1. THE IMPACT OF HEAVY VEHICLE TRAFFIC ON ROAD PAVEMENTS

1.1 Background

The transport network in New Zealand compromises approximately 95,100 km of roads. About 12.5% or 11,900 km of these roads are State Highways managed by the NZ Transport Agency. State highways generally carry higher traffic volumes and are constructed and maintained to high design standards.

The remaining 83,200 km of roads are managed by local authorities. These roads carry lower volumes of traffic and accordingly they are designed to generally lower design standards.

New Zealand and Australia have led the world for many years in the design and management of low cost road pavements. This has allowed sealed road access to areas which would otherwise be serviced by unsealed gravel roads. Nevertheless, approximately 40% or 38,000 km of roads in New Zealand are unsealed gravel roads. The majority of these are rural local roads.

One of the largest challenges facing local authorities is the rapidly growing volume of heavy commercial vehicle (HCV) traffic being carried on roads which were not designed to carry this increased traffic. Predictions are for HCV traffic on rural roads to double in the next ten years. This is a result of more intensive land use activities, such as forestry, quarries, landfills or dairy farming.

Additionally there has been an increase in the allowable weight that HCV can carry with the introduction of High Productivity Motor Vehicles (HPMV). This has in turn resulted in increased axle loadings on some road pavements.

Local authorities are being faced with the need to make predictions of the impact of increased HCV traffic on their road networks and the funding required to maintain and upgrade the road networks to cope with this increasing demand.

1.2 The Function of Road Pavements

The road pavement must serve two basic functions: it must perform structurally and at the same time meet functional and operational requirements.

In terms of structural performance, it must be strong enough to support the axle loading from the heaviest vehicles (HCV traffic) using the road and the cumulative effects of the passage of these vehicles on the road. The surface must also be capable of resisting stresses imposed by axle loading in order to maintain its structural integrity. If a road surface is damaged and cracked by heavy axle loads, water can enter the underlying pavement layers, which weakens the pavement and can result in premature failure.

In terms of functional and operational performance, the road pavement must be wide enough and of suitable geometry to permit all vehicles to safely operate at an acceptable speed. The pavement must have a surface which has adequate strength, drainage, skid resistance, and visual delineation to ensure safe travel.

1.3 Characteristics of New Zealand Roads

The majority of New Zealand roads comprise either granular pavement layers with a thin chip seal or asphalt surface or unsealed gravel roads which have been built up over time. These have been designed and maintained to carry the loading imposed by the historically forecast traffic.

Chipseal surfaces are not considered to contribute structurally to pavement strength; however, an intact chipseal surface prevents the ingress of water into a pavement, with water having a negative impact on pavement performance, particularly of the subgrade.

Research since the 1960's by AASHTO, ARRB, Austroads and the NZ Transport Agency has shown that pavement deterioration of granular pavements is a function of the axle load applied to the pavement, the number of axle loads applied (expressed as Cycles) and the strength of the road pavement.[1]

This relationship between the load and the pavement structure is the key determinant of the rate of pavement wear. Pavement wear caused by the passage of HCV traffic depends not only on the gross weight of the vehicle, but also on the distribution of the vehicle weight onto the pavement. In particular it depends on:

- The number of axles on the vehicle
- The manner in which these axles and their wheels are configured into axle groups
- The loading applied to the pavement through each of these axle groups – the axle group load and the contact stress (governed by tyre size and pressure).

Figure 1 below shows the dispersion of the wheel load from a vehicle axle onto the underlying pavement and the imposed stress on the pavement layers.

