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Impact Of Heavy Vehicles On Saskatchewan's Low Strength Roads

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Abstract

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Continued grain delivery point consolidation and closure of high cost railway branch lines has placed increased heavy truck traffic on Saskatchewan's municipal and provincial roads. Many of these roads were constructed to handle low traffic volumes and lack the structural integrity to carry significant volumes of heavy truck traffic.

A methodology was developed for determining when these low strength roads require upgrading to provide an adequate level of service. Two types of low strength roads were examined: gravel surfaced roads and thin membrane pavements. The gravel surfaced roads consist of a thin layer of gravel directly on the soil subgrade. The gravel is basically added to reduce slipperiness in wet conditions. The thin membrane pavement consists of a thin layer of asphalt placed directly on the subgrade, primarily for mud and dust control. For both road types, strength is controlled by the subgrade.

Subgrade strength was found to be extremely sensitive to subgrade soil water content. At higher water content, only a few passes of a legally loaded truck results in roadway failure. At lower water content, several tens of thousands of passes may be required.

Based on research conducted at the University of Saskatchewan and historical performance of these road types, estimates of number of loaded axle passes to produce road failure were developed. Separate values were developed for each road type and two major soil types prevalent in Saskatchewan. Where these load levels are exceeded with a specified frequency the roads become candidates for upgrading.

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1.0 Introduction

Due to the continuation of grain delivery point consolidation and closure of high cost railway branch lines, heavy truck traffic on Saskatchewan's municipal and provincial roads has increased. Many of these roads were constructed to handle light traffic volumes and lack the structural integrity to carry significant volumes of heavy truck traffic.

In response to this concern, and at the request of the Senior Grain Transport Committee [1], Transport Canada, in cooperation with the Saskatchewan Department of Highways and Transportation (SDHT), commissioned a study to determine how roadway performance would be affected by increased grain truck traffic. The study focused on the performance of low strength roads and identifying when these roads need to be upgraded to handle increased truck traffic.

2.0 Grain Handling in Saskatchewan

Saskatchewan is Canada's leading producer of grain accounting for over 55 percent of the country's grain production area. Over the past ten years, the total number of producers has decreased by 6 percent while total land under cultivation has increased 25 percent. As a result, the average production area per producer has increased by nearly one-third. Larger handling facilities have therefore become more economical resulting in increased pressure to use larger trucks for grain delivery to the elevator system.

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1. *This Committee, pursuant to the Western Grain Transportation Act, provides advice to the Minister of Transport on matters concerning transport, shipping and handling of grain. The Committee has 29 members, each having a direct interest in a particular aspect of the grain industry.*

The predominant movement of grain is from the farm gate to the primary country elevator; over 95 percent of producer deliveries to the licensed elevator system fall into this category. One of the significant trends noted by the study is the consolidation of these delivery points. This consolidation has been evolving for several decades and involves the closure of the older, smaller and less efficient elevators. From 1975 to 1987, the number of delivery points in Saskatchewan declined from 863 to 560. At this rate of consolidation, only 340 delivery points will be operating in Saskatchewan in the year 2000. Grain truck haul distances are therefore increasing as producers travel further to deliver their grain.

3.0 Transportation System Evolution

3.1 The Rail System

Saskatchewan's rail system has also been undergoing change to operate efficiently. With these changes, Saskatchewan now has nearly 12,000 kilometres of rail line, following the closure of 1,800 kilometres over the past decade. Under the Government of Canada's Branch line Rehabilitation program nearly 45 percent of the existing trackage are scheduled for improvement during the 12 year period ending in the fiscal year 1989/90.

3.2 The Highway System

Saskatchewan's municipal road system is one of the most extensive in Canada, accounting for 18 percent of Canada's roads and streets. In total, there are 160,000 kilometres of road under the jurisdiction of several hundred rural municipalities which are responsible for their construction and maintenance. Most of these roads are gravel surface. Approximately one-third of these roads are eligible for provincial funding assistance.

The Province of Saskatchewan, through the Department of Highways and Transportation, is responsible for an additional 24,000 kilometres of road, of which 20 percent are gravel surface. The gravel surface roads are located in the northern forested part of the province; all Department roads in the grain growing part of the province are either thin membrane pavements or full structural pavements.

In terms of length of road per capita, Saskatechewn has the most extensively developed road system in Canada, reflecting the province's basic demographic and geographic characteristics.

