheel load and a minimum thickness of 4 in. (100 mm) base course is recommended to prevent disturbance of the subgrade. If $P > P_{h=0,\ unreinf}$ the use of reinforcement is required and the solution continues to the next step.

Step3: Determine the required base course thickness for reinforced or unreinforced roads. The calculation of the base course thickness requires iteration. The minimum thickness of the base course is 100 mm.

GEOGRID REINFORCEMENT

Determine an appropriate aggregate thickness for a rural over weak subgrade that is required for a mining construction project. Investigate a conventional unreinforced solution and a geogrid reinforced alternative using the Giroud and Han method (2004) for the given set of design parameters using the following inputs.

- **Input Data**
  - Axle load = 80 kN,
  - Tire pressure = 550 kPa,
  - Number of axle passes = 5000
- **Failure Criteria:**
  - Maximum rut depth = 75 mm and Aggregate and Subgrade
  - Aggregate fill CBR = 15 and Field subgrade CBR = 1
- **Geosynthetic Reinforcement:**
  - Extruded Biaxial Geogrid with Aperture Stability Modulus, J = 0.32 N-m/degree

- **Bearing capacity factors:**
  - Nc = 3.14 for unreinforced road section and
  - Nc = 5.71 for geogrid-reinforced road section

Step1

Wheel load, P = 9,000 lbs (40 kN)

Allowable rut depth, s = 3 in. (75 mm)

Radius of tire contact: $r = \sqrt{\frac{40}{3.14 \times 550}} = 0.152$ m = 6 in

Ratio of base course

$\frac{E_{bc}}{E_{sg}} = \frac{3.48CBR_{bc}^{0.3}}{CBR ...}$ (3...

The rati...

Step2

: CHECK CAPACITY OF SUBGRADE SOIL TO SUPPORT WHEEL LOAD WITHOUT REINFORCEMENT

$$P_{h=0,unreinf} = \left(\frac{75}{75}\right)\pi(0.152)^2(3.14)(30 * 1.0) = 6.83 \quad kN$$

$P = 40\ kN > 6.83\ kN = P_{h,\ unreinf}$

The subgrade soil cannot support the wheel load and use of reinforcement is required.

Step 3

$$h = \frac{0.868 + 0.661\left(\frac{0.152}{0.5045}\right)^{1.5} \log 5000}{[1 + 0.204(5-1)]} \left(\sqrt{\frac{550}{\frac{75}{75}\left[1 - 0.9e^{-\left\{\frac{0.152}{0.5045}\right\}^2}\right]3.14 \times 30 \times 1}} - 1 \right) 0.152 = 0.5045 \quad m$$

Therefore the calculated thickness for the unreinforced case is 20 in. (510 mm).

Step 4

$$h = \frac{0.868 + \left(0.661 - 1.006 \times 0.32^2\right)\left(\frac{0.152}{0.3054}\right)^{1.5} \log 5000}{\left[1 + 0.204(5-1)\right]} \left(\sqrt{\frac{550}{\frac{75}{75}\left[1 - 0.9e^{-\left(\frac{0.152}{0.3054}\right)^2}\right] 5.71 \times 30 \times 1}} - 1 \right) 0.152 = 0.3054 \ m$$

The calculated thickness for the geogrid reinforced unpaved road is 12 in. (300 mm).

Step 5

The geogrid-reinforced option for the unpaved road has been selected for: Aggregate thickness (300 mm) Use of a geotextile separator is recommended unless the aggregate meets the natural filter criteria for the subgrade.

Soil		Subgrade	Aggregate	
			Option 1	Option 2
Classification per USCS		ML Low plasticity silt with sand	SP-SC Poorly graded sand with clay and gravel	SP Poorly graded sand with gravel
Gradation (% Passing)	3 in. (75 mm)	100	97	97
	No. 4 (4.75 mm)	88	71	77
	No. 40 (0.425 mm)	-	28	39
	No. 200 (0.075 mm)	78	11	4
	No. 400 (0.038 mm)	41	-	-
	0.01 mm	5	-	-
Plasticity	LL	33	32	-
	PI	4	16	Non Plastic
Coefficient of Uniformity, C_u		-	4.8	5.4
Coefficient of Curvature, C_c		-	2.9	3.6

SUBGRADE SEPARATION CHECK USING NATURAL FILTER CRITERIA

The subgrade soil has been identified by the geotechnical engineer as Low Plasticity Silt with Sand (ML) and the following filter criteria apply (Cedergren, 1989):

$$\frac{D_{15\,\text{Aggregate Fill}}}{D_{85\,\text{Subgrade}}} \leq 5 \quad \text{and} \quad \frac{D_{50\,\text{Aggregate Fill}}}{D_{50\,\text{Subgrade}}} \leq 25$$

