3.3 Road Surfacing

Properly designed road surfaces serve a dual purpose. First, they provide a durable surface on which traffic can pass smoothly and safely. If heavy all-season use is anticipated, the surface should be designed to withstand the additional wear. Second, the road surface must protect the subgrade by distributing surface loads to a unit pressure the subgrade can support, minimizing frost action, and providing good surface drainage. A crowned surface of 3 to 5 cm/m of half-width will ensure adequate movement of surface water and reduce the potential for subgrade saturation.

Improper road surfacing or ballasting affects water quality in two ways: 1) Surface material is ground up into fines that are easily eroded. It has been demonstrated that surface loss is related to traffic levels and time in addition to erosional forces. Larger gravels present in the road surface must be mechanically ground up by traffic before they can be acted upon by surface erosion processes (Armstrong, 1984).

Reid and Dunne (1984) have demonstrated the significance of traffic intensity in the mobilization of sediment in an area of the Pacific Northwest Region of the United States which receives an average annual rainfall of 3900 mm/yr (150 in/yr). The results from their study demonstrated that although road segments receiving "heavy" use accounted for only a small proportion of total road length in the basin study area (6 percent), 70 percent of the total amount of sediment generated from road surfaces could be attributed to those segments during periods of heavy use. Reid and Dunne found the sediment production for a paved and gravelled road to be 2.0 and 500 tonnes/km/year, respectively (Table 22).

table 28 Calculated sediment yield per kilometer of road for various road types and use levels (Reid, 1981; Reid and Dunne, 1984)*

Road Type	Average Sediment Yield tonnes/km/year
Heavy use (gravel)	500
Temporary non-use (gravel)	66
Moderate use (gravel)	42
Light use (gravel)	3.8
Paved, heavy use	2.0
Abandoned	0.51

* Road width 4 m, average grade 10%
6 culverts/km, annual precipitation 3900 mm/year

Heavy use consisted of 4 to 16, 30 tonne log-trucks per day. Temporary non-use occurred over weekends with no log-truck traffic but occassional light vehicles. Light use was restricted to light vehicles (less than 4 tonnes GVW).

A road surface in its simplest form consists of a smoothed surface, in effect the subgrade. Dirt roads would fall into this category. Obviously, dirt roads are only useful where the road is expected to receive intermittent, light use and is not affected by climate. Sediment production from dirt road surfaces is high. Significant erosion rate reductions can be achieved by applying a rock or ballast layer. Even a minimal rock surface of 5 to 10 cm effectively reduces erosion and sediment yield by a factor of 9. Kochenderfer and Helvey (1984) documented soil loss reduction from 121 down to 14 tonnes per hectare per year by applying a 7.5cm rock surface on a dirt road.

Inadequate ballast or rock layers will not provide wheel load support appropriate for the subgrade strength except in cases where the subgrade consists of heavily consolidated materials. As a result, the ballast material is pushed into the subsoil and ruts begin to form. Ruts prevent effective transverse drainage, and fine soil particles are brought to the surface where they become available for water transport. Water is channeled in the ruts and obtains velocities sufficient for effective sediment transport. Sediment yield from rutted surfaces is about twice that of unrutted road surfaces (Burroughs et. al., 1984).

An improvement over a simple dirt road consists of a ballast layer over a subgrade, with or without a wearing course. The function of the ballast layer is to distribute the wheel load to pressures the subsoil can withstand. The wearing course provides a smooth running surface and also seals the surface to protect the subgrade from surface water infiltration. The wearing course can either be a crushed gravel layer with fines or a bitumenous layer.

Required ballast depth or thickness not only depends on subgrade strength but also on vehicle weight and traffic volume. The time or service life a road can support traffic without undue sediment delivery depends on:

- soil strength
- ballast depth
- traffic volume (number of axles)
- vehicle weight (axle load)

Surface loading from wheel pressure is transmitted through the surface to the subgrade in the form of a frustrum of a cone. Thus, the unit pressure on the subgrade decreases with increasing thickness of the pavement structure. Average unit pressure across the entire width of subgrade for any wheel load configuration can be calculated from the following formula:

$$P = L / \pi(r+d)^2$$

Where: P = unit pressure (kN/cm^2)
L = wheel load (kN)
r = radius of circle, equal in area to tire contact area (cm)
d = depth of pavement structure (cm)

A useful parameter for determining the strength of subgrade material is the California Bearing Ratio (CBR). CBR values are indices of soil strength and swelling potential. They represent the ratio of the resistance of a compacted soil to penetration by a test piston to penetration resistance of a "standard material", usually compacted, crushed rock (Atkins, 1980). The range of CBR values for natural soils is listed in Table 23 together with their suitability as subgrade material. Poorer subgrade material requires a thicker ballast layer to withstand traffic load and volume.