4.0 Roadway Standards

4.1 Roadway Types

Saskatchewan's extensive road network combined with typically light traffic volumes and limited supplies of granular materials, has lead to the development of two types of low strength roads in addition to the typical high strength asphalt concrete pavement. These low strength roads perform well where traffic volumes are low and truck traffic is relatively light. Where truck traffic is heavy, these pavements often demonstrate poor levels of service and high surface maintenance costs.

Figure 1 illustrates these three types of roads. For purposes of this presentation, these pavements are termed structural, thin membrane and gravel surface.

4.2 Structural Pavements

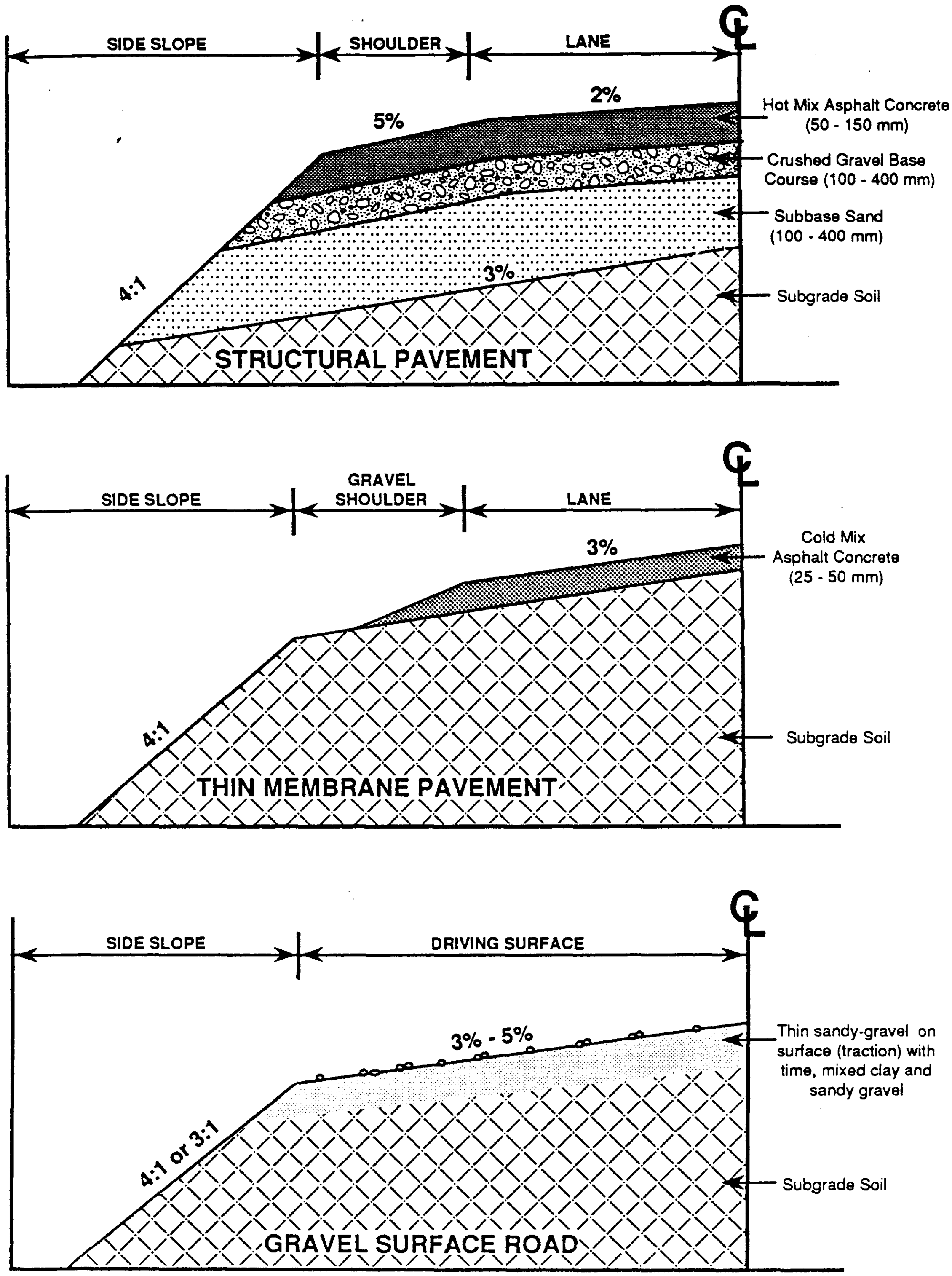
Structural pavements consist of an asphalt concrete surface placed over a crushed gravel base course and a sand subbase. Typical construction costs are $ 300,000 per kilometre of two lane roadway.

