

APPENDIX H: Pavement Structural Damage from Single Large Tyres

Pavement Structural Damage from Single versus Twin Tyres

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GeoSolve Ltd

AT A GLANCE

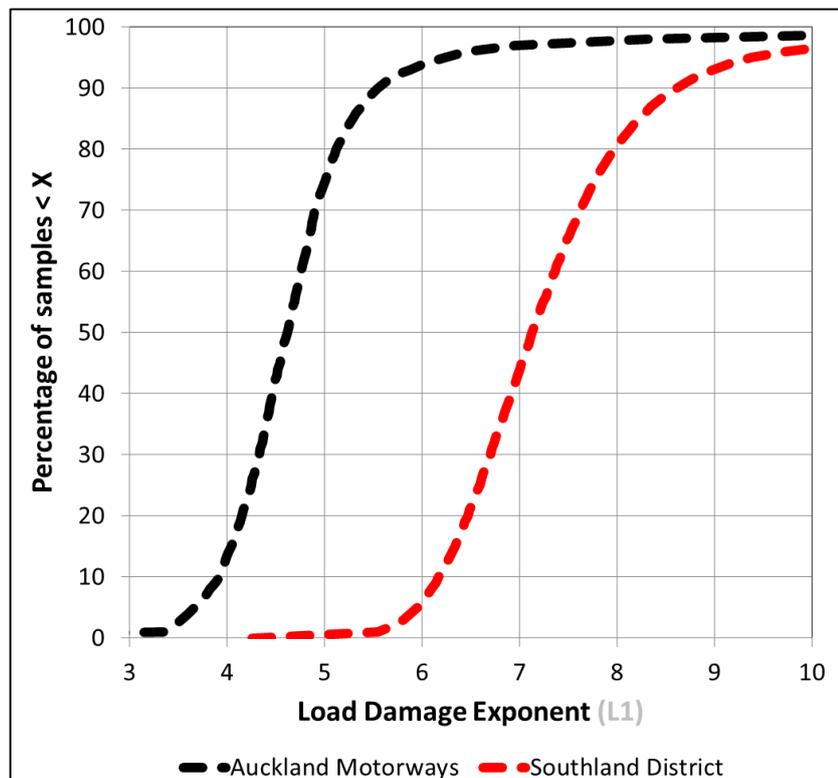
A detailed study of the performance of low-volume roads in New Zealand has been carried out, using in situ testing of in-service roads and an evidence based procedure for the practical evaluation of pavement structural damage from alternative tyre configurations and loadings. The issues studied are the effects of increasing loads on specific axles or using single instead of twin tyres as those changes tend to be more significant than increasing the gross mass of vehicles where the number of axles can be increased also.

The study is different in that it uses in situ testing of in service local roads in their exposed environments rather than accelerated testing of artificial test tracks. It systematically quantifies the substantial increase in damage that can be expected on unbound granular basecourses with thin seal surfacing where pavement deflections are moderate or high. It is not appropriate to draw on overseas studies of pavements with low deflections or where thick structural asphalt is used for surfacing.

One key factor for determining the relative damage imposed by a given increase in load on a single tyre is the “load damage exponent” from which the increased cost of structural wear is readily quantified.

The load damage exponent must relate to the layer which will govern the pavement life (first to reach a terminal condition) and the distress mode occurring in that layer.

The cumulative distribution curves for load damage exponents for the Auckland Motorways and all Southland District Roads tested over the last two decades, provide definitive evidence that the load damage exponents for each network differ substantially. Advanced statistical analysis methods developed and refined very recently, for the first time enable RCA’s to readily quantify cost implications of any proposal for increased loading on the entire network, or on individual roads, in a rigorous and justifiable manner.



Pavement Structural Damage from Single versus Twin Tyres

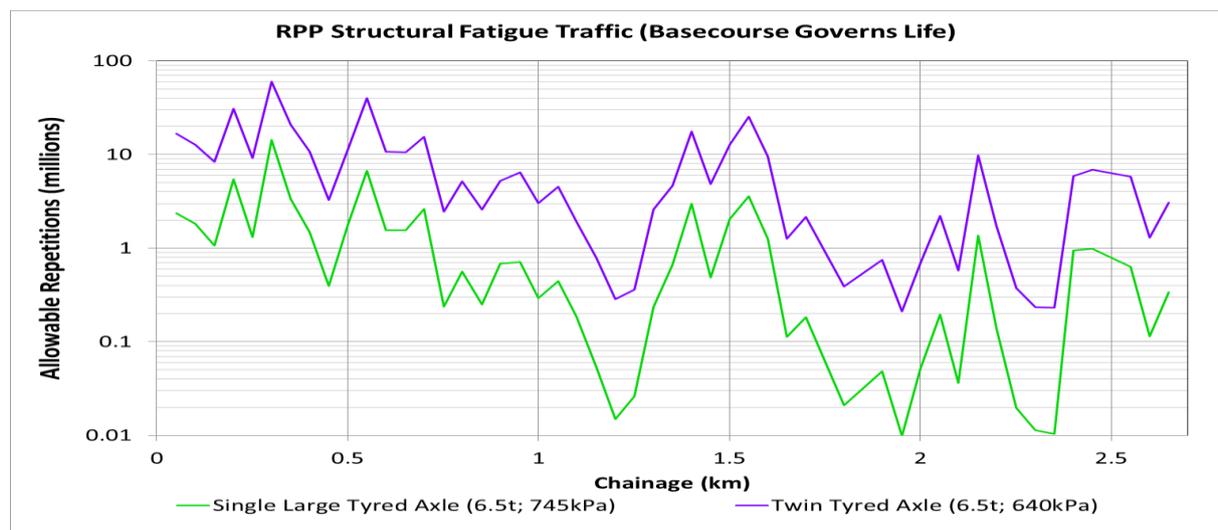
ABSTRACT

An issue arising for local authority asset managers is whether the same axle load with customary tyre pressures, results in more damage from single large tyres than from twin tyres.

Detailed analysis of local roads has been carried out for Southland District, to establish a reliable pavement life model for its unbound granular pavements, using regional precedent performance (RPP) of the entire network. This calibrated mechanistic model enables comparison of the damage from alternative axle configurations, and one road, nominated as a representative case for local low volume unbound granular pavements has been examined in detail.

Structural analysis of this road, when considering only the subgrade (as with the Austroads method), indicates there is little difference between the two axle configurations (single 7.2 t versus twin tyres with 8.2 t) in terms of expected number of axle load repetitions until a terminal condition is reached.

However, the basecourse of this road is only of moderate quality and forms the critical layer (governing pavement life as it has the capacity for lesser load repetitions than the subgrade). Much of this specific road indicates a tenfold decrease in pavement life when changing to a single large tyred axle as shown below:



In Southland's low volume unbound granular pavements where the critical layer may be either the subgrade or one of the aggregate layers, the decrease in allowable repetitions for a single tyre will alternate between a factor of about 1 and 20 or more. The calculations are straightforward for this network because a calibrated mechanistic model has been developed. These graphs (or an average damage factor and/or cost consequence for each road) can now be readily generated for the entire network, allowing informed assessment of single tyre damage or any other set of vehicle/tyre configurations, from first principles, rather than empirically.