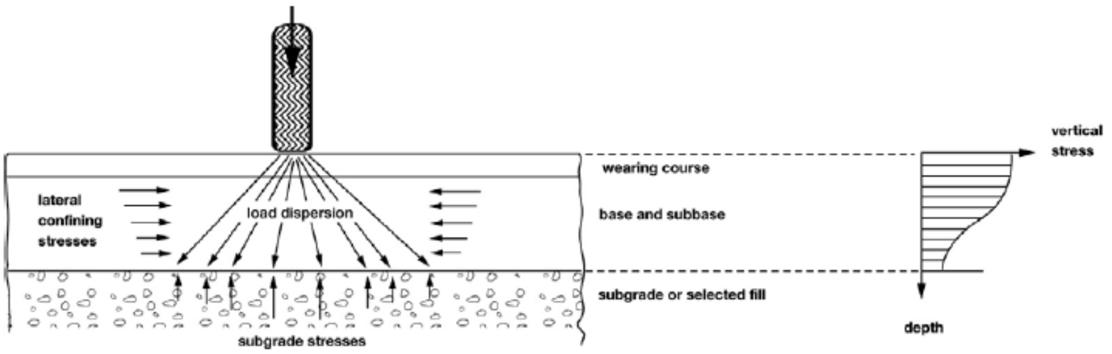

Figure 1: Stresses within a pavement under loading

Anecdotal evidence also indicates that the rate of pavement deterioration and the road maintenance costs increase with increased repetitions of axle loads on a road pavement and increased axle loads imposed by HCV traffic.[2]

Figure 2 below shows the typical road pavement performance over time.

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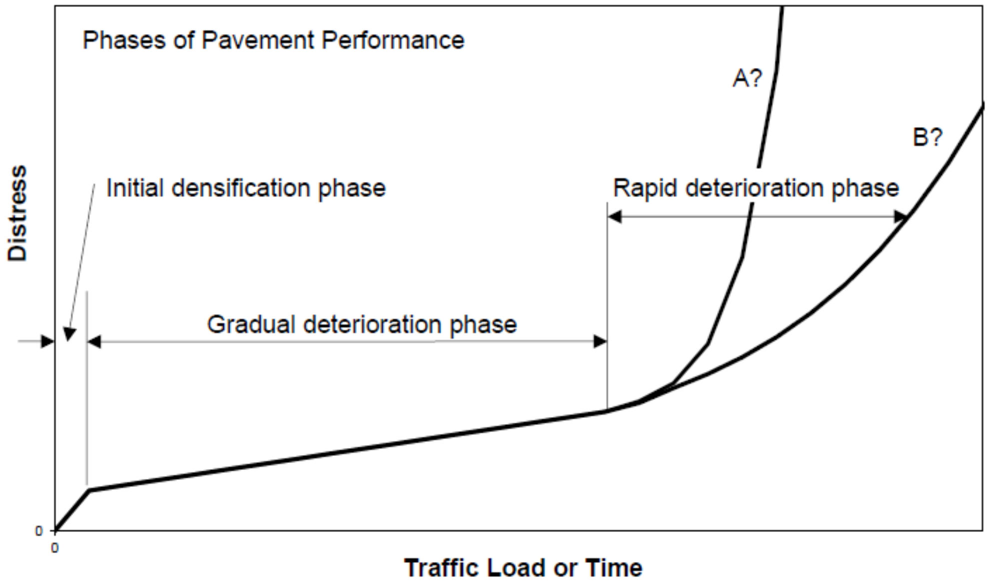
[1] Austroads Technical Report AP-T104/08 *Relative Pavement Wear of an Unbound Granular Pavement due to Dual Tyres and Single Tyres*

[2] Austroads Research Report AP-T216-13 *Estimating Accelerated Road Wear Costs Due To Increased Axle Mass Limits*



Over time, the road pavement slowly deteriorates during the gradual deterioration phase due to the wear caused by axle loadings imposed by HCV traffic. During this phase maintenance work carried out by local authorities will maintain the road in an acceptable condition. At some point in the life of the road pavement, the road condition reaches a point when rapid deterioration occurs due to structural failure of the road pavement. At this point the road pavement is no longer able to a carry the loads imposed by HCV axle loading and accelerated wear of the pavement occurs. This is shown as the rapid deterioration stage on Fig 2. At this stage the pavement has reached its terminal condition and the road pavement will require reconstruction or rehabilitation to restore the road pavement structural capacity.

