Multilayers of woven/grid geotextiles in a granular base mattress for access roads and working platforms - recent experience

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ABSTRACT: The use of multilayers of woven/grid geotextiles in a granular base mattress for access roads and working platforms on low strength subgrades provide's significant advantages. The load bearing capacity of the granular base increases and the vertical and horizontal deflection is reduced during cyclic loading. This paper presents a simple analytical model for calculating the thicknesses required in a multilayer system and demonstrates the results of case studies where the multilayer technique has been used. The paper demonstrates that a multilayer geogrid matrix acts as a composite mattress that provides significant load carrying capacity with a reduced granular mattress thickness. A multilayer reinforced granular base has positive environmental impacts by reducing volumes of imported granular backfill and reducing volumes of unsuitable subgrade material that needs to be disposed of. The aim of the paper is to demonstrate that multilayer systems of geosynthetic reinforcements can be used safely and effectively in unpaved access roads and working platforms on wind farms, solar farms and housing developments where soft subgrades are encountered.

KEY WORDS: geotextiles, reinforced geogrids, unpaved access roads, temporary works, working platforms

1 INTRODUCTION

The design of unpaved access roads and windfarm haul roads has traditionally used three design methods: Giroud and Noiray [1], CIRIA 123 [2], Giroud & Han [3], [4]. Giroud & Han is the most used design method. The suitability of the Giroud & Han method has been demonstrated by the authors previously [5]. The main drawback of these three common design methods is that they take account of only one layer of geotextile over the soft subgrade and ignore the benefit provided by additional reinforcing layers. Through laboratory research carried out at TU Dublin, there is evidence that multilayer reinforced granular bases could improve the load carrying capacity and bearing resistances of multilayer reinforced granular bases [6]. This research found that increasing the number of geogrids in a simulated access road had a very significant impact in reducing the strain and displacement of the geogrid. This paper presents a recently developed, intuitive and simple, analytical model for calculating the thicknesses required in a multilayer system and reports the results of three successful case studies recently completed in Ireland which have used the multilayer reinforcing method.

2 DESIGN METHOD

2.1 *Introduction to design method*

A multilayer design method has been first presented by Rimoldi and Simons [7] and examples of its application shown by others Rimoldi and Brusa [8]. The design method applies to both woven geotextiles and geogrids. However, reinforcing geogrids ensure effective interlock between the geogrid and granular soil particles. The imposed vertical and horizontal stresses developed by the vehicle's tyre footprint are dispersed radially into the reinforced granular base.

2.2 *Load Spread.*

For a surface load imposed on a granular layer, the convention in foundation engineering is to assume a load spread angle β from the road surface through the granular layer of 27º [2]. The sense of β is shown in Figure 2-1. Giroud & Noiray [1] assume a load spread of 31º. However, a wider load spread could occur in strong granular bases which should not exceed 45º. This research assumed a load spread of 30º as recommended by CIRIA SP 123 [2].

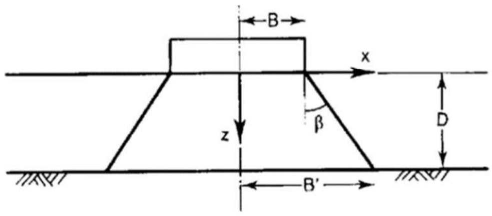

Figure 2-1: Load spread in a granular layer (CIRIA SP123)

2.3 *Granular road bases on low strength subgrades*

As traffic loads are imposed onto the granular road base, vertical and horizontal stresses are mobilised. The horizontal stresses in the granular base result in outward shear stresses on the surface of the soft clay subgrade. This shear stress reduces the bearing capacity of the clay subgrade by 50%. When horizontal reinforcing geosynthetic is introduced at the subgrade level, the imposed horizontal shear stresses are supported by the geotextile reinforcement. This action restores and mobilizes the original bearing resistance of the soft clay subgrade.

When granular road bases are considered, three different reinforcing mechanisms are believed to be mobilised.