Factors other than CBR values must be considered when determining the thickness of the pavement structure. Subgrade compaction will depend upon construction methods used and the control of moisture during compaction. Subgrade drainage effectiveness, frost penetration and frost heave, and subgrade soil swell pressure are associated with water content in the soil and will also affect final design thickness. To counteract these factors, a thicker, heavier pavement structure should be designed.

table 29 Engineering characteristics of soil groups for road construction (Pearce, 1960).

Unified Soil Classification	Field CBR Value	Dry weight* (kN/m3)	Frost Action	Suitability Subgrade**
GW	60-80	19.6-22	none to very slight	excellent
GP	25-60	17.3-20.4	none to very slight	good to excellent
GM-d***	40-80	20.4-22.8	slight to medium	good to excellent
GM-u***	20-40	18.9-22	slight to medium	good
GC	20-40	18.9-22	slight to medium	good
SW	20-40	17.3-20.4	none to very slight	good
SP	10-25	15.7-18.9	none to very slight	fair
SM-d***	20-40	18.9-21.2	slight to high	good
SM-u***	10-20	16.5-20.4	slight to high	fair to good
SC	10-20	16.5-20.4	slight to high	fair to good
ML	5-15	15.7-19.6	medium to very high	fair to poor
CL	5-15	15.7-19.6	medium to high	fair to poor
OL	4-8	14.1-16.5	medium to high	poor
MH	4-8	12.6-15.7	medium to very high	poor
CH	3-5	14.1-17.3	medium	poor to very poor
OH	3-5	12.6-16.5	medium	poor to very poor
PT			slight	unsuitable

* Unit dry weight for compacted soil at optimum moisture content for modified AASTO compactive effort.
** Value as subgrade, foundation or base course (except under bituminous) when not subject to frost action.
*** "d" = liquid limit ≤ 28 and plasticity index < 6; "u" = liquid limit > 28.

An alternative to the cost of a heavier pavement structure is the use of geotextile fabrics. Fabrics have been found to be an economically acceptable alternative to conventional construction practices when dealing with less than desirable soil material. The U. S. Forest Service has successfully used fabrics as filters for surface drainage, as separatory features to prevent subgrade soil contamination of base layers, and as subgrade restraining layers for weak subgrades. A useful guide for the selection and utilization of fabrics in constructing and maintaining low volume roads is presented by Steward, et al. (1977). This report discusses the current knowledge regarding the use of fabrics in road construction and contains a wealth of information regarding physical properties and costs of several brands of fabric currently marketed in the United States and abroad.

Proper thickness design of ballast layer not only helps to reduce erosion but also reduces costs by requiring only so much rock as is actually required by traffic volume (number of axles) and vehicle weight (axle weight-wheel loads). The principle of thickness design is based on the system developed by AASHO (American Association of State Highway Officials) and adapted by Barenberg et al. (1975) to soft soils. Barenberg developed a relationship between required ballast thickness and wheel or axle loads. Soil strength can be simply measured either with a cone penetrometer or vane shear device, such as a Torvane.

Thickness design for soft soil is based on the assumption of foundation shear failure where the bearing capacity of the soil is exceeded. For rapid loading, such as the passage of a wheel, the bearing capacity q is assumed to depend on cohesion only.

$$q = N_C * C$$

where q = Bearing capacity of a soil (kg/cm^2).
C = Cohesive strength of soil (kg/cm^2).
N_C = Dimensionless bearing capacity factor

Based on Barenberg's work, Steward, et al. (1977) proposed a value of 2.8 to 3.3 and 5.0 to 6.0 for N_C. The significance of the bearing capacity q is as follows:

A. q = 2.8 C is the stress level on the subgrade at which very little rutting will occur under heavy traffic (more than 1000 trips of 8,160 kg axle equivalencies) without fabric.

B. q = 3.3 C is the stress level at which heavy rutting will occur under light axle loadings (less than 100 trips of 8,160 kg axle equivalencies) without fabric.

C. q = 5.0 C is the stress level at which very little rutting would be expected to occur at high traffic volumes (more than 1000 trips of 8,160 kg equivalency axles) using fabric.