The prediction of pavement performance based on mechanistic structural analysis provides reliability that cannot be obtained using the empirical "Structural Number" approach now discouraged by US authorities (NCHRP).

Summary

Various studies have concluded there are only minor differences in pavement wear for single large tyres versus the same load on twin tyres. However, these studies mostly relate to (i) accelerated trafficking in protected environments (ii) thick structural asphalt pavements and (iii) subject to heavy traffic loading. Because few existing pavements in Southland District are in these categories, a study has been carried out on what is expected to be a representative, in-service unbound granular pavement with thin seal surfacing designed for low-volume traffic.

The study, comparing damage from a standard twin tyred axle to a single large tyre, has been carried out using state-of-the-art mechanistic analyses to determine what impact this arrangement (and others like it) will have on the deterioration rate for a given pavement. The proposed technique (using stresses and strains in each pavement layer) reliably quantifies specific load damage exponents and consequent pavement wear under the prescribed axle load(s) or load combination. Pavement fatigue parameters have been calculated based on regional precedent performance of the network. Variables including relevant heavy vehicle types, lane-width, climate, subgrade characteristics, aggregate sources, as well as customary construction and maintenance practices, are all inherently taken into account to some degree with this method. The distinct advantage of this technique over traditional methods (such as accelerated test track loading in the CAPTIF environment) is the ability to incorporate in-service precedent performance of all roads in any given region, for more reliable forecasting of future performance. The internationally peer-reviewed and endorsed methodology is the first of its kind globally, and provides an economic, rapid, and sound basis for HPMV decision making.

The calculations confirm that for many roads (particularly where there is thick structural asphalt and where the subgrade governs the life of the road) it can be reliably established that for the same axle load, the number of passes, before structural rehabilitation will be required, changes minimally when using single large tyres compared to standard twins with similar axle loads. (Damage ratio of about 1).

However, in a flexible granular pavement where the subgrade is deep and an unbound basecourse with thin surfacing forms the top layer (and governs the life of the pavement), the damage ratio can easily reach 4 or more. The increase in cost from road damage will not be to the same ratio. For example, if the subject road has over 100 years structural life with the twin tyre loading, net present value cost consequences of a change to single large tyre with the same load are minimal. However, if pavement life is only 20 years, the Forward Work Programme will be significantly affected. (Costs of structural rehabilitation in this case will be "brought forward" from 20 years to 5, hence NPV cost consequences will be substantial.)

For this reason, the cost consequences of two alternative tyre configurations (twin versus single) cannot be computed in isolation. The tyre condition, route and traffic intensity, are critical inputs. The tyre inflation pressure is also a key factor and the other parameters required for each treatment length on the route are (i) the mode of distress that will cause a terminal condition, (ii) the layer that first reaches that terminal condition, (iii) the pavement layer fatigue criteria and load damage exponent for that layer/ distress mode (iv) the life of the entire treatment length under both loading scenarios. Most of the necessary input data for this region are readily available in RAMM and this can now be used with specifically developed software to readily compute the cost consequences of any alternative loading/tyre configuration scenario.

Homestead Rd, nominated as a representative unbound granular pavement, gave a damage ratio of 3.7 (for 7.2 tonne single versus 8.2 tonne twin tyred axle) using customary tyre pressures for trucks. If the same load is used on each axle, the damage ratio is 10 or more. The high values are primarily due to the unbound basecourse being the critical layer (governing pavement life). If the subgrade happened to be the critical layer, the difference in damage imposed by either axle at the same load would be much less.

Introduction

Single axles with “single large” tyres¹, or “super-single” tyres², are used by heavy commercial vehicles (HCVs) as a more economical alternative to standard twin-tyred axles. Concerns have been raised on appropriate road user charges or weight limits for such tyres in view of perceived higher rates of pavement deterioration³ expected from their use.

For unbound granular pavements, Austroads determines the equivalency of various axle types from the relative deflection induced under the respective loads and inflation pressures, assuming each footprint will exert uniform stress, and using a load damage exponent of 4.

Using Weigh-in-Motion data located on Auckland’s southern motorway and applying Austroads power laws, Hudson & Wanty⁴ concluded that heavy commercial vehicles with 6 or more axles using single tyres could cause damage up to 60% more when the 4th power law is used⁵ and up to 180% more when a 7th power law is considered, compared to the same load on twin tyres.

However, those exponents apply only for specific forms of pavement. A more detailed assessment of damage caused by single tyres using in situ testing from a New Zealand network which has suitably comprehensive information on pavement structural capacity, is provided in this article.

Previous Work

A major European study (COST 334) was carried out over a decade ago comparing large singles and twin tyred axles subject to the same load. However, for European pavements the average thickness of structural asphalt is 119 & 218 mm for design traffic loadings of 1 & 10 MESA respectively.

Unsurprisingly that study found that for a given total load, varying the contact area (wide single versus thinner twin tyres) on such a stiff load-spreading layer caused only minor change in pavement wear. A summary by Cebon⁶ indicates a range of results for the relative damage of single to twin tyres under the same load (the second column in the following figure). This indicates a wide range, for which the median appears to be a factor of about 2.5 for structural asphaltic pavements.

¹ Single large tyres are defined by NZTA as having width of at least 330mm and a rim diameter of at least 24 inches, or width of at least 355mm and a rim diameter of at least 19.5 inches

² NZTA refers to super-single tyres as those larger than 450 mm width. However, US and South African sources refer to “wide base tyres” or “super singles” as all tyres of at least 330 mm width.

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³ The use of super-single tyres requires a lower maximum axle load of 7200kg for a single axle set compared to 8200kg allowed for twin-tyred axles (NZ Transportation Agency, 2013).

⁴ (Hudson & Wanty, 2014) highlighted a discrepancy in the maximum loads for super-single tyres in the tri-axle and quad-axle configuration set by NZTA (NZ Transportation Agency, 2013), where the same limit is used for both twin and super single tyres (therefore assuming the same damage for both axle types).

⁵ Austroads Guide to Pavement Technology – Part 2 Appendix I.

⁶ Cebon, D 1999, [Handbook of vehicle-road interaction / David Cebon ... - Trove](#)

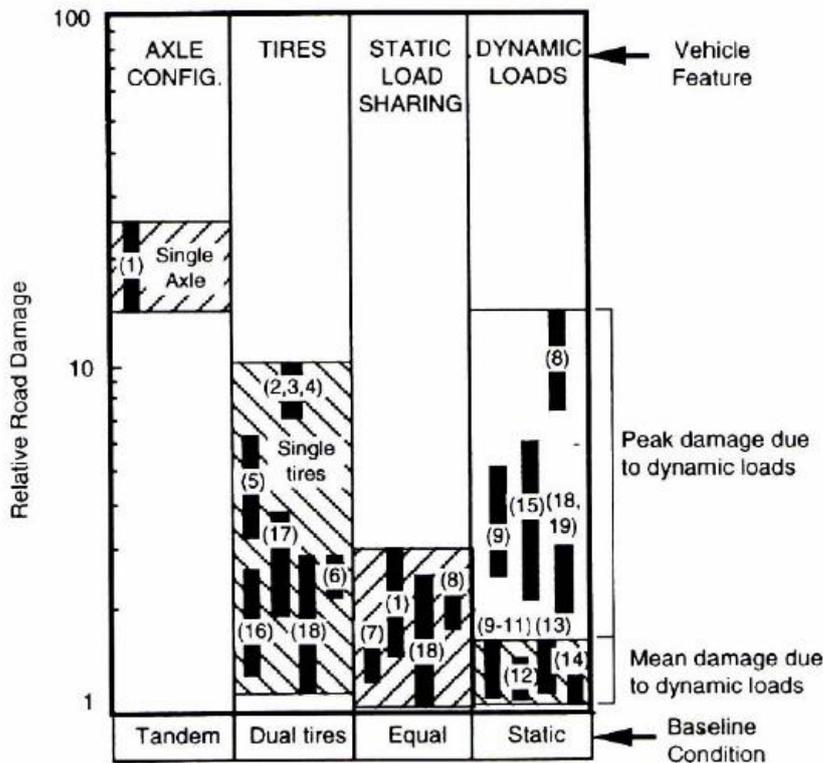


Figure 1 - Damage ratios from the same load applied to different axles, from previous studies. (Structural asphaltic pavements)