Road pavements are designed to carry the forecast HCV traffic and to operate in the gradual deterioration phase. If the pavement loading increases due to increased HCV loading, this will shorten the gradual deterioration phase, which in turn brings forward the rapid deterioration phase of the pavement. The result is a corresponding decrease in the pavement life. As a result, the amount of maintenance required to maintain the road in acceptable condition will increase substantially, and the pavement will require reconstruction or rehabilitation to strengthen it to carry the additional loading earlier in the life of the pavement.

As outlined above, the axle loading applied to road pavements due to HCV vehicles contributes disproportionately to the pavement wear. Unless the affected road pavements are designed to carry the extra loading, the pavement will suffer accelerated deterioration which will result in the need to reconstruct or rehabilitate the road pavement, rather than maintaining the pavement with periodic resurfacing and maintenance. The increase in pavement maintenance and reduction of the pavement life is directly proportional to the pavement deterioration, which in turn is proportional to the HCV loading on the pavement.

Where the axle loading due to HCV movements on a road increases, the road's structural wear will generally increase in proportion with the increasing cycles of axle loads on the road pavement. A substantial increase in axle loading from HCV traffic on a road that is not designed to carry the additional axle-loading will result in multiple adverse effects in the form of:

- increased routine maintenance and resurfacing
- reduction in the level of service (road quality) as the road pavement deteriorates
- reduction in the pavement life

- increased reconstruction and/or rehabilitation costs due to the increase in required structural capacity
- increased lateral instability and damage along roads due to heavy wheel loads tracking close the edge of the road
- added traffic effects and cost of control measures (eg lower speed limits, signage, turning lanes, lane widening, islands, pedestrian paths or cycleways, removal of spillage or detritus to maintain safety and restore traffic flow

1.4 Road pavement design

Design of road pavements in New Zealand generally adheres to the guides produced by Austroads (2012) and the New Zealand Transport Agency's Supplements to Austroads (Transit 2007 for new pavement design, Transit 1999 for rehabilitation). These documents identify the methods by which the design traffic and the pavement structure are determined.

The design life of a pavement is typically chosen as 25 years, based on the period over which the expected traffic is calculated. The total design traffic loading may be applied earlier than 25 years if the design assumptions are not met and thus the theoretical life of the pavement will be less. Conversely, the pavement may not be subjected to the design traffic in the design period and the achieved life may theoretically be greater.

The design traffic is the product of a number of factors: typically the average daily traffic (averaged over a year as the annual average daily traffic), the percentage of heavy vehicles, the axle load per heavy vehicle, and the growth rate. Other factors, including the design period, the average number of axle groups per heavy vehicle, lane distribution and the direction factor, need to be considered in calculating the design traffic.

Design traffic is calculated by quantifying all the loading from heavy vehicles into Equivalent Standard Axles (ESA). This is achieved by determining the allowable Standard Axle Repetitions (SAR) before expected failure, based on the ratio of the load on an axle group to the standard load for an axle group to the power of an exponent. This is expressed in the equation: $SAR=(L/SL)^m$ where L is the load on the axle group, SL is the standard load on the axle group, and ^{m} is the load damage exponent.

The load applied by a single axle with dual tyres subjected to a load of 80 kN with an individual tyre contact area of 0.0267 square metres is 1 ESA. With a load damage exponent of 4, a doubling of axle load has a sixteen-fold increase on the pavement wear induced by the axle.

The standard loads for various axle groups that cause the same pavement wear as a single standard axle are reproduced from Austroads (2010) in Table 1 below. Austroads assumes that roads with the same surface deflection will suffer the same pavement wear, after the SAR value for the relevant case is taken into account.