D. q = 6.0 C is the stress level at which heavy rutting will occur under light axle loadings (less than 100 trips of 8,160 kg axle equivalencies) using fabric.

(Heavy rutting is defined as ruts having a depth of 10 cm or greater. Very little rutting is defined as ruts having a depth of less than 5 cm extending into the subgrade.)

Charts relating soil strength (as measured with a vane shear device) to axle load and ballast thickness are shown in Figure 56 through 58. Figure 56 is based on a single axle, single wheel load. Figure 57 is based on a double wheel, single axle load, and Figure 58 is based on a tandem wheel configuration typical of 3 axle dump trucks or stinger type log-trucks.

It should be noted that axle and wheel configuration have a tremendous impact on the load bearing capacity of a road. The relationship between axle load and subgrade failure is not linear. Allowing 16,000 kg axle load vehicle to use a road designed for a standard axle load of 8,200 kg, is equivalent to 15 trips with the 8,200 kg axle load vehicle. Premature rut formation and its prevention depend on the selection of the proper axle load and strict enforcement of the selected load standard.

Some typical truck configurations, gross vehicle weights (GVW), and axle or wheel loads are given in Table 24. Vehicles under 3 tonnes GVW have no measurable effect on subgrade stress and deterioration.

Design Example

A road is to be constructed to access a watershed. Because of erosive conditions and traffic volumes, only 5 cm of rutting can be tolerated. Expected traffic volume is high (greater than 1,000 axle loads).

Three vehicle types are using the road:

1. Utility truck - 10 tonnes GVW; 4,500 kg single wheel load
   (9,000 kg axle load on rear axle, loaded)

2. Dump truck - 15 tonnes GVW with two axles;
   (11 tonnes rear axle load or 5.5 tonnes per dual wheel)

3. Log truck - 36 tonnes GVW with 5 axles, rear tandem axle load
   equals 15.9 tonnes or 7.95 tonnes per tandem wheel set.

Soil tests: Visually segment the road into logical construction segments based on soil type. Take soil strength measurements with vane shear device. Measurements should be taken during wet soil conditions, its weakest state. Take at least 10 vane shear readings at approximately 10 cm and 40 cm below the surface (in mineral soil). Tabulate readings in descending order from largest to smallest value. Your design shear strength is the 25th percentile shear strength--the value at which 75 percent of the soil strength readings are higher.

Vane Shear Readings

1.	0.58 kg/cm^2	
2.	0.58	
3.	0.50	
4.	0.46	
5.	0.45	
6.	0.45	
7.	0.40	
8.	0.37	
9.	0.36	=> 0.36 (25 percentile) -Design strength to be used in calculation.
10.	0.32	
11.	0.32	
12.	0.30	

Subgrade strength for design purpose is taken as 0.36 kg/cm^2.

Ballast Depth Calculation: Calculate the soil stress value without fabric for little rutting (less than 5 cm for more than 1,000 axle loads).

$$q = 2.8 * 0.36 = 1.01 \text{ kg/cm}^2$$

(Conversion factor: Multiply kg/cm^2 by 14.22 to get psi. This gives a value of 14.33 psi in this example).

In the case of the utility truck with 4,500 kg (10,000 lbs) wheel load, enter Figure 56 at 14.33 on the bottom line and read upwards to the 4,500 kg (10,000 lbs) single wheel load. A reading of 42 cm (16.5 in.) is obtained. Since 7 -12 cm additional ballast is needed to compensate for intrusion from the soft subgrade, a total of 49 - 54 cm of ballast is required. When fabric is used, a factor of 5.0 (little rutting for high traffic volumes) is applied to determine the ballast depth.

$$q = (5.0 * 0.36 *14.22) + 25.6 \text{ psi}$$

A reading of 28 cm (11 in.) is obtained from Figure 56 indicating a saving of 21-26 cm of rock when fabric is used.

The same analysis is carried out for the other vehicles. Ballast depth required to support the other vehicles is shown in Table 24.

table 30 Required depth of ballast for three design vehicles. Road designed to withstand large traffic volumes (> 1,000 axle loads) with less than 5 cm of rutting.