Damage ratios are largely controlled by load damage exponents for which values of 4 to 7 are indicated by Austroads for unbound granular pavements. Accelerated pavement trafficking trials⁷ have reported load damage exponents in the range of 1.1 to 3.4 for local materials. These trials used (i) an artificial environment (ii) only one measure of distress (vertical surface deformation) and (iii) deformation was extrapolated rather than taken to a terminal condition. Because such low results are not consistent with internationally recognised ranges, and were not consistent with findings for in service pavements, re-analyses of these trials were carried out using (i) widely used software that correctly accounted for non-linearity of layer moduli (ii) recognised modular ratios between successive unbound granular layers, and (iii) non-linear projection to a terminal condition. This procedure resulted in average load damage exponents of about 8, for the same data.

A concise and very pertinent overview of twin-single tyre configuration effects is contained in Attachment 2, from the footnote reference.⁸ Key findings are summarised in the conclusions below.

Other relevant research is an Austroads study⁹ of damage from single versus twin tyres which was carried out in an ALF trial using unbound granular pavements with thin seal. The accelerated trafficking used vertical surface deformation as the primary measure of wear and a single pavement type under controlled Australian conditions with new high quality basecourse, the same material as subbase and

⁷ Arnold G, Steven B, Alabaster, Fussell A (2005). Effect of pavement wear of increased mass limits for heavy vehicles- Concluding Report Land Transport New Zealand

⁸ NVF Committee Vehicles and Transports, 2008. Road Wear for Heavy Vehicles. Report 08/2008 <http://www.nvfnorden.org/lisalib/getfile.aspx?itemid=261>

⁹ Yeo, R. (2008). Relative Pavement Wear of an Unbound Granular Pavement due to Dual Tyres and Single Tyres

compacted sand subgrade. This produced a moderately low deflection (0.7-0.8mm) under a 40 kN FWD load. Similar deflections are obtained in many of the highways in New Zealand, but much higher values are common in Southland District.

Deflection versus Stresses and Strains

The Austroads method for determining damage uses standard axle repetitions (SAR), defined as the ratio of applied axle loads to reference load is presented below.

$$SAR = \left(\frac{Load_{axle\ group}}{Load_{reference\ load\ for\ axle\ group\ type}} \right)^{load\ damage\ exponent}$$

On linear elastic unbound granular materials, Austroads considers that the above load ratio, can be determined from the ratio of pavement deflections under the corresponding loads. However, (Ullidtz, 1987) demonstrates with worked examples that deflection criteria, although simpler, are not compatible with the more fundamental strain criteria, stating: *“The process of calculating the stresses or strains complicates the structural evaluation compared to just using the deflections directly. But with the availability of modern micro computers, there is really no excuse for not doing it.”*

Although contrary advice is given by Austroads for unbound pavements, Austroads does at least require comparison of strains in the critical layers of pavements with bound layers.

Damage by Single Tyres

The structural damage imposed by single tyres on pavements was assessed by comparing the vertical strains at the top of the subgrade and within the basecourse and subbase layers under the two axle types. This was done using University of Sydney’s Finite Layer Elastic Analysis (FLEA5) software and DynELMOD. The DynELMOD program is basically the ELMOD engine (which has the advantage of modelling the non-linear elastic response of the pavement subgrade under given loadings) but allows more generalised treatment of dynamic response and non-linear moduli as they may be either stress or strain dependent as well as allowing the dependency to be either hardening or softening.

Falling-weight deflectometer (FWD) testing data from a section of Homestead Road nominated by local Council representatives was chosen for the study.

Tyre Size and Pressure

One implication of the use of the stress and strain criteria for pavement damage is the effect of tyre pressure on pavement damage, which is ignored in the Austroads deflection based method, but in mechanistic analysis 80 kN axle with twin tyres at 750 kPa are standard. The South African design standard is 80kN axle twin tyres at 520kPa. NZ Benkelman Beam is 80 kN, 420 kPa (implicit from contact area). Australia models the 80kN Benkelman Beam tyres at 580kPa.

Typical tyre pressures (customarily reported in psi within the tyre service industry) were found to be highly variable across various provinces, with enquiries from the service providers returning customary inflation ranges between 586kPa (85 psi) to 620kPa (90 psi) for twin tyres and 648 kPa (94 psi) to 724 kPa (105 psi) for single large tyres in Otago and Southland. Milk tankers, because they have no backload, use slightly lower pressure (586 kPa). Some logging trucks adjust pressures (Bigfoot Pressure Adjustment) on their driving wheels. Some buses adopt single large tyres at the rear beneath the engine, and these are typically at 830kPa (120psi). This is a substantial increase. Additionally, industry advice is that 20 kPa (3 but up to 5 psi) should be added for in-service temperature conditions. The pressures modelled in this assessment are shown in Table 1.

Table 1 –Tyre pressures used in our analysis

Tyre Type	Tyre Size	Tyre Pressure (kPa)
Single Large – (Trucks)	(385 65 22.5)	745
Single Large – (Buses)	(385 65 22.5)	850
Twin	(11 R 22.5)	640

Maximum Axle Loads

Maximum legal axle loads of 8.2T and 7.2T apply for twin tyred and single-large tyre axle configurations respectively. Models have been run with these limits and also, with the same load on each.

Load Damage Exponents

A recent network-wide study regional precedent performance (RPP) of Southland pavements has been undertaken, resulting in well-defined fatigue parameters and associated load damage exponents being established for each pavement layer, hence there is no need for arbitrary exponents relating to other forms of pavement. The RPP study collated the historic structural analyses carried out through New Zealand (with some regions, including Southland having close to 100,000 structural analyses). Pavement layer profiles collected from rehab related test pitting, FWD and additional sensor recordings over the last two decades were statistically analysed to establish relevant characteristics for each region, rather than defaulting to criteria derived by Austroads using Australian sources. An example of the effects of load damage exponent on relative damage (damage ratio) of pavement under the two axle combinations are shown in Figure 7 below.

Analysis under Design 25 year ESA.