The calculations for both options are presented in the following table:

Soil Type		Subgrade	Aggregate	
			Option 1	Option 2
		ML Low plasticity silt with sand	**SP-SC** Sand with clay and gravel (poorly graded)	**SP** Sand with gravel (poorly graded)
Characteristic Particle Size (mm)	D_{15}	-	0.11	0.13
	D_{50}	0.045	1.46	0.86
	D_{85}	1.37	-	-
Piping Ratio = $(D_{15\,Fill})/(D_{85\,Subgrade})$		-	0.08	0.1
$(D_{50\,Fill})/(D_{50\,Subgrade})$		-	32	19

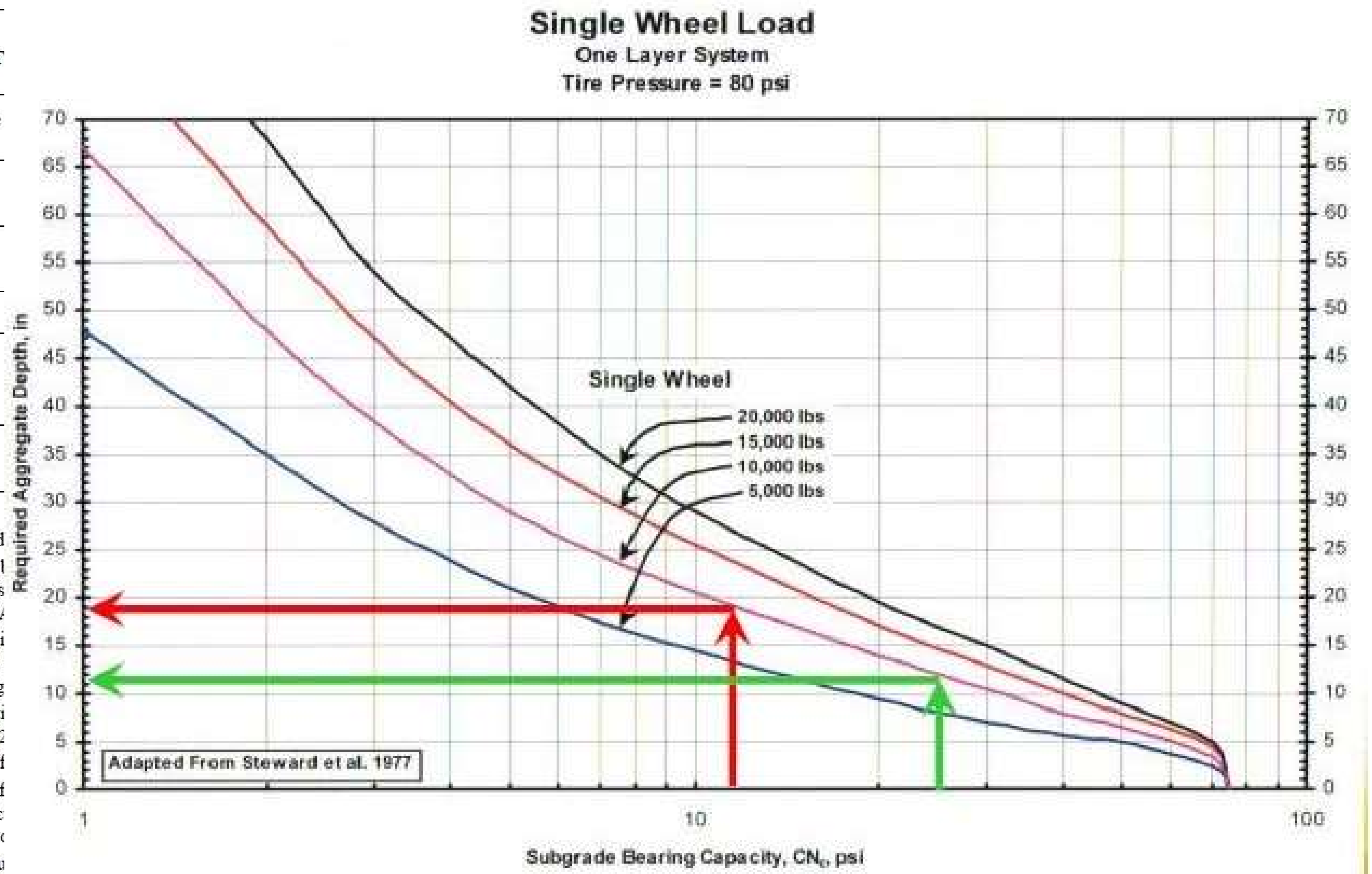
Aggregate Option 1: Sand with Clay and Gravel (SP-SC)