Bearing Capacity q $C*N_C*14.22$	Utility truck 10 t GVW 4,500 kg (10,000 lbs) Single wheel	Dump truck 15 t GVW 5,500 kg (12,000 lbs) Dual wheel	Log truck 36 t GVW 7,850 kg (17,500 lbs) Tandem wheel	
	----------------------------------Ballast Thickness	------------------------------		
Without* Fabric 14.33 psi kg/cm2)	41+10=51 cm	42+10=52 cm	40+10=50 cm	(1.01
With ** Fabric 25.6 psi (1.80 kg/cm2)	31 cm	28 cm	24 cm	

*7 -12 cm additional rock is needed to compensate for contamination from the soft subgrade.
**The fabric separates the subgrade from the ballast. No intrusion of fines into subgrade.

The dump truck (15 t GVW) represents the most critical load and requires 52 cm of rock over the subgrade to provide an adequate road surface. If fabric were to be used, the utility truck (10 t GVW) would be the critical vehicle. The rock requirement would be reduced by 21 cm to 31 cm. A cost analysis would determine if the cost of fabric is justified.

The above example shows that a simple, 2 axle truck can stress the subgrade more than a 36 tonne log truck. The engineer should consider the possibility and frequency of overloading single-axle, single-wheel trucks. Overloading a 4,500 kg (10,000 lbs) single wheel load truck to 6,750 kg (15,000 lb) increases the the rock requirements from 51 to 62 cm.