The methodology used in this study follows state-of-the-art mechanistic analyses incorporating the latest features of European, US (MEPDG) and South African (SAMDM) practices. The state-of-the-art design from all 3 of the sources mentioned is not to rely on ESA or other “fixed equivalencies”, per se, and “each vehicle is considered with its full axle/tyre configuration (i.e. tyre/axle loading and its associated tyre inflation pressure) as input into the SAMDM. From this input, the total “life” of each layer in the pavement is calculated under static loading conditions, and the pavement life is equal to the critical layer life (i.e. lowest life found for a particular layer in the pavement). The stresses and strains (i.e. mechanistic pavement response parameters) under each wheel of the vehicle are calculated and then directly related through the associated transfer functions for pavement damage to layer life”. In all of these methodologies “the vehicle or combination of vehicles are therefore not reduced to an equivalent axle load of 80 kN, based on the crude 4th power law of relative pavement damage.”

Some departures for this study from the above recognised state-of-the-art have been:

- (i) specific axle/tyre configurations have been used where possible but calibration has also called on ESA from RAMM
- (ii) rather than using transfer functions from heavy vehicle simulators for accelerated pavement testing, all transfer functions have been derived from analysis of regional in situ measurements and observations of distressed treatment lengths (FWD RPP)
- (iii) load damage exponents have been regionally evaluated (RPP) with multiple distress modes considered for each layer, and the specific distress mode, which is predicted to bring the critical layer to its terminal condition, is used to assign the governing load damage exponent.

A detailed analysis of Homestead Rd has been carried out (Attachment 1), and a summary of the relevant load damage exponents is shown below. Figure 2 shows the remaining life of this section of road and the exponents in Figure 3. The basecourse, also with the higher load damage exponent, is shown to be the critical layer.

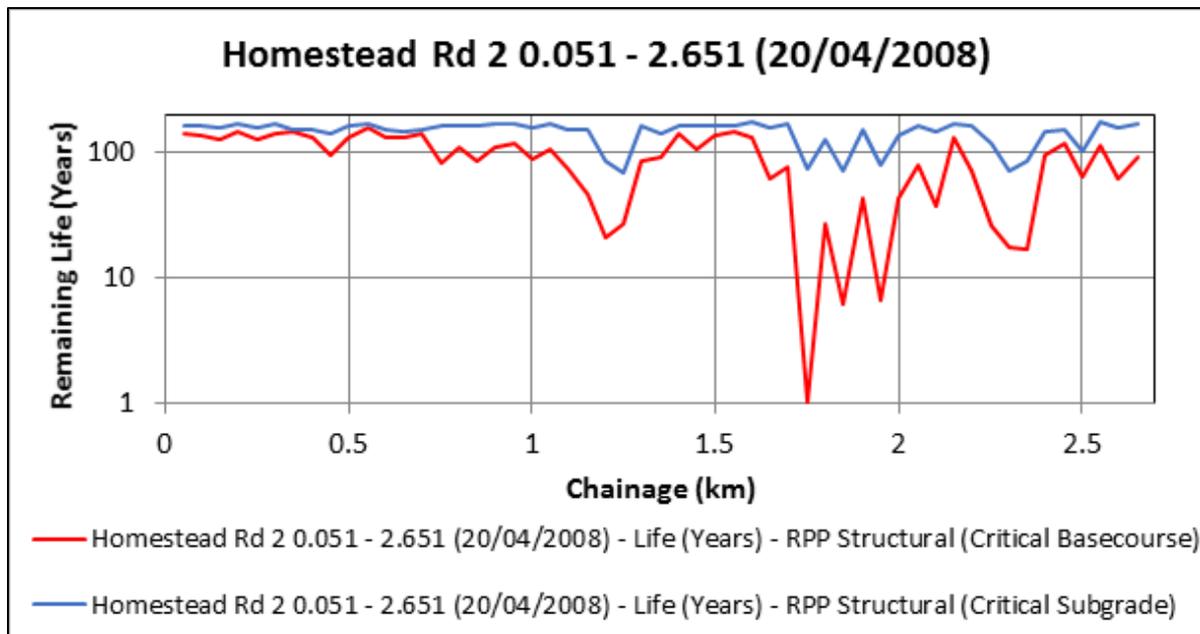


Figure 2 - Remaining life of the basecourse and subgrade for Homestead Rd. The lower of the two values (basecourse in this instance) governs the pavement life.

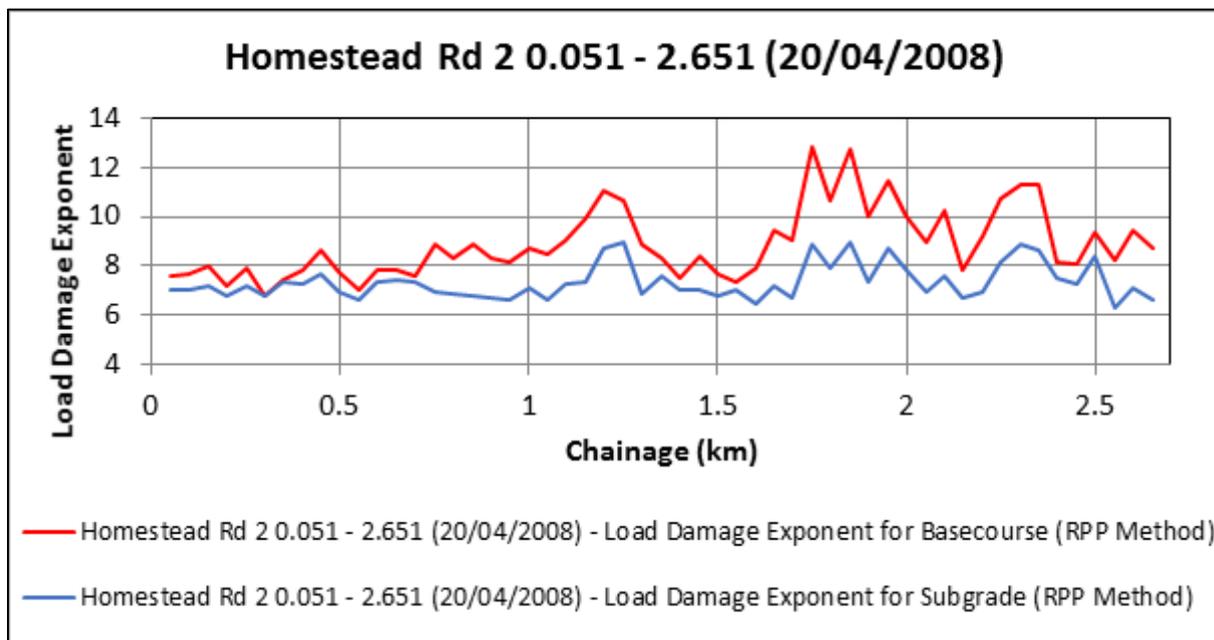


Figure 3 - Load damage exponents for basecourse and subgrade for Homestead Rd, showing that LDE's of mostly 8 to 12 (for basecourse) apply typically on this road.

Normally the characteristic points on the road in the vicinity of the 10th percentile structural capacity, are used to determine the pavement life and relevant critical layer, in this case being the basecourse (although the same layer is critical for full length here).

Damage applied to a single (characteristic) point on Homestead Rd.