Table 1 Axle group loads

Axle group type	Load (kN)
Single axle with single tyres	53
Single axle with dual tyres	80
Tandem axle with single tyres	90
Tandem axle with dual tyres	135
Tri-axle with dual tyres	181
Quad-axle with dual tyres	221

1.5 Road pavement wear effects of heavy vehicle traffic

Where the number of vehicle movements on a road increases, the structural wear will generally increase in proportion with the increasing movements if the axle loads remain constant. By contrast, the load-wear-cost relationship results in an exponential function that means even small increases in individual axle loadings induce disproportionately large decreases in road pavement structural life.

The anticipated pavement damage caused by different axle configurations and axle weights can be determined by converting the axle loading to an equivalent number of passes of the standard axle using the fourth power relationship. As a result of extensive full-scale road testing[1] in the USA in the late 1950s on heavy-duty structural asphaltic pavements, the pavement damage caused by an axle passing over any form of flexible pavement has traditionally been considered proportional to the fourth power of its weight relative to a standard axle.[2]

Rural roads usually have narrow traffic lanes and a surface water channel on each side of the road. This road construction is adequate for low levels of heavy commercial traffic. With increased pavement loading, however, the additional loading often over-stresses the pavement edge, resulting in loss of edge support followed shortly thereafter by edge break and shear failure, with associated substantial impacts on maintenance costs. Lane widening may be necessary, as truck and trailer units tend to track along a wider traffic path on corners than normal traffic, thus requiring a wider traffic lane than lighter traffic and placing greater stresses on the road edges.

1.6 Determining the impact of heavy vehicle traffic alternative loadings

A pavement impact assessment should be undertaken where a proposed increase in heavy vehicle traffic equals or exceeds 5% of the existing ESA loading on the road. A design horizon of at least twenty years should be adopted for the pavement life assessment. The 30-year Long Term Plan horizon is likely to be appropriate, and a longer horizon can be appropriate in some circumstances. In practice it is very straightforward to allow modelling to be projected out to 50 years or more in order to carry out a sensitivity analysis for the impact of any given cut-off date on the associated net present value calculation of future life-cycle costs. Where only a small number of roads is being considered, a long evaluation period is often necessary because of the irregular (markedly stepped) profile of the cumulative cost curve as the date for each life-cycle renewal expenditure is reached.

A pavement impact assessment should consider the surface condition and structural capacity of the pavement, and the effect on the forward works programme. Surface condition should be assessed, preferably from high speed data surveys as well as visually, and recorded with detailed location data. Structural capacity can be assessed readily with measurement of pavement deflection. Increased deflection before and after a temporary increase in loading of the pavement can be used to quantify any evidence of pavement deterioration.

Measured change requires falling weight deflection structural evaluation for the affected road prior to the increase in heavy vehicle traffic, as well as subsequent to that increase. Comparison of the change in

[1] AASHO Interim Guide for the Design of Flexible Pavement Structures. AASHO Committee on Design, Oct. 12, 1961
[2] A standard axle has been defined as a twin-tyred single axle loaded to 80kN or approximately 8.2 tonnes.

deflection, considering any increase in pavement deflection and allowing for any seasonal variation in moisture content, allows the remaining pavement life to be recalculated. Hence the cost of the additional traffic can be determined from the difference in net present value between the respective forward work programmes.

While it has been widely recognised that routes carrying increased traffic loadings will incur additional road pavement wear and associated additional costs, quantification of such wear has, until very recently, been contentious and uncertain. Advances in pavement asset management technology and more comprehensive databases available for many authorities' pavement networks now enable relatively reliable quantification of pavement structural wear and the marginal cost of increased loading. Once the current and proposed future axle loadings are defined it is possible to consider both the (i) "*bring forward"* costs of the added wear and (ii) *consumption of existing assets* to calculate equitable apportioning of those marginal costs.

Pavement wear and associated costs can be calculated, once the distress mode and relevant critical layer are identified and the relevant load damage exponent determined, where the region has a suitable database of pavement structural information (FWD data).

For many low volume roads, however, such a database may be unavailable and this procedure could be disproportionately costly for the levels of service and likely maintenance costs if the length of the affected route is short. The methods adopted to determine the cost of the impact of heavy vehicle traffic on low volume road pavements need to be appropriate to the use and requirements of the road.