Structural pavements are designed for a fifteen year design life, or a staged design life with additional pavement structure added in five year stages. In Saskatchewan, structural pavements are designed using modified Shell design curves which use subgrade California Bearing Ratio (CBR) and equivalent single axle loads (ESAL's) as design parameters.

Structural pavements are generally used on highways where average daily traffic volumes exceed 500 vehicles. Pavement deterioration tends to be related to fatigue from repeated heavy axle loadings, and weathering of the asphalt concrete surface. Deterioration develops slowly, and is normally expressed as a function of the accumulated number of applied loads and age of the pavement. The ESAL concept for measuring damage is applicable to these pavements. Increased traffic volumes reduce the life of the road surface and create the need for increased pavement thickness in the future.

For the rail branch lines closures investigated in Saskatchewan the magnitude of incremental traffic applied to structural pavements was relatively small, and only minor deterioration could be attributed to the incremental traffic resulting from closure of these lines. However, where rail line closures result in large incremental traffic volumes on these pavements, there would be a need for an increased pavement thickness to prevent a reduction in roadway surface life. The procedures for determining the additional requirements are documented in the Surfacing Manual produced by Saskatchewan Highways and Transportation.

Figure 1
Typical Saskatchewan Road Surfaces



4.3 Thin Membrane Pavements

Thin membrane pavements consist of thin layers of asphalt bound aggregate placed on the subgrade surface. This surface is typically less than 50 mm thick which means the majority of the road's strength is derived from the subgrade.

These pavements are placed on low volume roads with limited truck traffic to provide a mud and dust free surface and to avoid the problem of windshield damage by stones on gravel surface roads. Compared to structural pavements, thin membrane pavements have low construction costs, typically in the order of $ 100,000 per two-lane kilometre of roadway. However, annual surfaces maintenance costs are much higher than those of a structural pavement, and may reach $3,000 to $5,000 per kilometre. Approximately 40 percent of the provincial road system is surfaced with these thin membrane pavements.

These pavements provide a reduced level of service and a lower ride quality than structural pavements. The road surface does not have a prescribed design life and often requires repair annually. They are generally suitable for car traffic throughout the year, as opposed gravel roads which may become impassable during spring and/or wet periods. As a result, the thin membrane pavement on low volume roads in rural Saskatchewan is a significant benefit to its residents.

The thin membrane pavements derive their strength from the subgrade. Subgrade strength varies significantly by season and from year to year. When the subgrade is wet and weak, roadway failure may occur after a few loaded truck passes. When the subgrade is dry and strong, a large number of loaded truck passes is required to produce failure; indeed, failure may not occur at all with the traffic loads normally experienced by these roads.

4.4 Gravel Surface Roads

Gravel surface roads perform similar to thin membrane pavements because they both rely on subgrade strength for satisfactory performance. The gravel surface road is seldom used on the provincial highway system in Saskatchewan's grain producing areas, but is the dominant road type for rural municipality roads. The road is a constructed subgrade with a thin application of gravel on the surface to increase trafficability. Traffic and routine blading over time mixes the gravel into the upper 150 mm to 200 mm of road surface. Additional applications of gravel occur periodically, resulting in the development of a gravel-rich soil at the surface of the subgrade.

The term "gravel surface road" has a different meaning in Saskatchewan than generally used in other locations. In Saskatchewan, gravel surface road means an earth subgrade with a small quantity of surface sandy gravel placed to improve wet weather traction. In other locations, gravel surface road means an earth subgrade with 150 mm to 300 mm of gravel. This presentation uses the Saskatchewan meaning for "gravel surface road".

5.0 Factors Affecting Performance of Thin Membrane Pavements and Gravel Surface Roads

5.1 Introduction

Three major factors affect the performance of these low strength roads: subgrade soil type; subgrade soil water content; traffic loadings. Each of these factors is discussed below.

