TANK TRAIL DESIGN

GENERAL: Tank trails provide a stable surface to ensure that all tank crews operating on the range can maneuver as required. The following section addresses the design of the gravel tank trails for 63,000-kg-class (70-ton-class) vehicles. (See TM 5-822-12, General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas). The thickness requirements and the design curves for determining the thickness are included in the tables below. The material requirements for nonfrost and frost conditions are also presented. To provide a stable surface for the operation of tanks, two parameters must be considered: (1) the required thickness of the trails for normal conditions, and (2) the effects of frost conditions on the design. These and other items pertinent to tank trail design are addressed below.

REQUIRED THICKNESS: The tank trail design for normal conditions is based on a design index that reflects expected lifetime traffic. The design indexes applicable for use with tracked vehicles are listed in Table 1 below. The thickness design requirements are shown in Figure 1 in terms of the design index and California Bearing Ratio (CBR) values. The thickness determined from the figure may be constructed of compacted granular fill for the total depth over the natural subgrade or in a layered system of granular fill and compacted subgrade for the same total depth. The layered section should also be checked to ensure that, for the CBR of the compacted subgrade, an adequate thickness of granular fill covers the compacted subgrade. The granular fill may consist of base and subbase material if the top 150mm (6in) meet the gradation requirements of Table 4 of this document.

FROST AREA CONSIDERATIONS: In areas where frost affects the design of pavements, additional considerations concerning thickness and required layers in the pavement structure must be addressed. Specific areas where frost affects the design are discussed below; however, a more detailed discussion of frost effects is presented in TM 5-822-5, Pavement Design for Roads, Streets, Walks and Open Storage Areas.

Table 1. Design Indexes for Tracked Vehicles

Vehicle Passes	Design Index
1 per week	4
1 per day	5
4 per day	6
10 per day	7
40 per day	8
100 per day	9