Assessing impacts on the Forward Works Programme involves a comparison of the nature and timing of roadworks required with and without the extra heavy vehicle traffic, based on predicted ESA loads. Forecasting required pavement works requires a sound knowledge of the issues involved, solid data and good professional judgement. RAMM condition data is often not sufficient on its own, for this purpose.

Works to provide heavy vehicle access, such as widening, corner radius smoothing or pavement strengthening, can be identified separately from the load related damage. Routine resurfacing and maintenance costs need to be allocated with appropriate consideration of potential damage caused by all other road users.

1.7 Assessing the Impacts of HCV Traffic Loading on Road Pavements

Calculation of the remaining life of the road pavement can be conducted as a desk top analysis from records of the existing pavement design, current pavement loading (ESA), pavement age, and past traffic The remaining life (in ESA's) is the difference between the pavement design life (in ESA's) and the cumulative past traffic. The calculation of pavement life can be further refined using Falling Weight Deflectometer (FWD) testing to determine the existing pavement strength and to calculate the remaining life.

New developments or land use activities can generate increases in heavy commercial vehicle traffic which may have adverse impacts on road pavements. Typical impacts resulting from an increase in the number and /or weight of vehicles using the road include:

- a need for extra pavement width
- a change in surfacing type or pavement thickness
- an increase in maintenance, and
- a reduction in the pavement life, requiring road pavement upgrading, which may include strengthening works or reconstruction of the pavement.

The pavement assessment needs to consider the impact of the additional HCV traffic loading on the road pavement and to determine the extent, timing and costs of:

- pavement upgrading, such as road widening
- additional maintenance
- pavement strengthening and/or reconstruction.

Procedures for assessing the impacts of HCV traffic on road pavements are outlined in the Queensland Government Department of Transport and Main Roads "Guidelines for the Assessment of Road Impacts of Developments." These guidelines are consistent with the road pavement design and maintenance principles adopted throughout New Zealand, including:

- NZTA Economic Evaluation Manual (EEM)
- NZTA Supplement to Austroads Pavement Design Procedures
- Austroads Guide AGP-T01-09 Pavement Technology Part 1 Introduction to Pavement Technology
- Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design
- Austroads Guide to Traffic Management AGTM12-09 Traffic Impacts of Developments

The following steps outline the process described in the Queensland Guideline to assess the road pavement impacts due to increased HCV traffic generated by a development or changed land use activity:

Identify the Land Use

1. Such as forestry, quarrying, dairy farming, dry stock beef raising, stock finishing, sheep farming, horticulture, viticulture, arable, etc.

Determine the traffic loading

2. Determine the current road network affected by the proposed activity, and existing HCV traffic and pavement axle loading (ESA).

> Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design; NZTA Supplement to Austroads Pavement Design Procedures

Calculate remaining pavement life

3. Determine the condition of the existing road network and estimated remaining pavement life from road asset information held. Use RAMM data, maintenance records, as-builts, distress test results, condition data, deflection tests and unit rates for renewals.

Determine new HCV traffic

4. Determine the HCV traffic and pavement axle loading (ESA) generated by the proposed activity. List the types and number of HCV and calculate the total ESA generated.

Compare existing and new HCV traffic

5. Carry out a 'with" and "without" proposed activity HCV assessment for the pavement design period, based on likely traffic growth rates in both cases within the design period.

> Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design; NZTA's Supplement to Austroads Pavement Design Procedures

Determine remaining pavement life

6. Determine the remaining life of the pavement based on information held or from FWD testing of the road pavement. If the axle loading (ESA) is increased by more than 5 % above the existing loading, the increase will result in a reduction in the pavement life.

Estimate new works schedule

7. Predict when the road pavement will require upgrading and/or strengthening due to the increased axle loading (ESA) on the pavement.