The single to twin tyre damage ratio is calculated using the formula below. Table 2 shows the damage ratio between single large and twin tyred axles at the characteristic point. The results show similarity in the increase in damage by the single tyre except for the subgrade layer, where the non-linearity of the subgrade modelled by DynELMOD shows a reduction in damage to the subgrade for single large tyred axles (being a reflection of the reduced axle load from 8.2 to 7.2 t.) FLEA5 on the other hand cannot handle non-linearity, and gives a contrary result.

$$Damage\ Ratio = \left(\frac{vertical\ strain_{single\ large\ tyre}}{vertical\ strain_{dual\ tyre}} \right)^{load\ damage\ exponent}$$

Table 2 – Damage ratio using FLEA5 and DynELMOD software packages

Layer	FLEA5				DynELMOD			
	Single Large Tyre Vertical Micro strain	Twin Tyre Vertical Micro strain	Damage Exponent	Damage Ratio	Single Large Tyre Vertical Micro strain	Twin Tyre Vertical Micro strain	Load Damage Exponent (RPP)	Damage Ratio
Base-course	2340 (2740)	2050	9.7	3.7 (16.9)	2960 (3410)	2580	9.7	3.7 (14.5)
Top of Sub-grade	3240 (3260)	2960	9.4	2.4 (2.5)	3540 (3570)	3740	9.4	0.6 (0.6)

Note: Values in brackets () show microstrains and damage under loading from a super-single tyre as used for buses (inflated to 850kPa).

The above results indicate marked additional damage can be expected with higher inflation pressure on this particular road, where the basecourse is the critical layer.

A preliminary consideration of the intermediate (subbase) layer(s) indicated damage ratios even greater than those for the basecourse, so the damage ratios should be regarded as a lower bound.

Analysis of the Full Length of Homestead Rd with Nominated Vehicles

A 9 axle truck-trailer combination was nominated as a trial case for comparing damage between use of single and twin tyred axles on a 50MAX vehicle, (where the gross weight is constant) as shown in Figure 4 below.



Option 1 – Conventional Truck Tyre/Axle Type



Option 2 – With Single Large



Key

- Single steer tyres
- Twin tyred axle
- Single large-tyred axle

Assume 425mm wide tyres

Figure 4 - Axle loads and axle/tyre combinations used in the comparative scenario. (It should be noted that narrower tyres with the same load will cause greater damage.)

The methodology using the mechanistic approach involves several steps but each is straightforward, and readily computed as follows:

1. Input each loading including tyre pressures into the mechanistic model that has the layer moduli defined from FWD backanalyses for each test point on the road.
2. Sub-section each road into relevant treatment lengths. Using relevant fatigue criteria (preferably established for the specific region), calculate the damage factors for each axle load at each FWD test point, for all layers and distress modes, for both the twin and single tyre vehicles.
3. Calculate the life of each treatment length by establishing the number of passes of each vehicle type (summing the damage factors for each axle) to first develop a cumulative damage factor greater than 1, for 10% of each treatment length (or other defined level of service).
4. Calculate the most effective treatment and rehabilitation cost for each treatment length.
5. Plot the cost versus year cumulative curve for each of the two loading scenarios
6. Calculate the net present value for the two loading scenarios.

This routine provides a rational basis for quantitative evaluation of twin tyre loading relative to single. For the case of Homestead Rd, Figure 5 below presents the remaining traffic in million equivalent standard axles (MESA) under the two axle types when the same 6.5 tonne axle load is applied. If only the subgrade is considered (standard Austroads criterion) there is little difference in the remaining traffic that can be applied, for either tyre configuration.

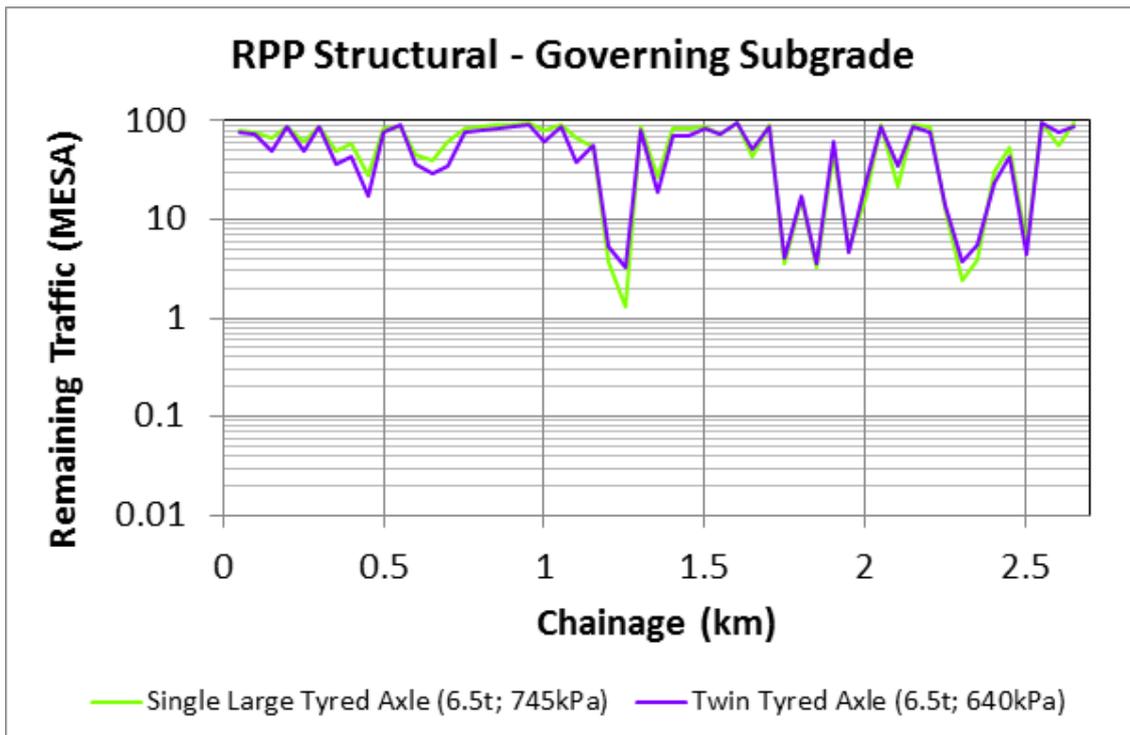


Figure 5 - Remaining traffic (subgrade governing) under loading by single large and twin tyred axles

However, for Homestead Rd, the calibrated mechanistic model indicates that the relatively weak basecourse, not the subgrade will govern pavement life. Furthermore, the basecourse life itself is on average about 10 times shorter when the single large tyred axle is used in place of the customary twin tyred option.