The first mechanism is the 'membrane tension effect' [1]. A tensioned membrane is modelled, located between the base couse and soft subgrade. The membrane support is generated only if the geosynthetic is stretched through deformation. The deformation can only occur with significant rutting of the granular base at the subgrade interface.

The second reinforcing mechanism is the imposed shear force at the bottom of the granular base which is generated from the traffic loading and granular base weight.

A third type of reinforcing mechanism is horizontal confinement (adherence) which is generated between the granular fill and frictional resistance of the geosynthetic reinforcement. This mechanism enables the transfer of horizontal shear forces into the geosynthetic reinforcement. As the adherence resistance is mobilised, load spread results in lower vertical pressures that are transmitted into the soft subgrade.

Barenberg [9] recommended that a permissible stress on the subgrade, σ, be adjusted to compensate for the effect of the geotextile modulus on the failure criterion:

$$\sigma = A \cdot \pi \cdot c_u.$$

where A is a coefficient related to the confining effects of the geotextile on the soil. A = 1 when no geotextile is used and A = 2 when geotextile is used.

2.4 Design of the geosynthetic

When an access track is constructed on a low strength subgrade, the geosynthetic enhances and reinforces the granular base. The geosynthetic facilitates the distribution of the radial wheel or track loading, and backfill loads, over a greater area of the subgrade. Simultaneously, the geosynthetic, assuming it has sufficient tensile strength and anchorage, prevents local shear failure through the subgrade. The introduction of geotextile reinforcement changes the failure mechanism from a local bearing failure to a wider enhanced general bearing capacity failure mechanism. When the imposed loads are calculated, the platform thickness can be determined. The use of geosynthetics allows the development of the following stabilising enhancements:

- Base course lateral restraint: developed by granular base self-weight.
- Base course lateral restraint: developed by vehicle wheel loads.
- Membrane mechanism at the base of the granular base: subgrade interface.

Each of these mechanisms generates tensile forces in geotextile reinforcing layers. The thickness of a granular base is influenced by considering each of the following factors:

- The effect of the imposed wheel loads,
- Granular base self-weight and
- Tensioned membrane mechanism.

From these parameters it is possible to determine the vertical distributed and subsequent horizontal tensile forces developed in each reinforcement layer within the granular base. Once the horizontal load has been calculated, the required strength of the geosynthetic can be determined by considering the limit state criteria. It should be noted that access roads and working platforms can be designed for the short term and the long term. Hence, the limit state criteria could include strain and creep effects. As has been outlined previously, deformation of the granular base is required before the tensile strength of the geotextile is mobilised. However, the strain could exceed the serviceability requirements of the access road or working platform. Rimoldi & Simons [7] recommend that geosynthetic strain should be limited to 3 to 5 % for non-critical structures when larger deformations can be tolerated and 1 to 2% for critical structures.

3 METHODOLOGY

The methodology is developed based on a conceptual model of an access road or working platform as presented in Figure 3-1 [7] The layers considered are asphalt course (AC), base course (BC), subbase course (SB), and subgrade (SG).

The conceptual model assumes that the load is applied as a uniform vertical pressure σ_{v0} = p on a rectangular area with half-length L and half width B (L and B being the half sizes of the wheel or tracks). This load spreads in the 3 layers of the platform structure (AC, BC, and SB) according to their load spreading angles α_1, α_2, and α_3.

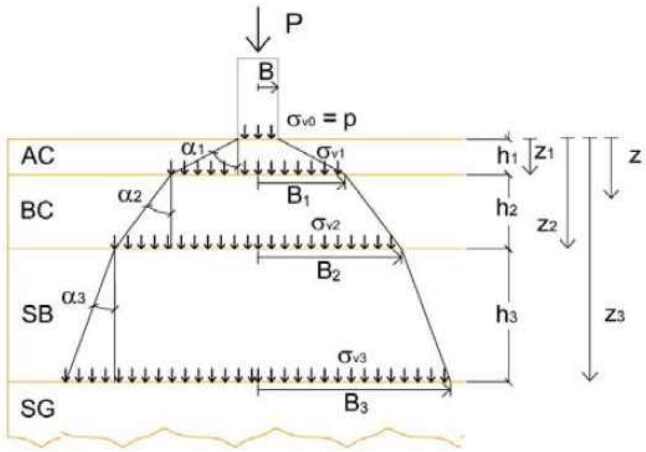

Figure 3-1: General scheme of the 3-geogrid layer model [7].