$$\frac{D_{15Fill}}{D_{85\,Subgrade}} = 0.1 \leq 5 \;\; (OK)$$

$$\frac{D_{50Fill}}{D_{50\,Subgrade}} = 32.5 > 25 \; (\textit{not satisfied})$$

Table 3
Geogrid Survivability Property Requirements[1,2,3]
For Stabilization and Base Reinforcement Applications

Property	Test Method	Units	Requirement
SURVI			
Ultimate Multi-Rib Tensile Strength			
Junction Strength[5]			
Ultraviolet Stability (Retained Strength)			
Aperture Size			
Separation			



NOTES:
1. Acceptance of geogrid
2. Acceptance shall be t ASTM D 4354, or bas using Procedure B of A
3. Minimum; use value i value (*i.e.*, test results Lot samples according
4. Default geogrid selecti conditions, see Table 2
   a) The Engineer has f
   b) The Engineer has f and visual inspec anticipated field c
5. Junction strength requ manufacturers shall submit data from full scale installation damage tests in accordance with ASTM D 5818 documenting integrity of junctions. For soft soil applications, a minimum of 6 in. (150 mm) of cover aggregate shall be placed over the geogrid and a loaded dump truck used to traverse the section a minimum number of passes to achieve 4 in. (100 mm) of rutting. A photographic record of the geogrid after exhumation shall be provided, which clearly shows that junctions have not been displaced or otherwise damaged during the installation process.

Design Methodologies

- AASHTO- MEPDG using MIF
- Modified AASHTO method using LCR

- AASHTO (1993)- MEPDG using MIF

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Where:

W18 = predicted number of 80 kN ESALs
ZR = standard normal deviate (example: ZR = -1.645 for 95 % reliability)
So = combined standard error of the traffic prediction and performance prediction SN = Structural Number [inches]
ΔPSI = difference between the initial, and the design terminal PSI
MR = Subgrade resilient modulus (in psi)

Structural Number

- Structural Number (SN) to quantify the structural strength.
  - Soil support
  - Total traffic
  - Reliability and,
  - Serviceability level
- Required SN is converted to the actual thickness of surfacing, base and sub-base, by means of appropriate layer coefficients representing the relative strength of the construction materials.

$$SN = a1D1 + a2D2m2 + a3D3m3 + ...$$

Modified AASHTO method with Geogrids for Base/Sub-base Stabilization-LCR

- LCR represents impact provided by a specific geogrid to the layer coefficient of the layer in which the geogrid is placed. The LCR approach applies and limits the geosynthetic benefit derived from trials to the specific layer improved by inclusion of reinforcement.
- SN = a1 x D1 + LCR2 x a2 x D2 x m2 + LCR3 x a3 D3 m3 +…
- Factors may differ from product to product
- How to Determine the LCR- Full Scale Traffic test

Data Requirement for Design of Pavements

- Design Variables
  - Performance Period
  - Traffic
  - Reliability
  - Environmental impacts
- Performance Criteria
  - Serviceability
  - Allowable rutting
  - Aggregates loss
- Material Properties for Structural Design
  - Resilient Modulus
  - CBR/ Modulus of Subgrade Reaction
  - Layer materials Characterization
  - Layer Coeffects
- Structural Character sticks
  - Flexible Pavement
  - Rigid pavement
  - Drainage aspects

MIF for Geogrid and Geocell

- MIF is the ratio of improvement of the modulus of a system where geosynthetic materials are incorporated, as compared to the system.
- MIF is evaluated by conducting plate load tests on soil subgrade and evaluating the respective moduli without and with geosynthetic materials and comparing the two moduli to estimate the MIF.

$$\text{MIF} = \frac{\text{Modulus of reinforced section at a given settlement}}{\text{Modulus of unreinforced section for a given settlement}}$$

Design of Flexible Pavement With Geosynthetics

- Input Data
  - Design Traffic: 50 msa
  - Subgrade CBR = 6%

Design resilient modulus of the compacted subgrade

M_R (MPa) = 10 × CBR ; for CBR 5

M_R (MPa = 17.6 × (CBR)0.64 ; for CBR > 5

M_R Subgrade =17.6 × 60.64= 55.4 Mpa

Thickness of unreinforced granular layers:

- For DT of 50 msa and,
- CBR of 6 .0% the thickness of layers from IRC:37-2018
  - Thickness of granular base (D2) = 250 mm,
  - Thickness of granular sub-base (D3) = 260 mm

M_R_G= 0.2×$h^{0.45}$×MR_Subgrade

- M_R Granular layer = 0.2 × $(510)^{0.45}$ × 55.4= 183.20 MPa.