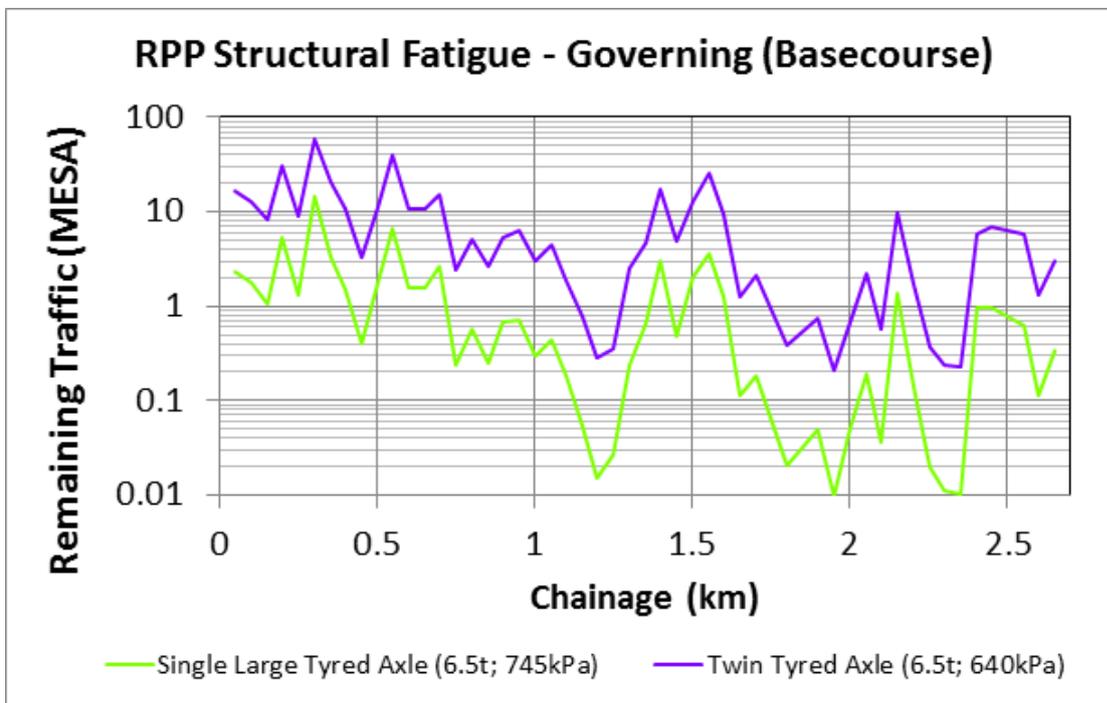


Figure 6 - Remaining traffic (basecourse) for Homestead Road under loading by single large and twin tyred axles.

The damage ratio can vary significantly depending on the load damage exponent for the basecourse (derived from the regional precedent performance model). Figure 7 shows increased pavement

damage ratios from 1.5 to more than 20 times, where singles are used instead of twin tyres depending on the applicable basecourse damage exponents. The total overall damage ratio of the nominated 50MAX truck-trailer combinations above (see Figure 4) remains high after taking account of the steering axles because only a small proportion of the total weight is on the steering axles which are the same on both vehicles, as shown in Figure 8.

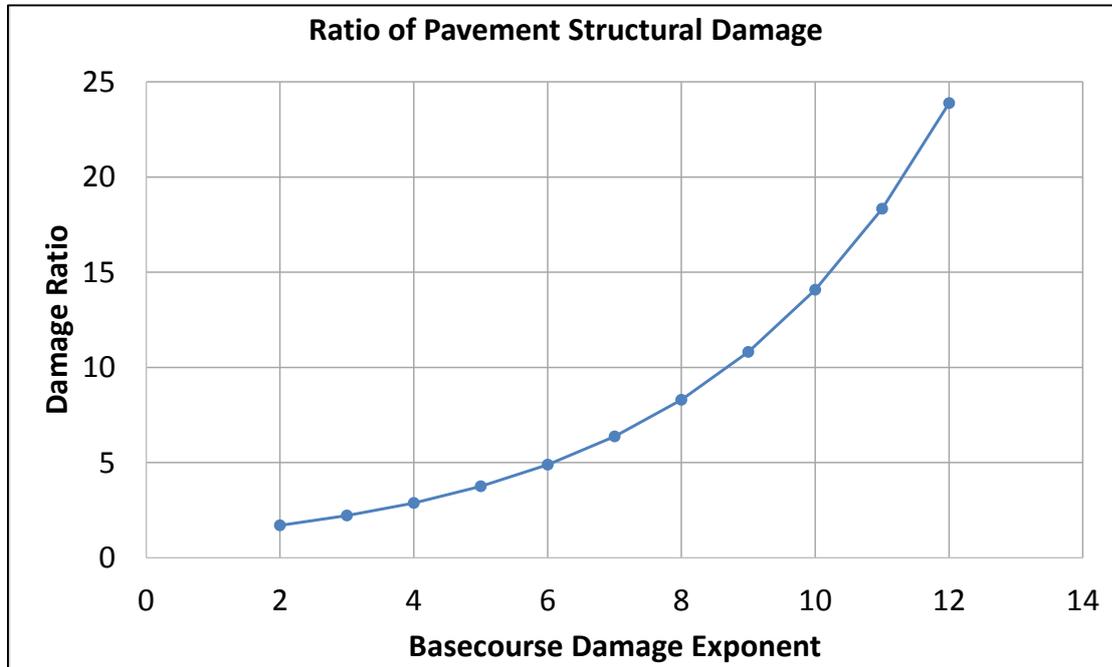


Figure 7 - Ratio of pavement structural damage (in the basecourse) for different LDEs at a 10th percentile characteristic point on Homestead Rd

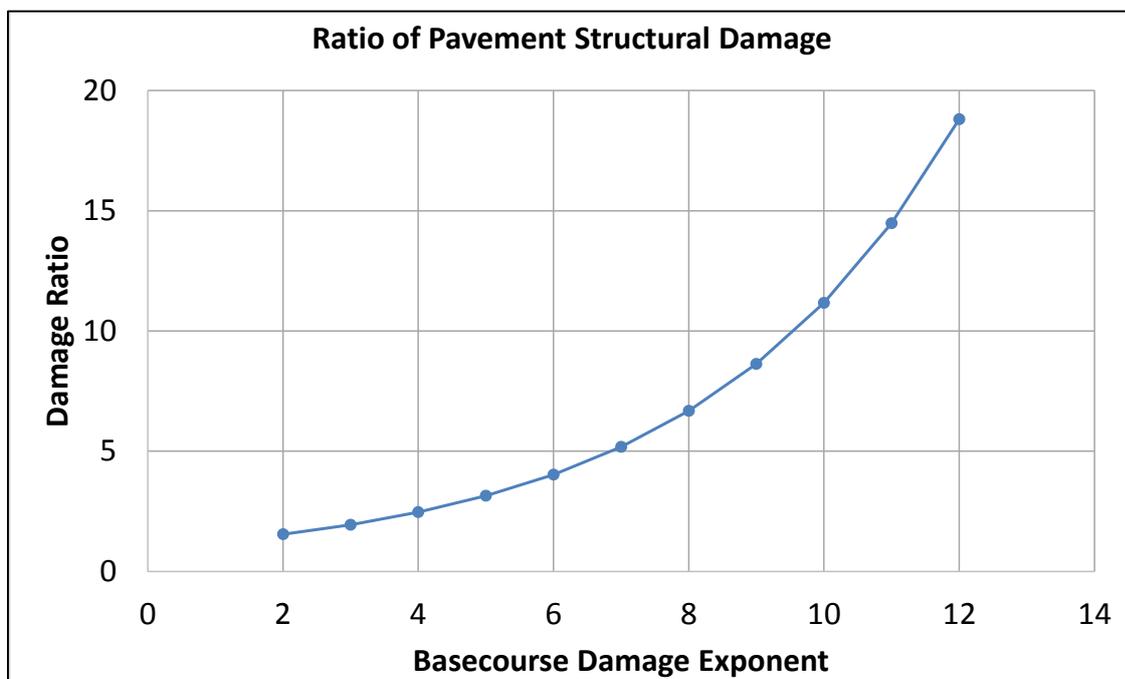


Figure 8- Overall ratio of pavement structural damage (in the basecourse) by the 50MAX truck-trailer combination for different LDEs.