As a minimum, it is assumed that the base course (BC) layer is in place and can be reinforced with geotextiles. The asphalt layer (AC) may or may not exist and it is not reinforced. The subbase (SB) layer may or may not be present and can be either reinforced or unreinforced.

Three components of horizontal force are derived: force as a result of horizontal soil thrust (T_{zi}), force due to horizontal stresses generated by uniform load (T_{Pi}), and force due to membrane mechanism at the interface with subgrade (T_{mi}).

3.1 Force as a result of horizontal soil thrust. (T_{zi})

The tensile force T_{zi} is calculated based on the vertical stress at depth Z_1 due to self-weight of the asphalt course, AC:

$$\sigma_{vi} = \gamma_1 Z_1$$

where γ1 = unit weight of the asphalt layer (kN/m^3).

For Z1 < Z < Z2:

$$\sigma_{v2} = \gamma_1 Z_1 + \gamma_2 (Z - Z_1)$$

The related horizontal stresses are:

$\sigma_{h2} = K_2\, \sigma_{v2}$

where $K_2 = \tan^2 (45° - \varphi_2 / 2)$ and φ_2 is the friction angle of soil layer BC.

The tensile force generated in the geosynthetic at the base course level is then:

$T_{zi} = 0.5\, K_2 \cdot [2\, \gamma_1\, Z_1 + \gamma_2\, (Z_i + Z_{i-1} - 2\, Z_1)] \cdot (Z_i - Z_{i-1})$

For $Z_2 < Z < Z_3$:

$\sigma_{v3} = \gamma_1\, Z_1 + \gamma_2\, (Z_2 - Z_1) + \gamma_3\, (Z - Z_2)$

The related horizontal stress is:

$\sigma_{h3} = K_3\, \sigma_{v3}$

where $K_3 = \tan^2 (45° - \varphi_3 / 2)$ and φ_3 is the friction angle of soil layer SB.

Similarly, the tensile force T_{zi} generated in the geosynthetic at the subbase level is:

$T_{zi} = 0.5\, K_3 \cdot [2(\gamma_1\, Z_1 + \gamma_2\, Z_2) + \gamma_3\, (Z_i + Z_{i-1} - 2\, (Z_1 + Z_2)] \cdot (Z_2 - Z_1)$.

3.2 *Force due to horizontal stresses generated by uniform load. (T_{Pi})*

For $0 < Z < Z_1$, $L_1 = L + Z \tan \alpha_1$ and $B_1 = B + Z \tan \alpha_1$. It follows that $L\, B\, \sigma_{v0} = L_1\, B_1\, \sigma_{v1}$. The vertical stress produced by the load at depth Z is:

$\sigma_{v1} = \sigma_{v0}\, (L\, B) / (L_1\, B_1)$

Therefore,

$\sigma_{h1} = K_2\, \sigma_{v1}$

For $Z_1 < Z < Z_2$:

$L_2 = L_1 + (Z - Z_1) \tan \alpha_2$
$B_2 = B_1 + (Z - Z_1) \tan \alpha_2$
$\sigma_{v2} = \sigma_{v1}\, (L_1\, B_1) / (L_2\, B_2)$

and

$\sigma_{h2} = K_2\, \sigma_{v2}$

Similarly, for $Z_2 < Z < Z_3$:

$L_3 = L_2 + (Z - Z_2) \tan \alpha_3$
$B_3 = B_2 + (Z - Z_2) \tan \alpha_3$
$\sigma_{v3} = \sigma_{v2}\, (L_2\, B_2) / (L_3\, B_3)$
$\sigma_{h3} = K_3\, \sigma_{v3}$