Step 2: Design Calculations of Bitumen Pavement With Geogrid Reinforced Granular base and Subbase Layers Using LCR of Geogrid

- Reducing thickness of pavement layers
  - Design Traffic = 50 msa
  - Subgrade CBR = 6 percent
  - Reliability = 90 percent
  - Resilient Modulus of Subgrade (MR):
- M_R (MPa) = 17.6×60.64= 55.40 Mpa; M_R of Subbase and Base

  Granular sub-base thickness (MR_GSB) = 260 mm

  MR_GSB = 0.2×h0.45×MR_subgrade
- M_R of unreinforced subbase layer

  = 0.2 × (260)0.45 × 55.4 = 136 MPa = 19724.624 Psi
- Granular Base thickness = 250 mm
  - M_R_GB = 0.2×h0.45 × MR_GSB
- M_R of unreinforced base layer = 0.2 × (250)0.45 × 136 = 327MPa = 47426.118Psi
- M_R of Bituminous Mixes = 3000 MPa=435102 Psi

Structural layer coefficient of each layer (AASHTO 1993)

- LC for bituminous layer (a1) = 0.171 x (LN (MR))-1.784

  = 0.171 x (LN (435102))-1.784=0.436

- Structural layer coefficient for base layer (a2)

  (a2) = 0.249 × (log10 MR_BC) – 0.977

  = 0.249 × (log10 47426.118) – 0.977 = 0.188

- Structural layer coefficient for subbase layer

  (a3) = 0.227 (log10MR_SB) – 0.839

  = 0.227 × (log1019724.624) – 0.839= 0.136

- Layer coefficient for base layer (a2) = 0.188
- Layer coefficient for sub base layer (a3) = 0.136

- LCR for geogrid is taken on the basis of the laboratory tests/filed tests, or it can be provided by the manufacturer.
  - ❖ (LCR base) for geogrid used in base layer = 1.4
  - ❖ (LCR Subbase) for geogrid used in sub-base layer = 1.61

Modified layer thickness values for reinforced sections by IITPAVE Thickness of sub base layer = 180 mm

Thickness of base layer = 160 mm

Modulus of reinforced Subbase and Base layers

Granular sub-base thickness = 180 mm

M_R_GSB = 0.2×h0.45 × M_R_subgrade

M_R of reinforced subbase layer = 0.2 × (180)0.45 × 55.40

= 115 MPa =16678.91Psi

Granular Base thickness = 160 mm

M_R_GB = 0.2 × h0.45 × MR_GSB

M_R of reinforced base layer = 0.2 × (160)0.45 × 115

= 225 MPa= 32632.65 Psi

Layer coefficient for bituminous layer (a1) = 0.436

Structural layer coefficient for base layer

$a2 = 0.249 \times (\log10 MR\_GB) - 0.977 = 0.249 \times (\log10\ 32632.65) - 0.977 = 0.147$

Structural layer coefficient for subbase layer

$a3 = 0.227 (\log10 MR\_GSB) - 0.839 = 0.227 \times (\log10\ 16678.91) - 0.839 = 0.120$

Therefore,

Modified Layer coefficient for base layer (a2) = 0.147

Modified Layer coefficient for sub base layer (a3) = 0.120

Modified layer coefficient for base layer (a2') = LCR base × a2
= 1.4*0.147= 0.2058

Modified layer coefficient for sub-base layer (a3') = LCR Subbase × a3
= 1.61*0.120= 0.1932

With the improved layer coefficients, improved elastic modulus of respective layers shall be back calculated using below equations.