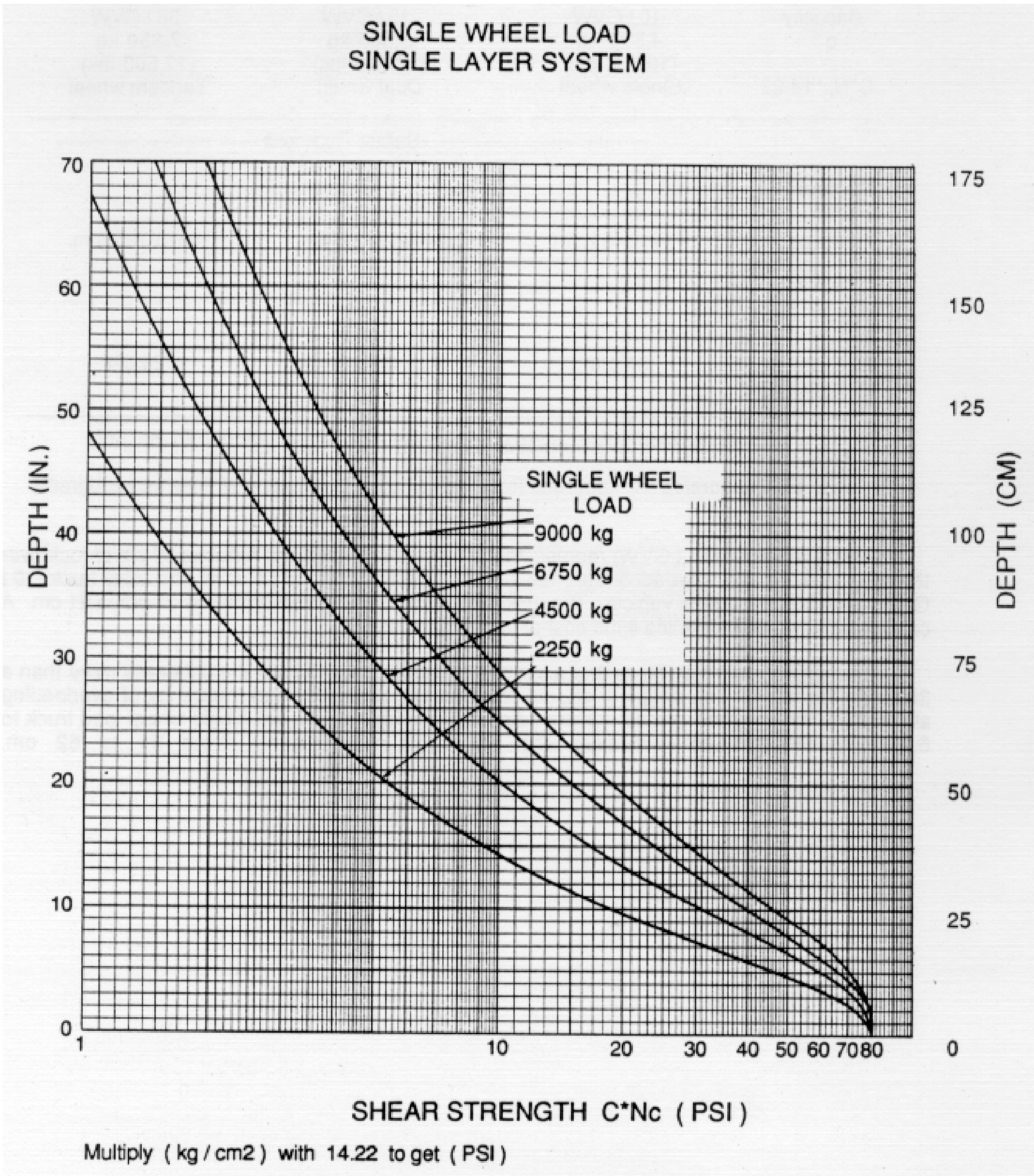

Figure 56. Ballast thickness curves for single wheel loads (from Steward, et al., 1977). Conversion factors: 1 inch = 2.5 cm ; 1kg/cm^2 = 14.22 psi.

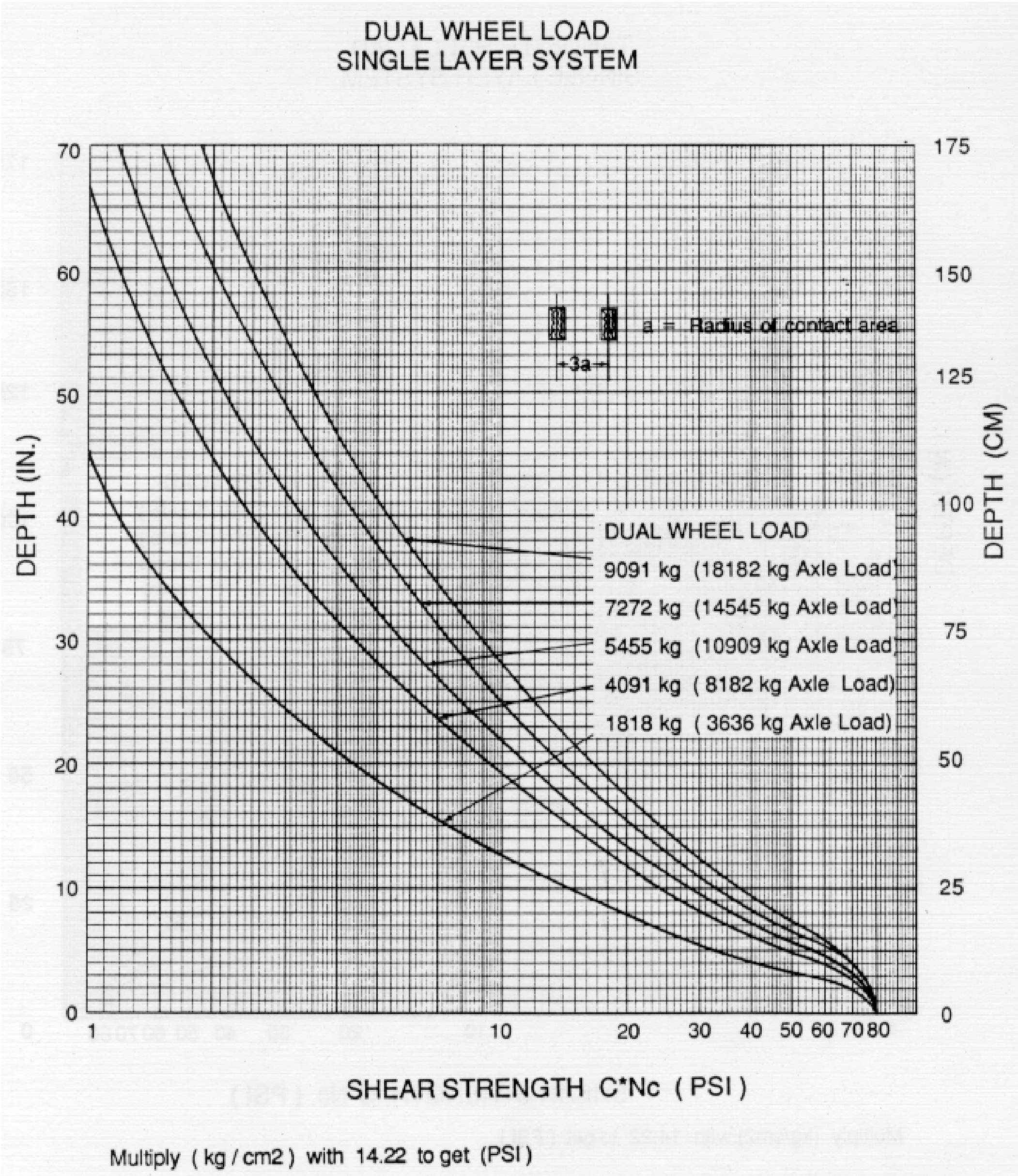

Figure 57. Ballast thickness curves for dual wheel loads (from Steward, et al., 1977). Conversion factors: 1 inch = 2.5 cm ; 1kg/cm^2 = 14.22 psi.