We assume that the tensile force T_{Pi} generated in the i^{th} geogrid in the base course by the load is the integral of the horizontal soil stresses between the i^{th} geogrid layer and the $(i-1)^{th}$ geogrid layer, which can be expressed as:

$T_{Pi} = 0.5\, (\sigma_{hi} + \sigma_{hi-1})\, (Z_i - Z_{i-1})$

3.3 *Force (T_{mi}) due to membrane mechanism at the interface with subgrade.*

The geogrid layer at the interface with the subgrade is subject to the highest vertical deformations when the first soil layer is spread and compacted. This is due to the settlement of the soft subgrade; the subsequent geogrid layers are far less susceptible to vertical displacements. The method assumes that the first geogrid layer is subject to the tensioned membrane effect. This geogrid layer can be considered as a catenary layer, while for the next layers such a mechanism is not applicable. We will refer to the scheme shown in Figure 3-2.

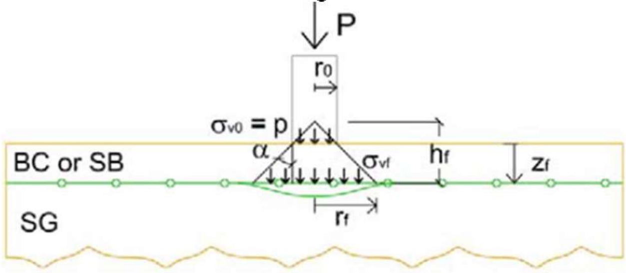

Figure 3-2: Scheme of the first geogrid layer [7]

According to tensioned membrane theory, the uniform vertical load W_{TC} on a catenary layer of reinforcement is:

W_{TC} = [(volume V of load cone below the wheel) · (fill density γ) + wheel load P – subgrade reaction R] / (area A at reinforcement catenary layer)

For the first geogrid layer V and A become, by reference to Figure 3-2:

$V = 1/3\, \pi\, r_f^2\, h_f - 1/3\, \pi\, r_0^2\, (h_f - Z_f)$
$A = \pi\, r_f^2$

where Z_f = depth of first course lift (m) and h_f = height of the load cone (m).

We can assume the wheel load P is the result of tyre pressure p = 600kPa and radius of wheel circular contact area: $r_0 = 0.15$.

The subgrade reaction R is equal to the allowable bearing capacity of a cohesive soil layer with geogrid reinforcement:

$R = 2\, \pi\, c_u\, A / FS = 2\, \pi\, (30\, CBR_{SG})\, A / FS = 60\, \pi\, CBR_{SG}\, A / FS$

where:
FS = Factor of Safety for subgrade bearing capacity,
c_u = undrained shear strength of subgrade = $30CBR_{SG}$,
CBR_{SG} = California Bearing Ratio of subgrade.
Since:

$r_f = r_0 + Z_f \tan \alpha_j$
$h_f = r_f / \tan \alpha_j$
$(h_f - Z_f) = r_0 / \tan \alpha_j$
$P = \pi\, r_0^2\, p$

where: j = 2 for base course and j = 3 for subbase course, we finally get for the first lift of the base or subbase course:

$$W_{TCj} = [(\gamma_j / 3)\ (r_f^3 - r_0^3) / (r_f^2 \tan \alpha j)] + p\ (r_0^2 / r_f^2) + 60\ \pi\ CBR_{SG}\ A / FS$$

The tensile load in the catenary reinforcement at the subgrade interface is determined based on tensioned membrane theory determined from the following equation from Giroud and Noiray [1]:

$$T_{mj} = W_{TCj}\ \Omega\ r_f$$

where:

Ω = dimensionless factor from tensioned membrane theory as a function of reinforcement strain ε_r as shown in Table 1.

Table 1: Values of dimensionless factor Ω

ε_r (%)	Ω
1	2.07
2	1.47
3	1.23
4	1.08
5	0.97

If the bearing capacity of the subgrade is robust enough to support the first lift of the base or subbase course and the wheel load, W_{TC2} becomes negative. In such case no tensioned membrane effect occurs, hence:

$$T_{mj} = 0$$

If the subbase is present, it is assumed that $T_{m2} = 0$.