$a2^1 = 0.249 \times (\log10\ MR\_GB) - 0.977$; $M_R\_GB1 = 393$ MPa $a^31 =$

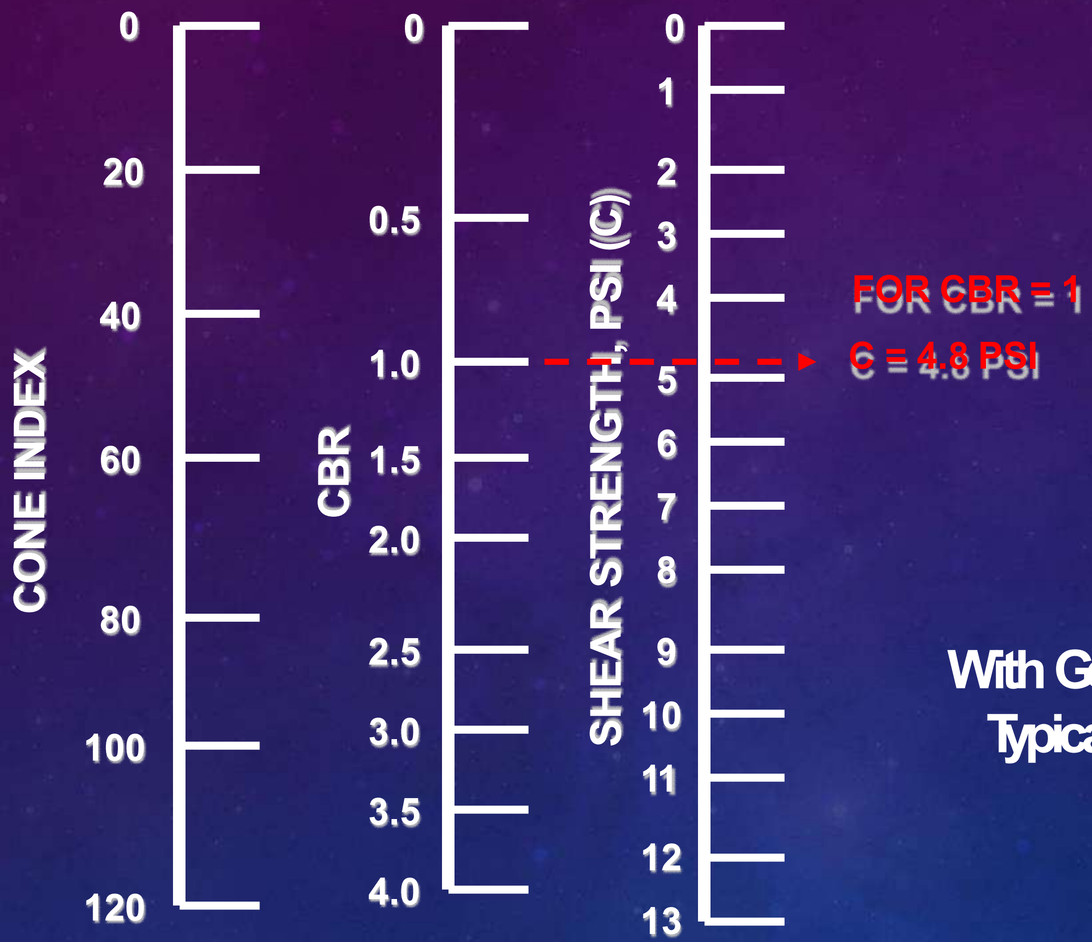
$0.227 (\log10 MR\_GSB) - 0.839$; $M_R\_GSB1 = 244$ Mpa

- Reinforced base layer thickness = 160 mm
- Reinforced subbase layer thickness = 180 mm
- Surface layer (BC+DBM) =150 mm

Unpaved Road Design

- Based on Procedure in TM 5-818-8
  - Determine design subgrade strength (CBR, C, etc.)
  - Determine design traffic
    - (Single, dual, tandem axle)
    - Loading by wheel or gear
    - Design good for 2-in. rut at 1,000 passes
  - Determine if geotextile or geogrid recommended
    - Use geotextile for CBR < 4 and fine-grained soil
    - Consider geogrid for CBR < 8 and thin pavements
  - Determine appropriate bearing capacity factor, nc
  - Determine subgrade bearing capacity cnc
  - Use design curve to determine aggregate thickness (6” min.)
  - Conduct life-cycle cost analysis of alternatives

Unpaved Road Design



Relationship between shear strength, CBR, & cone index

Bearing Capacity Factors

Unreinforced: $N_C = 2.8$

With Geotextile: $N_C = 5.0$

With Geogrid/Geotextile: $N_C = 5.7$
Typically CBR < 4

With Geogrid: $N_C = 5.7$
(CBR > 4)