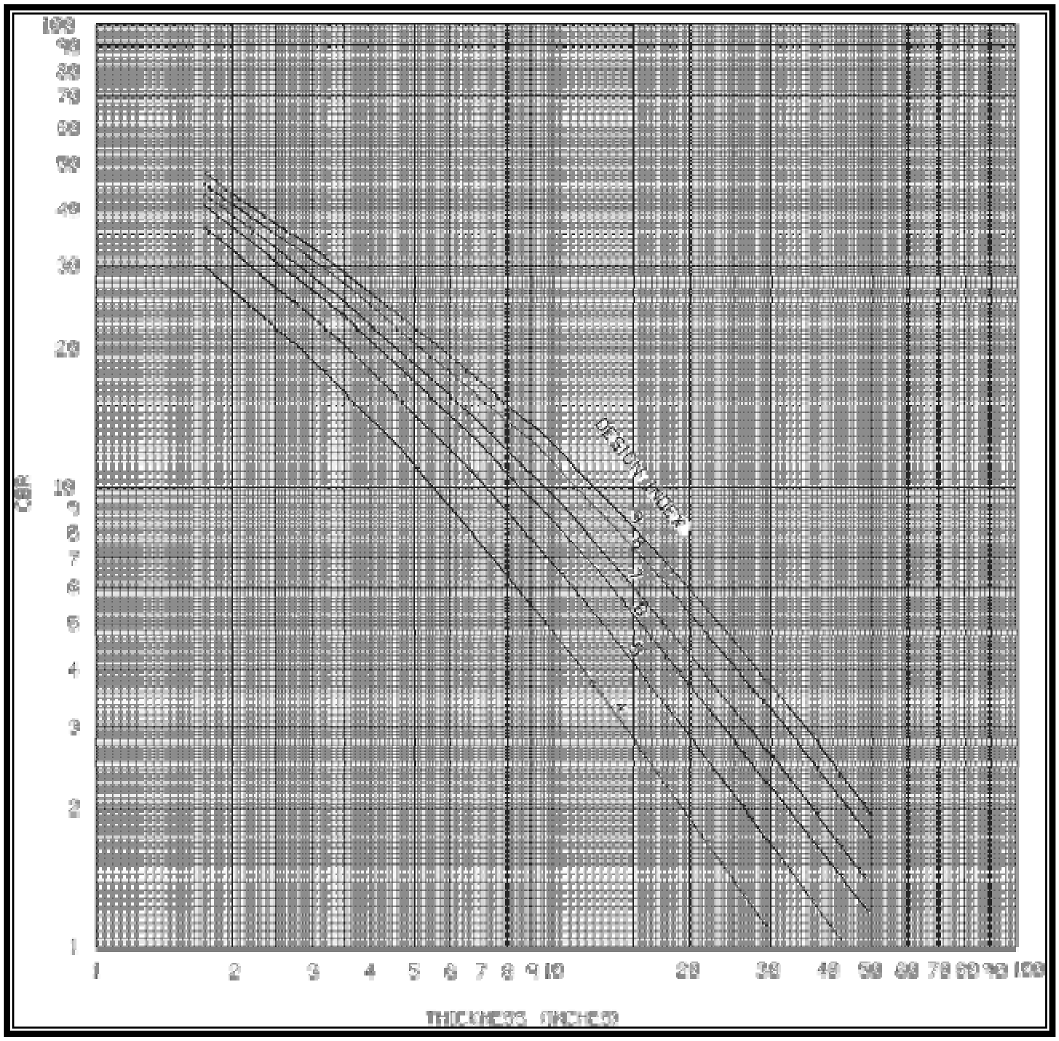

Figure 1. Thickness Design Curves for Tank Trails

SOIL GROUPS: For frost design purposes, soils have been divided into eight groups as shown in Table 2. Only the nonfrost-susceptible (NFS) group is suitable for the base course. NFS, S1, or S2 may be used for the subbase course. Any of the eight groups may be used in subgrade soils. Soils are listed in approximate order of decreasing bearing capacity during periods of thaw.

SOIL THICKNESS: When the subgrade is frost susceptible, the required section thickness should be determined from Figure 1, using the item with a CBR value equal to the frost area soil support index listed in Table 3. The soil support index for S1 and S2 materials meeting current specifications for base or subbase will be determined in the same manner as that of a nonfrost area design.

USE OF GEOTECHNICAL FABRICS: To reduce the thickness of granular materials, geotechnical fabrics may be used over F3 or F4 subgrade materials in seasonal frost areas. A geotechnical fabric will reduce the thickness requirements obtained from the curves in Figure 1 by 150mm (6in). The geotechnical fabric should provide at least 110lb at 10-percent strain when the material is tested by the Grab Strength Test (ASTM D1682). If the material exhibits different loads in perpendicular directions, the lowest value will be used. If longitudinal seams are required, they must meet requirements in ASTM D1683. End overlap at transverse joints should be a minimum of 600mm (2ft). The fabric must be placed directly on the subgrade and must extend laterally to within 300mm (1ft) of the toe of the slope on each side.

REQUIRED LAYERS IN PAVEMENT SECTION: When frost is a consideration, the tank trail section should consist of a series of layers that will ensure the stability of the system, particularly during thaw periods. The layered system in the granular fill will consist of a wearing surface of fine crushed stone, a coarse-graded base course, and a well-graded subbase of sand or gravely sand. To ensure the stability of the wearing surface, the width of the base course and subbase should exceed the final desired surface width by a minimum of 1ft on each side.

Wearing Surface. The wearing surface contains fines that provide stability in the road surface. The presence of fines helps the compaction characteristics of the layers and help to provide a relatively smooth riding surface.

Base Course. The next layer, the coarse-graded base course, is important for providing drainage for the granular fill. It is also important that this material be NFS, so that it retains its strength during spring thaw periods.

Subbase. The third layer, the well-graded sand subbase, is used for additional bearing capacity over the frost-susceptible subgrade and as a filter layer between the coarse-graded base course and the subgrade. The filter layer helps prevent the migration of the subgrade into the voids of the coarser material during reduced subgrade strength. The sand subbase must be either NFS or low-frost susceptible (S1 or S2). The filter layer may or may not be necessary, depending upon the type of subgrade material under the trail. If the subgrade consists principally of gravel or sand, the filter layer may not be necessary and may be replaced by geotechnical fabric. If geotechnical fabric is used, the sand subbase/filter layer may be omitted, since the fabric will be placed directly on the subgrade and will act as a filter.