The total horizontal force that the i^th^ geotextile layer must support is then:

$$T_{tot\text{-}i} = T_{zi} + T_{Pi} + T_{mj}$$

where T_{mj} applies only to the first geogrid layer at the interface with the subgrade, either of the base course or of the subbase course.

4 CASE STUDIES

4.1 Woodstream, Bailis, Navan Access Haul Road

TerraTech Consulting Ltd was requested by Pinnacle Consulting Engineers to provide a haul road design proposal which was to support construction traffic during the construction phase for a site in Bailis, Navan, Co. Meath. Publicly available mapping showed the quaternary geology was glacial till derived from limestone, however concerns had arisen about soft ground. The building contractor was Andrews Construction Ltd. BHP Laboratories carried out a suite of plate loading tests along the haul road route. The first set of tests were carried out on the 18.11.2022. A plan view of haul road is shown in Figure 4-1.

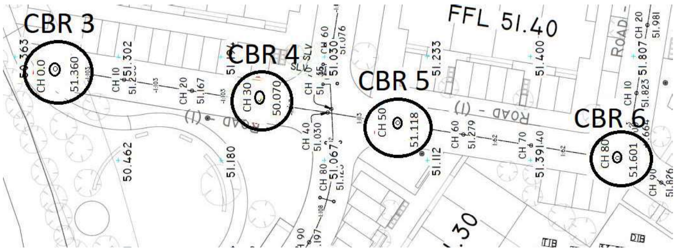

Figure 4-1: Plan view of haul road.

The initial plate loading tests indicated that the subgrade had negligible bearing resistance, with a median CBR of 0.1% being measured. The base thickness sizing of 1.6m with a rut depth of 0.05m was determined using Giroud and Han [3] method and refined using Rimoldi and Simons [7] design method. One layer of WG50 woven geotextile was placed on the subgrade and a second layer of TG3030S geogrid was placed midway in a 0.60m thick granular base constructed from Class 6F2 fill with an assumed angle of friction of 38 degrees. A second suite of plate loading tests was carried out on 06.12.2022 to verify the design. The target result was 10% and this target was met in all but one case, as indicated in Table 2.

Table 2: Plate Loading Test Results

CBR Test	Initial test on soft subgrade	Second test on top of Class 6F2 base 600mm thick	Target CBR %
3	4%	9%	10%
4	0%	17%	10%
5	0%	12%	10%
6	0%	33%	10%

An axle load of 80kN (wheel load 40kN) with a tyre pressure of 600kPa was used in the design. The horizontal stresses in the geotextile (kN/m) and vertical stresses at the bottom of the base and subbase are indicated in Table 3.

Table 3: Rimoldi Simons [7] method results

Horizontal Stress kN/m		Vertical Stress kPa		Geotextile Type	
Base	Subbase	Base	Subbase	Base	Subbase
26.09	48.56	125.22	52.58	TG3030	WG50

The Rimoldi & Simons multi-layer design method resulted in a saving of 1.0m thick layer of 6F2 fill (0.6m vs 1.6m).

4.2 Clara, Raheen Access Haul Road

In June 2020, IGSL Ltd was commissioned by Hayes Higgins Partnership Consulting Engineers to carry out a series of ground investigation tests on the Raheen Housing Development Project in Clara, Co. Offaly. The ground investigation found that most of the site was covered by a 1.2m thick layer of soft black PEAT. A soft grey sandy silt extended 1.2m to 4.8m below ground level. The measured CBR values on the soft sandy SILT were approximately 0.5%.

TerraTech Consulting Ltd was commissioned to carry out the design for an unpaved access road to facilitate construction traffic. Additional site testing was carried out by the first author using a handheld shear vane. The measured undrained shear strength was between 20kPa to 30kPa. A design supporting an axle load of 80kN on a subgrade of 0.5% CBR (c_u = 20kPa) was used. The base thickness sizing of 0.75m with a rut depth of 0.04m was determined using Giroud and Han [3] method and refined using Rimoldi and Simons [7] design method.