Unpaved Road Design

Subgrade Bearing Capacity CN_c

WITHOUT GEOTEXTILE

FOR 1 CBR, C = 4.8 PSI

Use $N_C = 2.8$

CNC = 4.8 (2.8) = 13.5

WITH GEOTEXTILE

Use $N_C = 5$

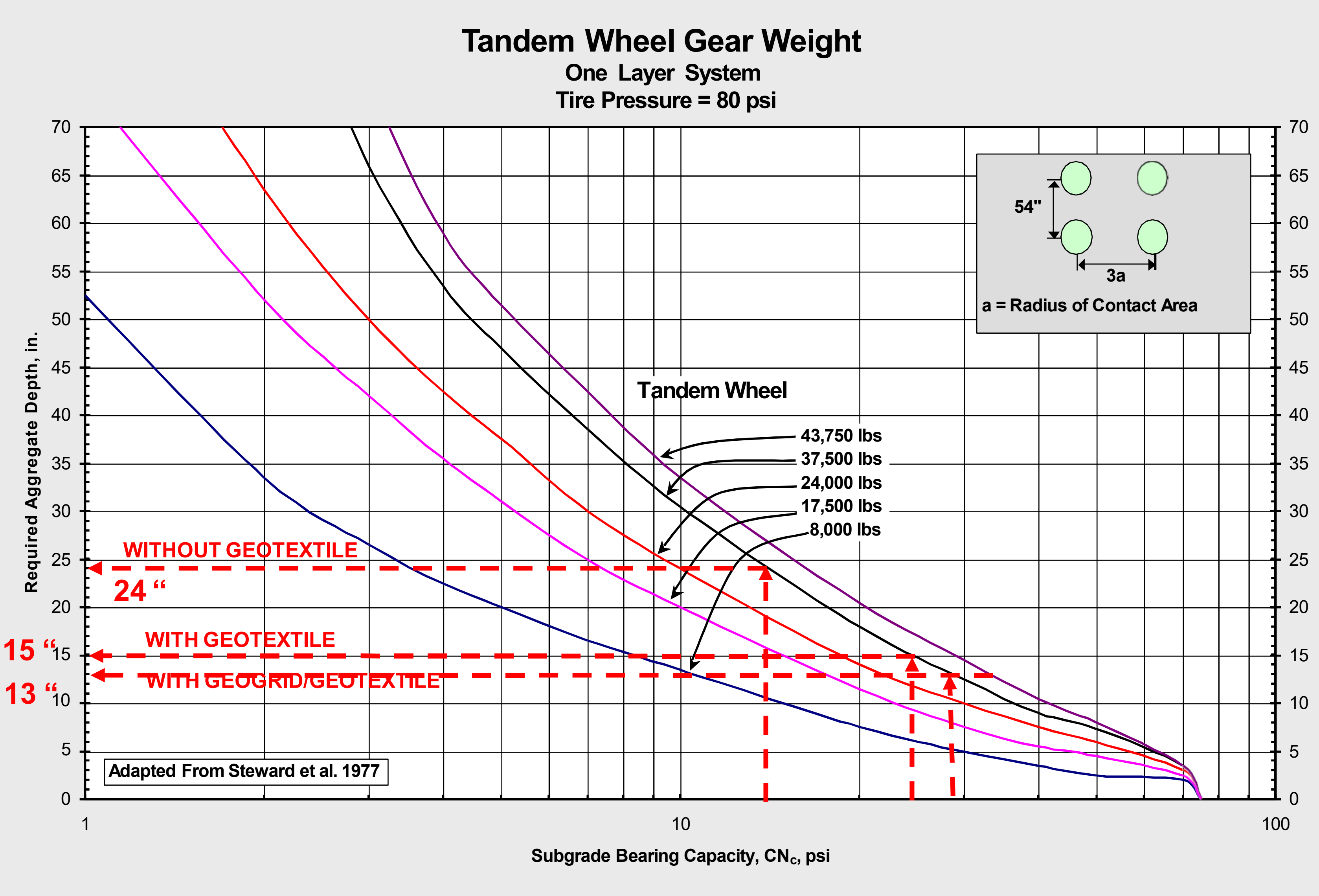
CNC = 4.8 (5) = 24

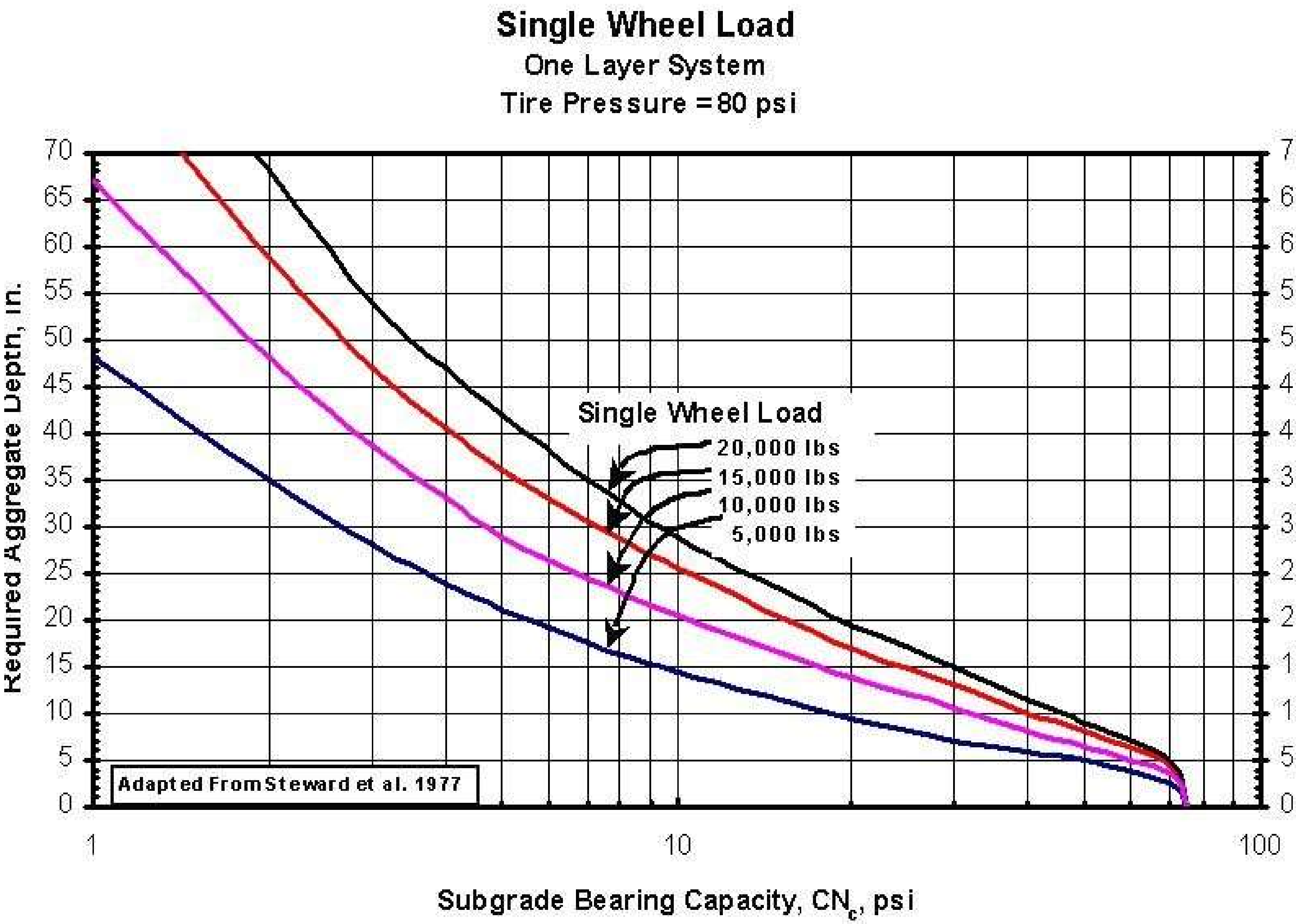
WITH GEOGRID OVER GEOTEXTILE (CBR < 2)