Results are provided in graphical form in Attachment 1, showing the various distress modes for

- (i) ESA loading
- (ii) Twin tyred axle
- (iii) Single large tyred axle

Tyre Pressure Considerations

Tyre pressure is now a specific input for pavement design for US designers using the M-EPDG¹⁰. Traditional ESA concepts are convenient, but rely on invalid assumptions. The M-EPDG inputs include the full spectrum of traffic parameters:

- Base year truck-traffic volume (the year used as the basis for design computations).
- Vehicle (truck) operational speed.
- Truck-traffic directional and lane distribution factors.
- Vehicle (truck) class distribution.
- Axle load distribution factors.
- Axle and wheel base configurations.
- Tire characteristics and inflation pressure.
- Truck lateral distribution factor.
- Truck growth factors.

This more fundamental approach allows a substantially more meaningful quantification of pavement wear. The “one size fits all” ESA approach used in RAMM 4th power calculations is an over simplification that can give approximate results for a network which has (i) been designed for traffic of at least 10 MESA and (ii) a limited allowable ESA range (less than a factor of 2). Southland local roads are poorly suited to ESA methods. Examples are given in a subsequent section.

The issue of tyre pressure was examined closely in the COST 334 study (Attachment 2) in determining the TCF (Tyre Configuration Factor) – being damage ratio of a given tyre compared to a standard tyre- as follows:

¹⁰ NCHRP 2004. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. http://onlinepubs.trb.org/onlinepubs/archive/mepdg/Part2_Chapter4_Traffic.pdf

On tyre inflation pressure and contact stress distribution:

11. The tyre inflation pressure is not a direct parameter in the TCF formulae. For the same load and tyre, higher inflation pressures generally result in a smaller tyre-pavement contact area, and thereby increased surface stress in the pavement. As a consequence, higher inflation pressures generally result in higher pavement wear, especially on thin pavements.
12. The ratio of actual to recommended inflation pressure was shown to be influential for the cases of primary rutting on thick (and probably medium) pavements and secondary rutting on thin and medium pavements. An inflation pressure 10% higher than that recommended for the actual tyre load results in about 15% increase in pavement wear. In such a case of over-inflation, the contact stress distribution is non-uniform and the load is concentrated on a smaller area.
13. The detailed contact stress distribution within the contact area is probably relevant for distress modes whose origin is at or close to the pavement surface, such as ravelling.

Because the COST 334 study addressed only thick structural asphaltic pavements, it follows that somewhat higher damage ratios should apply when unbound basecourse with thin seal forms the critical layer (governing pavement life).

Consistency with Other Studies

The accelerated trafficking of a relatively strong pavement at ALF, reported by Yeo¹¹ is relevant to some degree as it uses an unbound granular pavement with chip seal. This used accelerated trafficking of an artificial chip seal unbound granular pavement with 40 kN plate load deflections of 0.7-0.8 mm after bedding-in. "Structural Number" SNP values were about 4.0-4.2. Poor correlations with pavement life are commonly reported^{12,13} for central deflection and SNP. However, the ALF pavement structural capacity was more representative of high volume highways, than local roads ie there are significant differences between that new pavement and the in-service existing pavements in Southland District, so the same conclusions are not appropriate.

Load damage exponents for the basecourse layer are primarily dependent on their support from the underlying layer(s). The stiffness of the subbase plays a governing role, as shown in the following network comparisons from recent studies of regional precedent performance.

¹¹ Yeo, R. (2008). Relative Pavement Wear of an Unbound Granular Pavement due to Dual Tyres and Single Tyres

¹² REAAA Working Group (2015). REAAA Technical Report TC-5. Pavement Durability.

¹³ Salt, Henning, Stevens & Roux (2010) Rationalisation of the structural capacity definition and quantification of roads based on falling weight deflectometer tests.

<https://www.nzta.govt.nz/assets/resources/research/reports/401/docs/401.pdf>

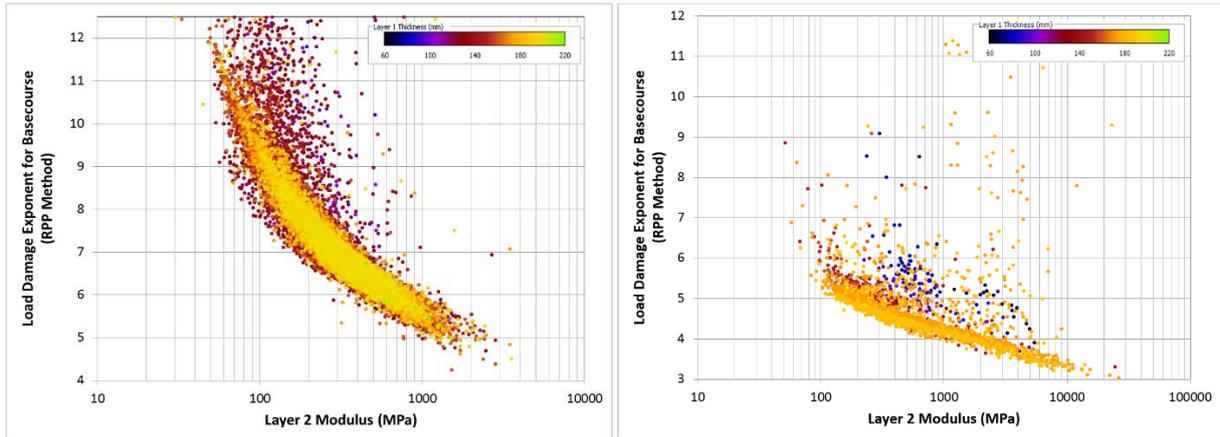


Figure 9. Load Damage Exponents for Southland District versus Auckland Motorways (AMA).

These extremes show the dramatic differences in susceptibility of different networks to increased loading, now that recent advances have established a reliable statistical analysis methodology for quantifying load damage exponents for each layer and each relevant distress mode.

Comparisons of the composite cumulative distribution curves of all load damage exponents (many tens of thousands of in situ measurements) from various networks are given below, showing that ranges are commonly 4 to 9, and reinforcing the general trend for higher exponents in a region where lower structural capacity is required.