Table 2. Frost Design Soil Classification

Frost Group	Type of Soil	% Finer Than 0.02 mm By Weight	Typical Soils Under Unified Soil Classification System

NFS*	Gravels: crushed stone; crushed rock	0 to 1.5	GW, GP
	Sands	0 to 3	SW, SP
PFS**	Gravels: crushed stone; crushed rock	1.5 to 3	GW, GP
	Sands	3 to 10	SW, SP
S1	Gravely soils	3 to 6	GW, GP, GW-GM, GP-GM
S2	Sandy soils	3 to 6	SW, SP, SW-SM, SP-SM
F1	Gravely soils	6 to 10	GM, GW-GM, GP-GM
F2	Gravely soils	10 to 20	GM, GW-GM, GP-GM
	Sands	6 to 15	SM, SW-SM, SP-SM
F3	Gravely soils	over 20	GM, GC
	Sands, except very fine silty sands	over 15	SM, SC
	Clays, PI>12	—	CL, CH
F4	All silts	—	ML, MH
	Very fine silty sands	over 15	SM
	Clays, PI<12	—	CL, CL-ML
	Varved clays and other fine-grained banded sediments	—	CL & ML; CL, ML, & SM; CL, CH, & ML; CL, CH, ML, & SM
*Nonfrost-susceptible. **Possibly frost-susceptible, but requires laboratory test to determine frost design soil classification.			

Table 3. Frost Area Soil Support Indexes of Subgrade Soils

Frost Group of Subgrade Soil	F1	F2	F3 & F4
Frost Area Soil Support Index	9.0	6.5	3.5

SUBGRADE: The subgrade should be compacted in order to provide a firm working platform for placement and compaction of the subbase. Compaction of the subgrade will not change its frost area soil support index; however, the frost action will cause the subgrade to revert to a weaker state. Hence, in frost areas, the compacted subgrade will not be considered part of the layered system of the tank trail, which should be comprised only of the wearing, base, and subbase courses.

Layer Thickness:

Typical Design. In common construction practice, the minimum layer thickness is 100mm (4in). However, it is recommended that a 150mm-minimum (6in-minimum) thickness be used for each of the required layers for the construction of tank trails. The relative thickness of the base course and the filter layer are variable and should be based on the cover required and economic considerations.

Alternative Designs. An economical alternative section involves the replacement of the lower 50-percent of the total thickness of granular material with S1 or S2 soils, as long as the filter requirement over the subgrade is met. Another alternative would be to use the frost group soils F1 or F2 in the lower part of the base over F3 or F4 subgrade soils. F1 materials may be used in the lower part of the base over F2 subgrades. The thickness of the F2 base material should not exceed the difference between the reduced-subgrade-strength thickness required over F3 and F2 subgrades and the base. The thickness of the F1 base should not exceed the difference between the thickness required over F2 and F1 subgrades and the base. Any F1 or F2 material used in the base must meet the applicable requirements of the guide specifications for base and subbase materials. The thickness of F1 and F2 materials and the thickness of pavement and base above the F1 and F2 materials must meet the nonfrost criteria of TM 5-822-5 or TM 5-822-6.

Turning Pad, Intersections, Short Radius Curves, *and Other High Traffic Areas*. When tanks turn around or make sharp turns (at intersections or short radius curves, for example), damage will eventually occur to the aggregate pavement. The designer should consider sections of concrete pavement (designed in accordance with TM 5-822-5) for these areas in order to reduce future maintenance costs. *Another option for the designer at these locations or other high traffic areas is the use of articulated concrete blocks, also known as "cable concrete" blocks. A cable concrete system is composed of individual trapezoid shaped concrete blocks that are strung together with steel cables into 8 ft by 16 ft "mattresses" that are placed side-by-side, clamped, and staked to the ground to provide one homogeneous system. Gaps between individual blocks are filled with aggregate base that is worked into crevasses between the blocks. The type of traffic that the system must support determines the block size. While there are several sizes of block commercially available, CC70 and CC90 size blocks should be used on tank trails, with the CC90 block being used on turn pads, short radius curves, and at intersections. CC70 size blocks can be used on straight sections of trail where vehicles do not make turns. The NFS classification group is suitable for the sub-base and base courses under the cable concrete. See the Civil Details in the Appendix of this document for design guidance.*