5.2 Subgrade Soil Type

Low strength roads derive their strength from the subgrade soils; therefore the type of subgrade soil is an important factor in road surface performance. Subgrades in Saskatchewan's grain producing area are generally constructed with clay or silty clay matrix till soils. The till is much stronger than the clay because it is well sorted with respect to grain size, and contains sand and gravel which increases the frictional strength of the soil.

5.3 Subgrade Soil Water Content

The subgrade soils described above are cohesive and their strength is therefore largely controlled by their water content. Wet cohesive soils are soft and weak, while dry cohesive soils are hard and strong. Water content varies seasonally and from year to year due to differences in precipitation, snow melt, temperature, wind and evaporation.

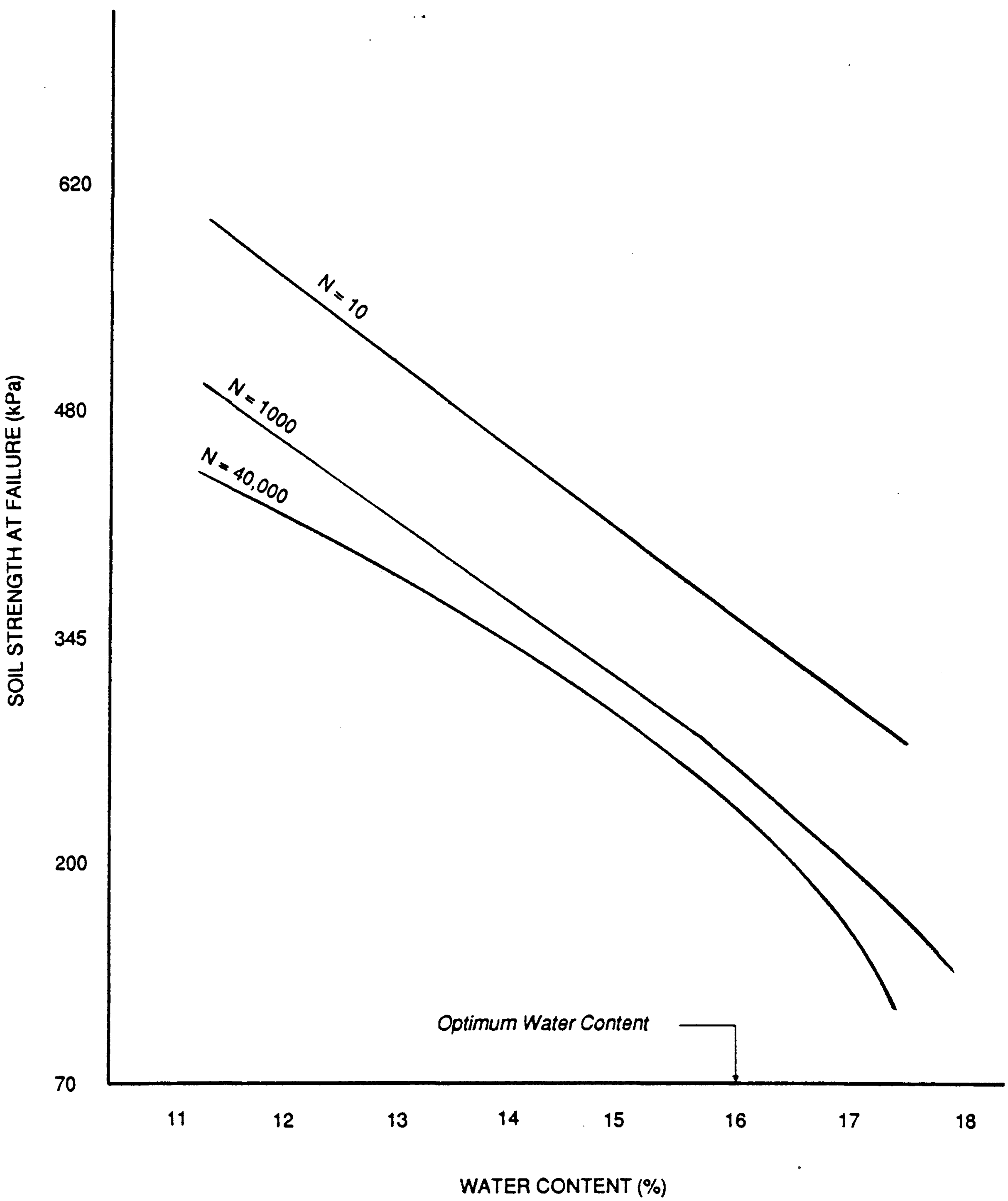
Subgrade soil water contents vary with depth below the road surface and with location in the road cross section. Typically, the upper subgrade beneath the centre of the road is driest with the subgrade becoming wetter towards the side slopes and with depth. Most heavy truck traffic travels along the centre of thin membrane pavements and gravel surface roads, where subgrade water contents are lowest and hence roadway strength the highest. If these trucks travel within the lanes, then the outer wheel paths fall above wetter, and hence weaker, soils. This variation in water content with position in the cross section partially explains the occurrence of subgrade failure in the outer wheel path before any other locations.