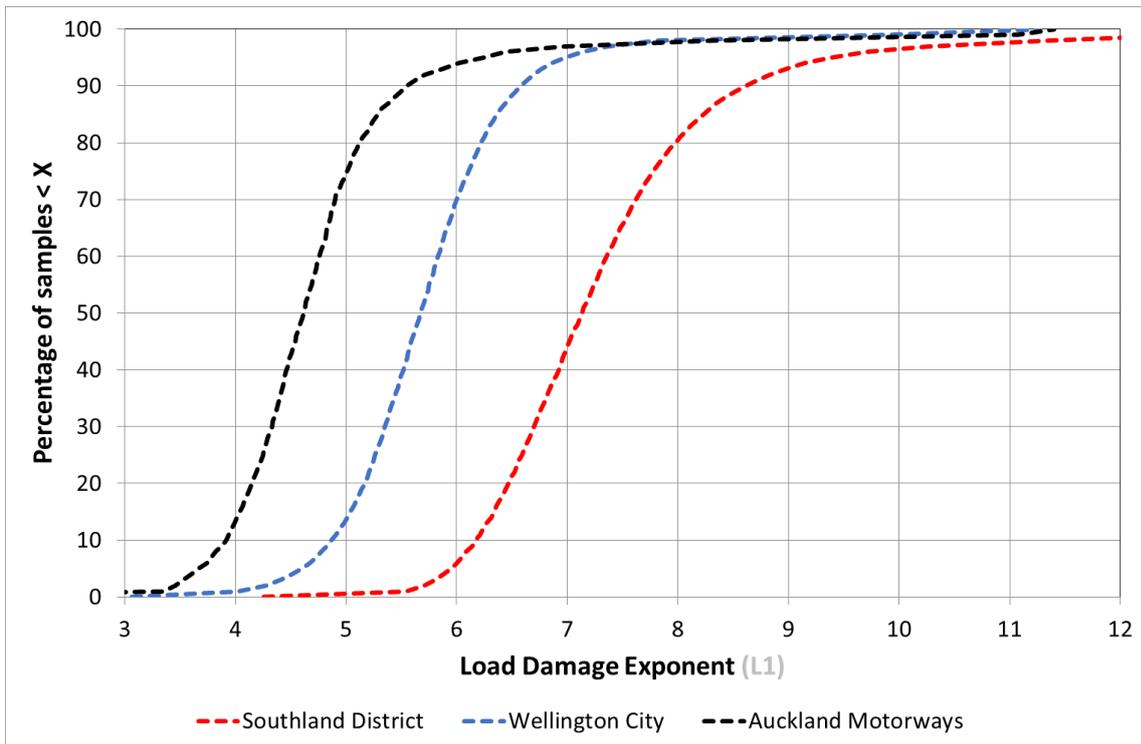


Figure 10. Comparison of the Composite Cumulative Distributions of Load Damage Exponents

Conclusions

1. The current Austroads simplified approach of comparing deflections imposed by different axle load configurations to calculate pavement damage is no longer state-of-the-art, nor is it supported by leading authorities. Stress or strain based [mechanistic] approaches using structural analysis have been promoted internationally for many years, and suitable software is now widely available.
2. Comparison between standard twin tyred axles and single large tyred axles demonstrates the advantage of structural analysis to reliably evaluate pavement wear under alternative loading regimes not normally captured by overly simplistic methods.
3. Use of a single large tyred axle under maximum legal axle loading (7.2 tonne) will tend to impose an increase in strains in the basecourse and usually a decrease in strains at depth when compared to an 8.2 tonne standard twin tyred axle.
4. Even though the axle load is less, the single tyre is likely to reduce pavement life substantially. Normally, heavily loaded singles will be in a minority, but it is important to appreciate that comparing only one 7.2 tonne single large tyred axle with one 8.2 tonne twin tyred axle, the truck single modelled will impose 3.7 times the damage of the twin while the bus single will impose 14.5 times the damage. This applies specifically to the case of Homestead Rd at the characteristic (10 percentile structural capacity) location where the basecourse is the critical layer governing the pavement life.
5. If both the twin and single tyre axles carry the same load, at customary tyre inflation pressures for trucks, the effect is compounded because the tyre pressure increases and the effective width decreases so both act to concentrate the load. The damage imposed if the subgrade is the critical layer is not high, but in the case considered, where the basecourse is the critical layer, the pavement wear increases by 10 fold or more under the single.
6. Software has now been developed so that a network wide evaluation can be carried out very quickly, on this basis, once two or more sets of alternative axle load configurations are defined for comparison, on any network where a calibrated mechanistic model has been established. The same process can be used to quickly assign the cost of running any spectrum of fleet loading. (This could readily be established as a fully automatic user-queried internet based service to automatically quantify and assign road user charges for any nominated route, based on structural damage.)
7. Load damage exponents are higher for structurally weak pavements compared to those that have high capacity. Values much higher than typically assumed (Austroads uses 4, 5 or 7) apply in many secondary roads where the unbound granular basecourse is the layer that will govern pavement life, rather than the subgrade where the additional damage caused by single large tyres is less marked (often similar if the current maximum loads are applied in each case).
8. The initial results confirm the expectation that for certain roads, (and these are predominantly local roads rather than highways) evidence based calculations show that road user charges should be much higher for single large tyres than for standard twin tyres, if both are loaded to their legal maxima. This presents an issue for the local authority, (i) because road user charges customarily relate to the vehicle, not the specific road or route, and (ii) at present, there is no enforcement of tyre pressure and that is a

very significant wear factor as far as basecourses on low volume roads are concerned. COST¹⁴ 334 (Attachment 2) specifically recommends that in order to reduce wear, legislation should be promoted for tyre pressure regulation. (Technology now allows remote monitoring and control of from the cab.)

9. Future proposals for increasing HPMV traffic may have much more adverse impacts than intended unless calculations are based on observed in-service performance (considering all pertinent distress modes) of similarly constructed pavements. Some specific roads, which can now be readily identified, should be avoided otherwise budget will be required for upgrades.
10. Damage in the subgrade is highly affected by non-linearity of the subgrade, as strains in highly non-linear elastic subgrades were found to decrease under single tyre loadings (i.e. calculations that do not account for non-linearity characteristics of subgrades can be misleading).
11. Rational determination of appropriate weight limits and/or road user charges, necessarily requires consideration of the axle configuration, loads, tyre pressure, and pavement structure (including identification of the layer and governing distress mode which will cause the pavement to reach a terminal condition). Greatly increased understanding and hence more realistic evaluation of heavy vehicle damage would be practical if traffic data could be made readily accessible in raw form (axle configuration and loading frequency distribution). Where a regional precedent performance study of any road network has been carried out, (as with Southland District), state-of-the-art mechanistic analyses (using stresses and strains in each pavement layer) are now available to reliably and quickly quantify specific load damage exponents and consequent pavement wear under any given axle load(s) or load combination, enabling rational evaluation of any HPMV impacts. The procedure is very straightforward and enables decisions to be technically based on real (in-service) precedent performance of roads in any given region, necessarily giving due regard the wide range of important controlling parameters that cannot be practically replicated in any test track, including climate, subgrade characteristics, aggregate sources, lane width (wheel path wander), as well as customary construction and maintenance practices. The peer-reviewed methodology provides a sound basis for HPMV decision making as well as documented evidence in the event of any challenge.
12. Now that more robust analytical methods are readily available, use of the obsolete “structural number” or SNP concept (the basis of which was officially dismissed as nebulous¹⁵ by its US originators (NCHRP) in 2004 when they shifted to mechanistic methods), can no longer be supported for any structural evaluation.
13. Calibrated mechanistic analyses provide the structural solution for rehabilitation, allowing SNP, to be limited to models for maintenance of surface condition. This parallel routing of structural and surface treatment models enables either to be continually advanced to fully utilise and gain maximum benefit from the rapid advances in technology and the exponentially growing database of pavement condition data.

¹⁴ COST 334 Effects of wide single tyres and dual tyres

¹⁵ NCHRP (2004). Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Final Report. “Nothing could be more nebulous than this parameter” <http://www.trb.org/mepdg/guide.htm>

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