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The perimeter (edge line) radius of curvature at an intersection should allow vehicles to make smooth unobstructed turns while staying on the hardened trail. An arc radius of 25 ft is recommended for the edge line, as shown on the Civil Details in the Appendix. If cable concrete blocks are used, then some blocks may need to be removed from the cable concrete mats in order to achieve this arc radius. A sufficient arc radius will minimize rutting at the intersection, since vehicles will be less tempted *to "cut corners" while making turns. The designer should also consider the use of concrete bollards at intersections and other short radius curves to help keep vehicles on the trail, and prevent them from "cutting corners". The bollards will greatly minimize rutting of the trail at these locations, since they force vehicles to stay on the hard surface. The bollards should be painted for high visibility under all conditions. Design guidance is included in the Appendix.*

Figure 1: Tank Trail Intersection that has been hardened with Cable Concrete with Bollards

MATERIAL AND GRADATION REQUIREMENTS: The construction material requirements for the tank trails depend on whether frost is a design consideration.

Nonfrost Areas. In areas where frost penetration is not a consideration, the granular layer (subbase) may consist of a compacted, gravely soil that has a liquid limit not in excess of 35, a plasticity index between 4 and 9, and a maximum size of about 25mm (1in). Material below the top 150mm (6in) may consist of any granular base or subbase material. The suggested gradation requirements for this type of granular layer are presented in Table 4. The inclusion of 10 to 20 percent passing the No. 200 sieve is important for two reasons. First, the fines help to make the gravel more dense and stable, which in turn provides a better wearing surface. Second, the fines help to decrease the openings in the granular layer, which prevents the migration of the subgrade into the granular layer during periods when the subgrade might become saturated.

Table 4. Gradation Requirements for the Granular Layer in Nonfrost Areas

Sieve Designation	% Passing By Weight
1 inch	100
3/4 inch	85 to 100
3/8 inch	65 to 100
No. 4	55 to 100
No. 10.	40 to 70
No. 40	25 to 45
No. 200	10 to 20

Frost Areas. Where frost is a consideration in the design of roads, a layered system should be used on the tank trails. The percentage of fines should be restricted in all layers in order to facilitate drainage and reduce the loss of stability and strength during thaw periods. The gradation requirements for the wearing surface, coarse-gravel base course, and sand subbase have been developed using standard filter design criteria that enable water to flow freely through the granular fill and prevent the migration of the smaller particles from the wearing surface downward or from the subgrade upward. The gradation limits of the various layers are presented in Table 5.

Table 5. Gradation Requirements for Frost Areas

Sieve Designation	Fine-Gravel Wearing Surface	Coarse-Gravel Base Course	Well-Graded Sand Subbase
4 inch	—	100	—
1 inch	100	50 to 90	—
3/4 inch	85 to 100	—	100
No. 4	45 to 65	20 to 40	85 to 100
No. 10	30 to 50	15 to 30	55 to 85
No. 40	15 to 30	—	25 to 50
No. 200	5 to 10	0 to 5	0 to 10

COMPACTION REQUIREMENTS: Soil compaction requirements for the subgrade and granular layers of a tank trail are expressed as a percent of laboratory maximum dry density as determined by ASTM D1557, method D (Modified Proctor soil density test). The wearing surface and base course materials should be compacted to 100-percent laboratory maximum dry density, and the sand subbase should be compacted to 95-percent laboratory maximum dry density. If a compacted subgrade layer is included in the trail section, it should be compacted to the density required in order to produce the CBR value used in design. However, the subgrade in fill sections will be placed at no less than 95-percent laboratory maximum dry density for cohesionless soils (PI≤ 5, LL≤ 25) and 90-percent for cohesive soils (PI>5, LL> 25).