Figure 2 illustrates the soil strength at failure for a range of water contents and number of load repetitions to failure for an Indian Head Till compacted to standard Proctor maximum dry density. Indian Head Till is a medium plasticity silty clay matrix till containing some sand and gravel.

The variability in subgrade strength with water content is shown by observing Figure 2. This soil at 16 percent water content (optimum water content) can support 10 applications of a 360 kPa tire. The same soil at 13.5 per cent water content can support 40,000 applications of the same 360 kPa tire. This is the difference between significant subgrade failures under one day's traffic when the subgrade is at 16 per cent water content and no failure for a season when the subgrade is at 13.5 per cent water content.

FIGURE 2

SOIL STRENGTH AT FAILURE VERSUS WATER CONTENT FOR RANGE OF LOAD APPLICATIONS TO FAILURE OF INDIAN HEAD TILL



Source: Dr. E. Karl Sauer

5.4 Traffic Loadings

Truck weight is a major factor in the performance of roadway surfaces, particularly for thin membrane pavements and gravel surface roads. The stress in the subgrade soil beneath a tire load decreases with depth. Heavier gross loads cause high stresses to penetrate to greater depths.

The conceptual relationship of stress to depth, tire pressure and gross loads is shown in Figure 3. If the applied stress at any depth within the subgrade exceeds the strength of the soil, then failure will start to occur. If this applied stress greatly exceeds the soil strength, a rapid and major failure will occur after a few passes.

6.0 Traffic Loadings to Failure

6.1 Introduction

Very limited literature exists regarding the failure mechanisms in road surfaces which derive their strength from subgrade soil. Published literature largely focuses on the performance of structural pavements because these generally have the greatest economic significance to highway transportation.