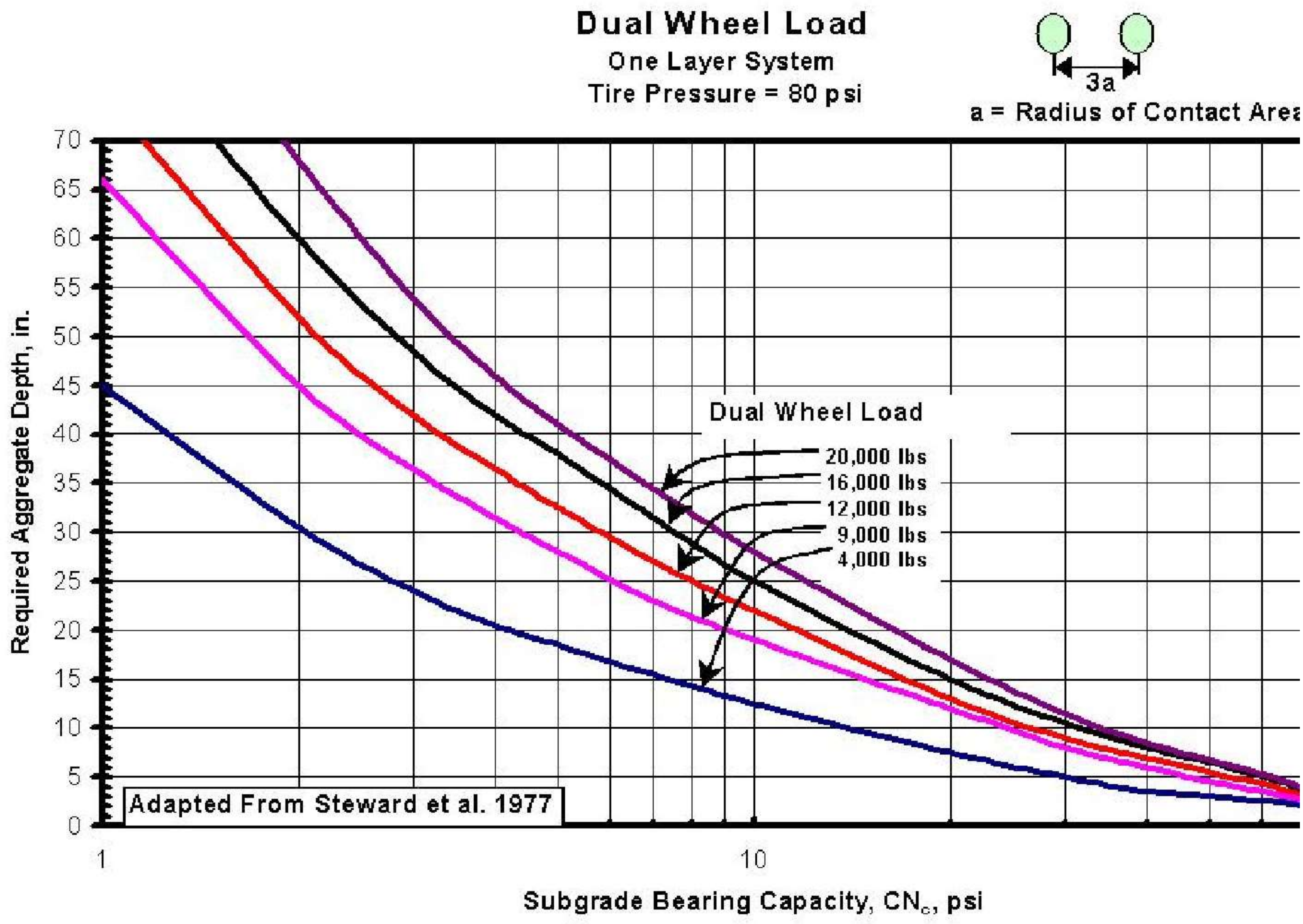
Use $N_C = 5.7$

CNC = 4.8 (5.7) = 27.4

Unpaved Road Design




Single Wheel Load
One Layer System
Tire Pressure = 80 psi
Required Aggregate Depth, in.
Subgrade Bearing Capacity, CN$_c$, psi
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
1
10
100
Single Wheel Load
20,000 lbs
15,000 lbs
10,000 lbs
5,000 lbs
Adapted From Steward et al. 1977


Dual Wheel Load
One Layer System
Tire Pressure = 80 psi
3a
a = Radius of Contact Area
Required Aggregate Depth, in.
Subgrade Bearing Capacity, CN_c, psi
Dual Wheel Load
20,000 lbs
16,000 lbs
12,000 lbs
9,000 lbs
4,000 lbs
Adapted From Steward et al. 1977

Construction Procedure

- Place nonwoven geotextile directly on the subgrade
- Overlap edges 30-90mm in the direction of aggregate spreading.
- Anchor with sandbags, staples, pines or piles of dirt if required.
- Place geogrid on top of the geotextile if required by the design.
  - Bottom of base for bases < 120mm.
  - Middle of base for bases > 120 mm
- CBR < 2, place the aggregate in one lift in the center of the traffic lane.
- CBR >2, place in lifts.
- Aggregate should always be spread in the direction of the geosynthetic overlaps.
- Use small front-bladed equipment for initial aggregate spreading.
- The front wheels of a grader may rut or damage the geosynthetic.
- A grader can be used to achieve the final grade.
- Care must be taken not to over-grade areas of thin bases.
- Once placed to grade, the aggregate can be compacted using normal procedures