MAINTENANCE:

Drainage. The environment is one of the primary causes of continual maintenance on gravel roads. Rainfall and water running over the gravel tend to wash the fines from the surface course, reducing the stability of the gravel. Therefore, to minimize maintenance, adequate drainage should be provided via ditches and the natural topography, thereby moving water away from the gravel tank trails. Culverts should be used sparingly and only in areas where an adequate cover of granular fill over the culvert is available. *The designer should consider the use of an engineered low water crossing constructed with articulated cable concrete blocks in place of a culvert. Use of a low water crossing instead of a culvert will eliminate the chance of the culvert being crushed or otherwise blocked, which would impede surface water runoff at the site, and eventually result in subsidence and cratering of the tank trail by vehicles due to moist soil from seepage under the trail (see Figure 2). It will also greatly minimize maintenance requirements of the trail at that location.*

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Figure 2: Low Water Crossing Constructed to Replace a Culvert on Tank Trail

Trailside ditches should be properly shaped, and stabilized as appropriate to minimize erosion in the ditch. The type of stabilization is dependent on flow velocities in the ditch and other site specific conditions. For example, a grass lined ditch (with or without turf reinforcement mesh) is very effective in minimizing erosion. However, if a vegetative cover cannot be maintained in the ditch or if flow velocities are too great, then it may be necessary to stabilize a ditch with geotextile fabric and rock rip rap to minimize erosion. The use of stone check dams (or temporary wood chip check dams) should also be considered to slow water flows in ditches. Details are shown on the drawings in the appendix. Stabilization of roadside ditches will help maintain surface water quality, and will also minimize trail maintenance because there will be less undercutting of the trails.

Frequency. Maintenance should be performed every 6 months, or more frequently if needed. Experience with gravel roads indicates that the frequency of maintenance will be high for the first few years of use, but will decrease over time to a constant value. The majority of the maintenance will consist of periodic grading and replacement of lost materials in order to remove the ruts and potholes that will inevitably be created by traffic and the environment. Occasionally during the lifetime of the tank trails, the wearing surface may have to be scarified, additional gravel added to restore the thickness originally required, and the wearing surface re-compacted to the specified density.

DUST CONTROL: The primary objective of a dust palliative is to prevent soil particles from becoming airborne as a result of wind or traffic. Dust palliatives for traffic areas must withstand the abrasion of wheels or tracks. An important factor limiting the applicability of a dust palliative in traffic areas is the extent of surface rutting or abrasion that occurs under traffic. Some palliatives tolerate deformations better than others, but normally ruts in excess of 13mm(1/2in) result in the virtual destruction of any thin layer or willow-depth penetration dust palliative treatment. Furthermore, the abrasive action of tank tracks may be too severe for the use of some dust palliatives in a traffic area. A wide selection of materials for dust control is available to the engineer. Although no one choice can be singled out as acceptable for all problems that may be encountered, several materials have been recommended for use on tank trails. (See Table 6).

Table 6. Summary of Soil-Stabilizing Material for Dust Control

Material	Form	Application Method	Applicable Soil Range	Relative Degree of Effectiveness	Gallons per Sq Yd*	Pounds per Sq Yd*	Minimum Curing Time	Remarks
APSB FSN 5610-99-3034	liquid	Penetration	gravel to clay of moderate plasticity	moderately effective	0.25 to 0.50	2.1 to 4.0	4 to 8 hours	Excellent penetration ability; heating required for spraying.
Lion Prime**	liquid	Penetration	gravel to clay of moderate plasticity	moderately effective	0.25 to 0.50	2.1 to 4.0	4 to 8 hours	—
Magnesium Chloride	Liquid	Penetration	gravel to sand	moderately effective	0.50	0	0	All salts are corrosive to metal; subject to leaching; rely on absorption of moisture from the air to palliate dust; brine solution forms surface crust.
Emulsified Asphalt (SS-1 or SS-1h)	Liquid	Penetration	gravel to silty sand	applicable, but effectiveness unknown	0.10 to 0.50	0.8 to 4.0	several hours	Requires water for dilution and requires careful control for proper emulsion break. Dilutions of up to 5:1 by water are used.

*For all admixture treatments, the quantities indicated are for a 1-inch depth of treatment, assuming a compacted dry density of 100 pcf.

**Proprietary material

A "Dust Control Guidance and Technology Selection Key" (USAEC Report # SFIM-AEC-EQ-CR-99002 / USACERL Report 99/21) was jointly developed by the U.S. Army

Environmental Command (USAEC) and the U.S. Army Construction Engineering Research Laboratory. The purpose of this report is to assist personnel in making informed cost effective decisions regarding the selection and application of appropriate dust control palliatives with proven performance and maintenance requirements. This simple to use guidance document is available on the USAEC website.