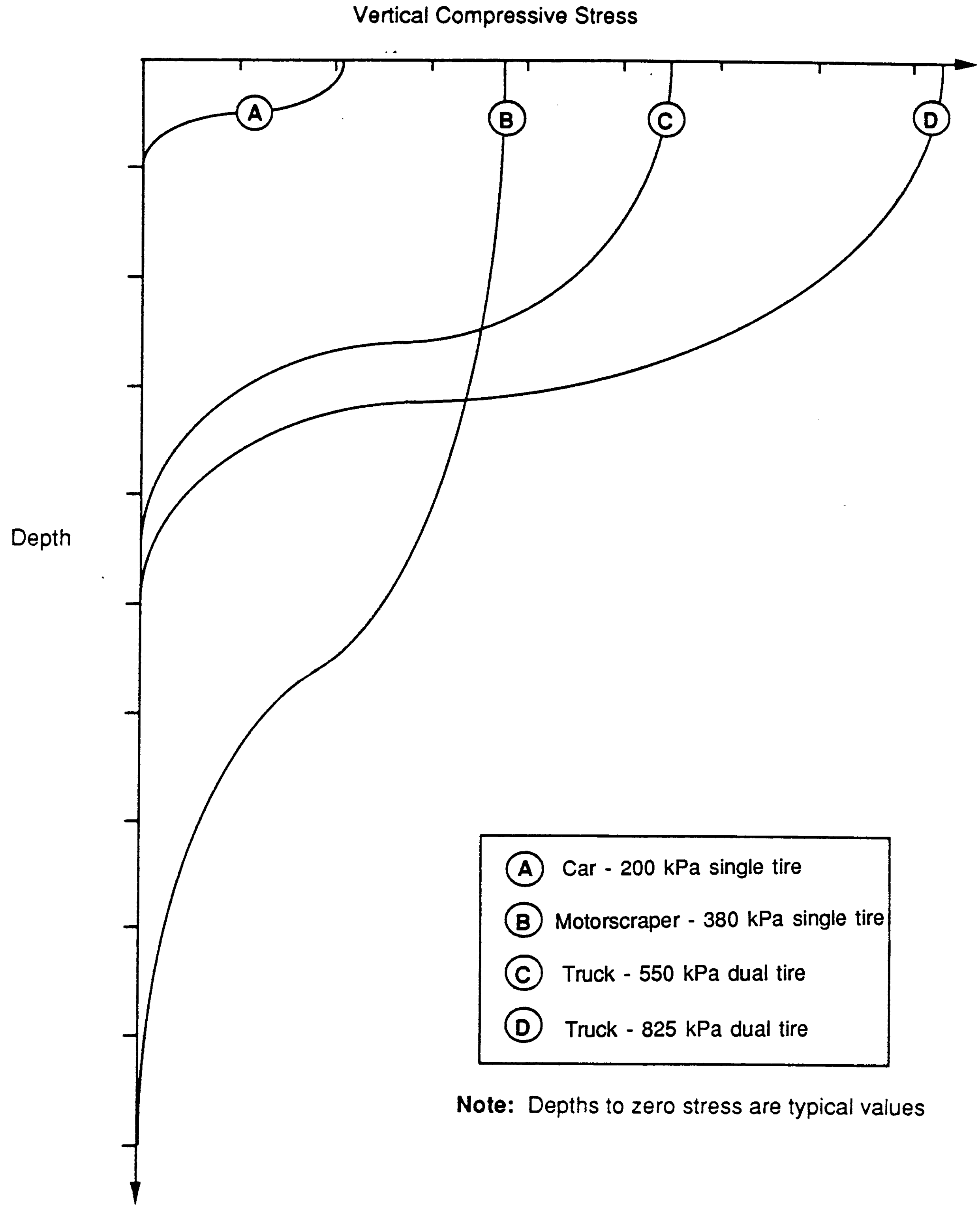
Information regarding traffic loadings versus roadway failure for thin membrane pavements and gravel surface roads was developed from a number of sources including: theoretical analysis of soil bearing capacity, historical road performance data, interviews with road maintenance personnel, pavement test track experiments and unpublished research.

6.2 Historical Roadway Performance

The historical performance of thin membrane pavements and gravel surface roads indicated that when traffic volumes (particularly truck traffic volumes) reach a certain level, serious and extensive failures occur. These failures are particularly prevalent when traffic volumes are concentrated over a short period of time, which is the situation for most grain truck hauls. These peaks often occur in the spring and fall when the roads are at their weakest, thereby compounding the problem.

The Equivalent Single Axle Load (ESAL), a procedure which relates the distress caused by any given axle weight to the distress caused by an 80 kN standard axle, is currently used for analysis of structural pavements. Pavement thickness is designed using traffic loading expressed in cumulative ESAL's for the design period. Any increase in truck traffic can be expressed as an increase in ESAL's, and the decrease in service life of the pavement under the higher traffic loading can be estimated from the design charts.

Figure 3
Stress Versus Depth Below Wheel Loads



Note: Depths to zero stress are typical values

In the case of the thin membrane pavement, or gravel surface road, the ESAL concept does not apply. The strength of the road surface is too variable to use the ESAL concept to express truck traffic loading. An extreme example of this strength variability is a two axle grain haul truck, which becomes stuck in ruts 100 mm to 150 mm deep on a gravel surface road recently soaked by rain. This same road performed without distress under 200 truck passes per day for several days in the week proceeding the rain, and when the subgrade was dry and hard.

The threshold loadings to failure concept appears to best explain the performance of these low strength roads. This concept is consistent with bridge design wherein sufficient strength is provided to support a maximum load. Any heavier load is likely to fail, or at least severely distress the bridge. These low strength roads are also subject to a failure or severe distress under a limited number of loads, much the same as an overloaded bridge.

6.3 Bearing Capacity Analysis

A theoretical analysis of wheel load stresses imposed on a subgrade by various truck weights was undertaken to examine the concept of threshold load limit. Typical grain truck weights were analyzed using two soil types (clay and till), each in weak and strong condition. Two criteria were used to assess the possibility of a single wheel load causing failure: plastic deformation and bearing capacity.