Calculate new works programme costs

8. Predict the cost of pavement upgrading and/or strengthening due to the increased loading generated by the development /activity. Establish if there is a change in the vehicle mix using the road that may require widening of the pavement or surfacing, and estimate the cost of the upgrading works and the associated maintenance and resurfacing throughout the design period.

Austroads / NZTA State Highway Geometric design requirements, for the appropriate traffic volume.

Calculate the added cost from new HCV traffic

9. Predict the total cost of routine and programmed maintenance in each year within the design period, with the current traffic (ESA), and with the current traffic plus the additional traffic (ESA) generated by the development / activity. Discount to determine net present value.

The above analysis should determine the extent to which any additional pavement upgrading works are required to accommodate additional HCV traffic generated by a development or changed land use activity.

In some cases the pavement may have reached the end of its design life, but it may continue to operate satisfactorily with the current traffic volume. However, an increase in the pavement axle loading due to HCV traffic generated by a development or activity might not be able to be sustained by the pavement. In such cases a full pavement evaluation using FWD testing is recommended to assess what pavement upgrading and strengthening is required to carry the additional pavement loading from the additional HCV traffic generated by the development or activity.

The results of the pavement impact assessment give an indication of the road upgrading or strengthening works and maintenance requirements (including resurfacing) required as a result of the increased pavement loading from HCV traffic generated by the development or activity.

The timing of the upgrading works depends on the residual strength of the existing road pavements and the increased axle loading on the pavement. In some cases the upgrading works need to be undertaken prior to commencement of the development or activity. However, if the existing road has sufficient strength to carry the additional axle loading, the upgrading works may be deferred. In these cases it is recommended that monitoring of the road pavement is carried out and the upgrading works are implemented before the road pavement reaches its terminal condition.

The impacts on bridge and other structures within the road corridor also need to be considered in cases where the additional axle loading imposed by HCV traffic generated by developments and changes in land use activities exceed the capacity of existing infrastructure.

1.8 Pavement Wear Calculations

Simplified vs Detailed Approaches

The spreadsheet calculation example in Appendix A demonstrates the calculation procedure using the Austroads Simplified Approach, as well as establishing a template for application elsewhere.

Simplified methods may suffice for specific instances of activities affecting pavement wear. However the nature of pavements in practice presents a need for due consideration of the level of detail warranted. A pavement is an assemblage of particulate materials that will vary in localised particle size distribution. As a result the pavement will have variations in stiffness within any constituent layer that can vary by an order of magnitude. The pavement will contain multiple layers with variations in stiffness and thickness.

The result will be variations in the pavement life in terms of ESA along any one road where the traffic is constant that can be several orders of magnitude. The cumulative distributions of pavement life highlight the importance of identification of valid structural treatment lengths. Homogenous sub-sections within each road will act in a similar fashion and will require a similar thickness of treatment for rehabilitation.

Effective sub-section identification for each road can reduce the variation in pavement life from two or three orders of magnitude to a typical variation of about one order of magnitude. A lesser variation should not be expected within a normal practical treatment length, which will encompass at least 100 m of pavement and usually more.

The consequence is that rehabilitation triggers are set based on a specified percentage of a given treatment length reaching a terminal condition. In practice the allowable percentage in terminal condition becomes a criterion beside maintenance cost in the selection of pavements for rehabilitation. The allowable percentage in terminal condition is, therefore, a key parameter in the FWP calculation.

If the identification of valid structural treatment length sub-sections has not been done in accordance with best practice, the modeled life of a pavement sub-section can change by a factor of five, depending on the adopted percentile for testing. This can have a massive effect on the NPV calculation. Some of this uncertainty can be offset by ensuring consistency, using the same assumptions and approaches for both original and altered activity calculations, but for equitable apportionment where costs are significant, detailed best-practice structural evaluation, rather than simplified approaches, should be considered.

REFERENCES

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AUSTROADS TP-T195-12 Improving Cost Allocation By Road Type

AUSTROADS Pavement Technology Guide Part 1 And Part 2

AUSTROADS Guide To Traffic Management Part 12