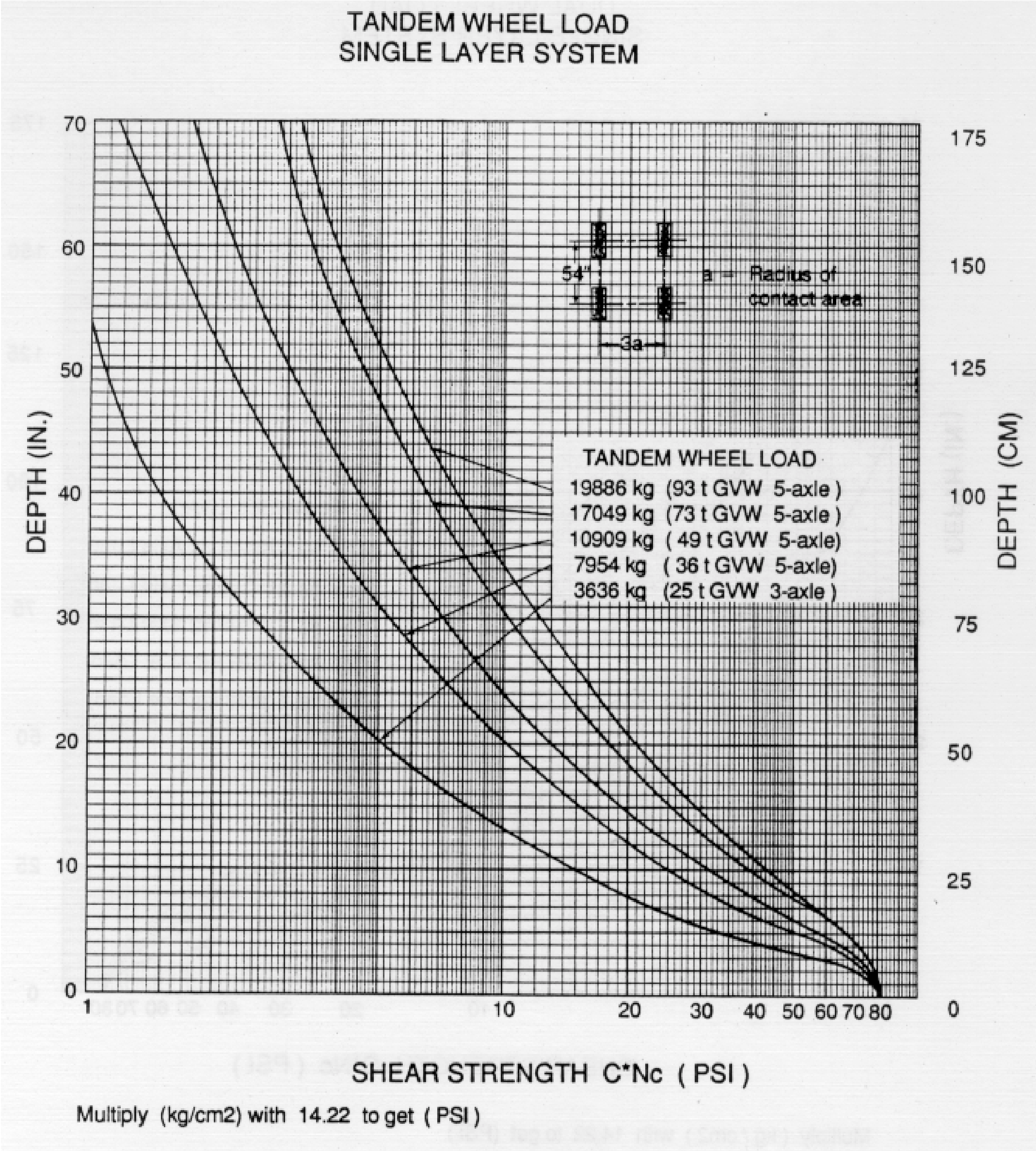

Figure 58. Ballast thickness curves for tandem wheel loads (form Steward et al 1977). Conversion factors: 1inch = 2.5 cm; 1kg/cm^2 = 14.22 psi.

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