The stress/strain analysis using ELSYM 5, a multiple layer stress analysis program, indicated that legally loaded trucks using common tire pressure will cause a plastic deformation failure in subgrade soils compacted to standard Proctor maximum dry density at optimum water content. These are standard compaction specifications for new subgrade construction. The bearing capacity analysis also indicated single load failure for some of the load conditions analyzed. This latter analysis did not consider the effects of repetitive wheel loadings and dynamic loading effects. These two factors would likely increase the number of conditions where failure would occur.

These analyses indicated that the existing subgrades under thin membrane pavements and on gravel surfaced roads are stronger than the well compacted, moisture conditioned natural soils. The analyses clearly indicated a superior strength crust present in both thin membrane pavements and gravel surface roads. Interviews with road maintenance personnel confirmed that these roadways needed 5 to 8 years to achieve optimum performance. During this time the surface traffic gravel works into the upper portions of the subgrade forming this higher strength layer. Road crews reported scarifying road surfaces to hasten the formation of this layer.

6.4 Test Track Failure

Saskatchewan Highways and Transportation operates a full scale pavement test track in Regina. The test track is totally enclosed, allowing for controlled environment pavement testing. The test track is 40 metres. in diameter, with a pavement width of 4 metres. Different pavement and subgrade conditions can be constructed in 5 different segments around the track. The test load is applied to the pavement by wheels mounted on a radial arm with a centre pivot drive. The wheel configuration, tire type, tire pressure and wheel load can be varied.

Testing of a thin membrane pavement with a 40 kN legal load on an assembly with dual tires at 550 kPa (80 psi) tire pressure produced 50 mm deep ruts in less than 56 passes. The soil density and water content conditions met or exceeded new construction compaction specifications. This failure under uniform and ideal laboratory conditions demonstrated the fragile nature of the thin membrane pavement under repetitive loadings.

7.0 Threshold Traffic Levels

7.1 Value Selection

Following assessment of all available information, threshold traffic levels required to produce roadway failure were developed, based largely on expert opinion derived from the analyses described above and discussion with road maintenance crews. These threshold levels are expressed in terms of loaded axle passes per lane per day. The values were developed for two low strength roads and subgrade soil types. Table 1 summarizes these levels.

Table 1: Threshold Traffic Levels
(loaded axles/day/lane)

Road Type	Subgrade Soil Type Clay	 Till
Gravel Surface	50	100
Thin Membrane	40	80

When the loaded axles per day per lane exceed the threshold level, the road section concerned will experience serious and extensive failure. Should these values be exceeded with sufficient frequency, the road section becomes a candidate for upgrading to a higher standard and stronger pavement.

These threshold values were compared to the actual experience of SDHT for these road types. The average traffic on the thin membrane pavements is approximately 300 vehicles per day. With traffic split equally in each direction, and the typical values of 12 percent trucks and an average 2.5 axles per truck, the average thin membrane pavement carries approximately 45 axles per day. At this traffic level these roads generally perform well. Using the same traffic characteristics, 80 axles per day produces an estimated average daily traffic of 533. This closely corresponds with the SDHT criteria of upgrading thin membrane pavements when average daily traffic is approximately 500. A further review of problem thin membrane pavements indicated they typically had truck traffic ranging from 60 to 90 truck axles per day per lane. This is consistent with the threshold levels selected.

7.2 Applying The Concept

Where base truck traffic plus incremental traffic exceed the threshold value with sufficient frequency, roadway upgrading is required. For thin membrane pavements it was considered that more than two such failures per year would produce unacceptable driving conditions for most of the year. For gravel surface roads, which can be repaired more expediently, more than three such failures per year would be unacceptable as the road would be under nearly constant repair.

Figure 4 illustrates the application of this concept where the incremental traffic produces volumes exceeding the threshold limit loadings for two periods of the year.

8.0 Summary and Conclusions

Saskatchewan's low strength roads provide a cost effective road network on low volume roads. However, they are subject to rapid deterioration under concentrated truck haul when the subgrade soil is near optimum water content. A methodology was developed in this study, based on the concept of threshold loadings, to identify when these roads require upgrading to accommodate future increases in truck traffic. Additional research on the performance characteristics of the top layer of these roads and the peaking characteristics of grain truck traffic should be conducted to refine the methodology.

Figure 4
Seasonal Distribution of Truck Traffic