The design recommendation was to place an S8NW separator membrane under one layer of TG3030S on the subgrade and a second layer of TG3030S midway in a 0.60m thick granular base. The base was constructed from Class 6F2 fill with an assumed angle of friction of 38 degrees. The base is shown in Figure 4-2 along with the locations of the confirmatory CBR by plate loading tests.

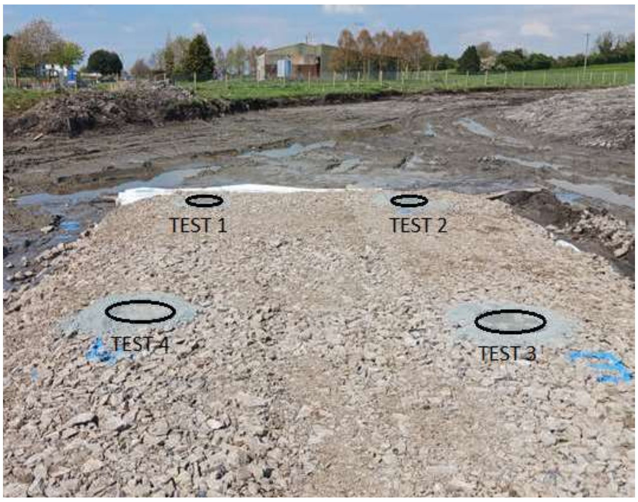

Figure 4-2:Second layer of Fill 600mm thick.

The plate loading tests were carried out on top of the first and second Class 6F2 fill layers. The results are summarised in Table 4.

Table 4: Plate Loading Test Results

CBR Test	Top of Subbase (300mm)	Top of Base Course (600mm)	Target CBR %
1	1%	5%	5%
2	1%	6%	5%
3	4%	8%	5%
4	3%	11%	5%

An axle load of 80kN (wheel load 40kN) with a tyre pressure of 600kPa was used for the design. The horizontal stresses in the geotextile (kN/m) and vertical stresses at the bottom of the base are indicated in Table 5.

Table 5: Rimoldi Simons (2013) [7] method results

Horizontal Stress kN/m		Vertical Stress kPa		Geotextile Type	
Base	Subbase	Base	Subbase	Base	Subbase
26.09	19.01	125.22	52.58	TG3030	TG3030

The Rimoldi & Simons multi-layer design method facilitated a saving of 0.15m thick layer of 6F2 fill.

4.3 Maxol Service Station Working Platform

BCD Partnership Limited were the engineers for the proposed redevelopment of the Maxol Service Station, 60 Milltown Road, Belvoir, Belfast. Geotechnical Environmental Services Limited (GES) undertook the ground investigations for the project. The ground investigation report shows the ground conditions at the site as made ground over alluvial clay/silts/sands, glacial sands/gravels and glacial clays overlying sandstone bedrock. Heterogeneous, non-engineered, made ground was reported to be very soft to soft clays and very loose to loose silty sands (water bearing) to depths of between 3.0m and greater than 5.5m below ground level.

The site investigation report indicated that the underlying strata are unsuitable for even lightly loaded foundations. A pile foundation solution was recommended with piles extending to the depth of the stiff glacial clay or dense silty sandy gravels. A working platform for a piling rig would clearly have to take account of the poor ground conditions, which were established as offering allowable bearing pressures of between 40 and 160kPa, far below the required bearing pressure of the piling rig to be used. The imposed piling rig loading was determined as per BRE 470[10] recommendations highlighted in Table 6.

Table 6: Casagrande B125-23 Hydraulic Piling Rig Loading

Load Case 1 (Handling)		Load Case 2 (Extracting)	
q_{1k} *[kPa]* =	254.00	q_{2k} *[kPa]* =	273.00
L_{1k} *[m]* =	1.96	L_{2k} *[m]* =	1.77
W_k *[m]* =	0.60	W_k *[m]* =	0.60

A working platform design to support a 273kPa load, spread over a track footprint of 1.06m^2, on a subgrade of 2.0% CBR was carried out using the Rimoldi & Simons [7] design method. The required factor of safety was set as 3. The geosynthetic reinforcement used was an S8NW separator membrane and one layer of TG3030S geogrid directly on the soft subgrade and a second layer of TG3030S geogrid midway in a 530mm thick granular base constructed from Class 6F2 fill. Table 7 indicates the calculated horizontal and vertical stresses.