LOW WATER STREAM CROSSINGS: *If a tank trail needs to traverse a stream channel, then the designer should consider the use of an engineered low water stream crossing at the site, or should otherwise harden the channel crossing site as outlined in the section on Low water Stream Crossings. This will mitigate degradation and erosion of the channel and stream banks, and help maintain surface water quality. It will also minimize maintenance to be performed at the crossing site.*

Figure 3: Engineered Low Water Stream Crossing on Tank Trail

STEEP GRADES: *Steep grades on tank trails are typically subject to more extensive erosion on the trail and in the ditches along the sides of the trail. Erosion in the ditches on steep sections of trail can over short periods of time begin to erode large gullies, which will begin to narrow the trail and make it increasingly unsafe for vehicle traffic. Eventually the trail will become impassable, and require maintenance. Designers should consider use of articulated cable concrete mats on steep sections of trail, and rip rap lined ditches to minimize erosion for these sections of tank trail. This will minimize maintenance that must be performed, and reduce future maintenance costs. Design guidance is included in the Appendix.*

TANK TRAIL DESIGN EXAMPLE NO. 1.

Parameters:

a. Subgrade CBR Values.

1) Natural subgrade is 5 (CL material with PI of 15, frost group F3).
2) Compacted subgrade is 10.

b. Road Materials CBR Values.

1) Fine-graded crushed-rock wearing surface is 80.
2) Course-graded crushed-rock base course is 80.
3) Clean sand subbase is 15.

c. Projected Range Usage. 20 round trips/day.

d. Design Index. Calculate the number of passes per day using the following parameters:

According to Table 1, a design index of 8 would accommodate 40 passes a day.

Nonfrost Area Section. Using the parameters listed above, determine the cross section of a tank trail for a nonfrost area. With a design index of 8, the total trail thickness for a natural subgrade with a CBR of 5 would be 21 inches, and the required cover over a compacted subgrade with a CBR of 10 would equal 11 inches (see Figure 1). Therefore, the tank trail section could be designed as follows:

Granular Layer		11 in.	
Compacted Subgrade CBR = 10			21 in.
Natural Subgrade CBR = 5			

Frost Area Sections

General Design Information: Using the parameters listed above, determine the cross section of the tank trail in a severely cold area where subgrade freezing is predicted. In areas where frost is a consideration, the tank trail should consist of the following layers:

a. Wearing surface of fine-graded crushed rock.
b. Base course of coarse-graded crushed rock.
c. Subbase of well-graded sand or geotechnical fabric.

The subbase in this example will need to function as a filter layer, since the natural subgrade is assumed to be CL--an F3 subgrade soil with a frost area soil support index of 3.5. (See Tables 2 and 3). Although the thickness of the wearing surface must always remain between 4 and 6in, the thickness of the other layers may be adjusted for economic reasons as long as a minimum 4 to 6in for each layer is maintained. A few of the possible alternatives for tank trail sections with sand subbase and with geotechnical fabric are shown below.

First Sand Subbase Alternative. For a sand subbase with a design index of 8 and a natural subgrade with a CBR of 5, use the soil support index of 3.5 as the CBR in Figure 1 to calculate the total thickness required for all the layers. That thickness would equal 28.5in. The minimum thickness of the layers over an NFS, S1, or S2 sand subbase with a CBR of 15 would equal 7.3in. If 150mm-thick (6in-thick) layers were used for the wearing surface and the course-graded base course, the actual cover would be 12in. Therefore, the section could be designed as follows:

Wearing Layer: Fine-Graded Stone		6 in.		
Coarse-Graded Crushed Stone			12 in.	
Well-Graded Sand Subbase CBR = 15				28.5 in.
Natural Subgrade				

Second Sand Subbase Alternative. An alternative section could be designed as follows:

Wearing Layer: Fine-Graded Stone		6 in.		
Coarse-Graded Crushed Stone			22.5 in.	
Well-Graded Sand Subbase				28.5 in.
Natural Subgrade				

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Geotechnical Fabric Alternatives:

First Alternative. With geotechnical fabric, either of the designs shown above could be used by deducting 6in of the well-graded sand subbase and replacing it with a geotechnical fabric. The total thickness above the geotextile must be a minimum of 22.5in. Sections using fabric could be designed as follows:

Wearing Layer: Fine-Graded Stone		6 in.	
Coarse-Graded Crushed Stone Geotechnical Fabric			22.5 in.
Natural Subgrade			

Second Alternative. An alternative section could be designed as follows:

Wearing Layer: Fine-Graded Stone		7.5 in.	
Well-Graded Sand Subbase Geotechnical Fabric			22.5 in.
Natural Subgrade			

Other Criteria:

a. The granular layers should be compacted to 100-percent laboratory maximum dry density.
b. The subgrade should be compacted to the density required for a CBR of 10 (or whatever CBR is determined by required laboratory tests).
c. The materials should meet the gradation requirements referenced in this manual.
d. After all possible design sections are determined, the final section used for the tank trails should be determined on the basis of an economic analysis.

TANK TRAIL DESIGN EXAMPLE NO. 2.

Parameters.

a. Subgrade CBR Values.

1) Natural subgrade is 4 (SM: silty sand material, frost group F2).
2) Compacted subgrade is 8.

b. Road Materials CBR Values.

1) Fine-graded crushed-rock wearing surface is 80.
2) Coarse-graded crushed-rock base course is 80.
3) Clean sand subbase is 15.

c. Projected Range Usage. 15 round trips/day.

d. Design Index. Calculate the number of passes per day using the following parameters:

According to Table 1, a design index of 7.5 would accommodate 30 passes per day.

Nonfrost Area Section. Using the parameters listed above, determine the cross section of a tank trail in a nonfrost area. With a design index of 7.5, the total trail thickness over a natural subgrade with a CBR of 4 would equal 23in. The cover required over a compacted subgrade with a CBR of 8 would equal 12.5in. (See Figure 1). The tank trail section could be designed as follows:

Granular Fill		12.5 in.	
Compacted Subgrade CBR = 8			23 in.
Natural Subgrade CBR = 4			

Frost Area Sections. Determine the cross section of the tank trail for a severely cold area where subgrade freezing is predicted. For this example, CBR 4 will govern the design because the CBR for the natural subgrade is less than the frost area soil support index of 6.5 for SM (F2) soils as shown in Table 3. As calculated in the previous paragraph, the total trail thickness for all layers covering the natural subgrade would equal 23in. Because filter fabric is restricted to F3 or F4 subgrade soils, geotechnical fabric will not be used. Therefore, using 6in for the wearing layer, the tank trail section could be designed as follows:

Wearing Layer: Fine-Graded Stone		6 in.		
Coarse-Graded Crushed Stone			17 in.	
Sand Subbase CBR=15				23 in.
Natural Subgrade CBR = 4				

Alternative Sections:

First Alternative. Alternative sections based on economic considerations may be developed using frost group soils S1, S2, and F1 with the lower portion of the base material. Such sections could be laid out as follows:

Wearing Layer: Fine-Graded Stone		6 in.		
Coarse-Graded Crushed Stone			17 in.	
Frost Group Soil S1 or S2				23 in.
Natural Subgrade				

Second Alternative. An alternative section could be designed as follows:

Wearing Layer: Fine-Graded Stone		6 in.		
Coarse-Graded Crushed Stone			14 in.*	
Frost Group Soil F1				23 in.
Natural Subgrade				

*Required for cover over frost group soil F1 per TM 5-822-5.

UXO CONSIDERATIONS: For information on tank trail design when UXO is present, go to the UXO Procedures in the Appendix of this document.

OTHER CRITERIA:

a. All layer depths should be rounded up to the next full inch for construction purposes.
b. The granular layers should be compacted to 100-percent laboratory maximum dry density.
c. The subgrade should be compacted to the density required for a CBR of 10 (or whatever CBR is determined by required laboratory tests).
d. The materials should meet the gradation requirements referenced in this manual.
e. After all possible design sections are determined, the final section used for the tank trails should be determined on the basis of an economic analysis.