Table 7: Rimoldi & Simons [7] method results

Horizontal Stress kN/m		Vertical Stress kPa		Geotextile Type	
Base	Subbase	Base	Subbase	Base	Subbase
14.88	9.31	154.27	100.57	TG3030	TG3030

The TerraTest Lightweight Deflectometer was used to determine the improved strength of the working platform. Twelve tests were carried out with a mean E_{vd} value of 49.93MN/m^2. The results are collated in Table 8.

Table 8: Lightweight Deflectometer Test Results

E_{vd} MN/m^2	E_{v2} MN/m^2	Modulus SGR MN/m^2	Target CBR %	Allowable Bearing Capacity kPa
46.93	94.86	95.00	32	275

Figure 4-3, Indicates the Casagrande B125-23 hydraulic piling rig in operation on the working platform.

Figure 4-3: Piling Rig on working platform.

5 RELATIONSHIP BETWEEN MODULUS AND CBR

An alternative approach to plate bearing load tests has been derived using ZTVE-StB 09: German Engineering Code for Soil and Rock in Road Construction method, for measuring deflections using a portable lightweight falling weight deflectometer. This method measures the modulus of subgrade reaction, Ev and then is converted to a CBR using the graph and equations Ev = 51log(CBR) & $Ev = 3.6CBR–0.088CBR^{1.73} + 3$ indicated in Figure 5-1 [11].

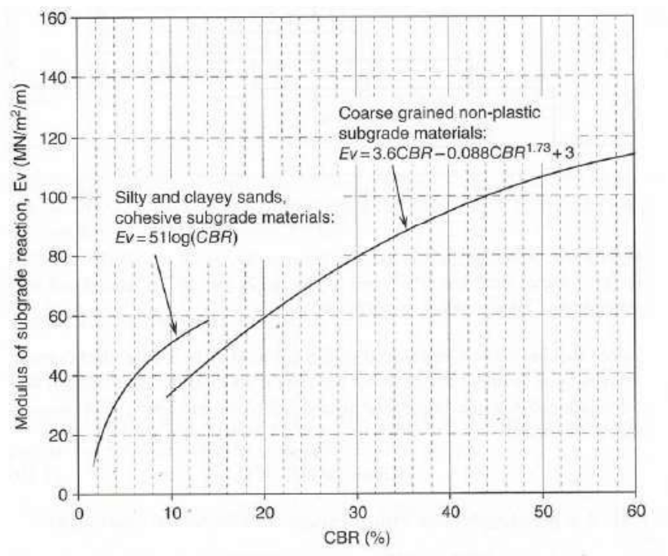

Figure 5-1: Relationship between California Bearing Ratio and modulus of subgrade reaction [11].

6 CONCLUSION

This paper has outlined the Rimoldi & Simons design method for multilayer geosynthetic reinforced unpaved roads and working platforms and documented three case histories where the method has been used to design reinforced unpaved roads and working platforms in Ireland. The main conclusions are as follows:

1. A multi-layer geosynthetic reinforced granular base for unpaved access roads and working platforms provides enhanced performance and reduces deflections and rutting at surface level.
2. The Rimoldi & Simons design method allows the determination of the vertical pressures and horizontal stresses in the reinforcement at the bottom of the base course and sub-base levels.
3. Using that method, granular base thickness can be reduced to an optimum without any detrimental impact to the structural performance of the unpaved access road or working platform.
4. A multilayer geotextile reinforced granular base reduces the need for excavation and replacement of unsuitable soft subgrades.
5. The introduction of one or more additional reinforcing grids in a multilayer reinforced granular pavement build up is a safe and efficient way to optimise the use of raw materials and reduce waste in construction.

7 ACKNOWLEDGEMENTS

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