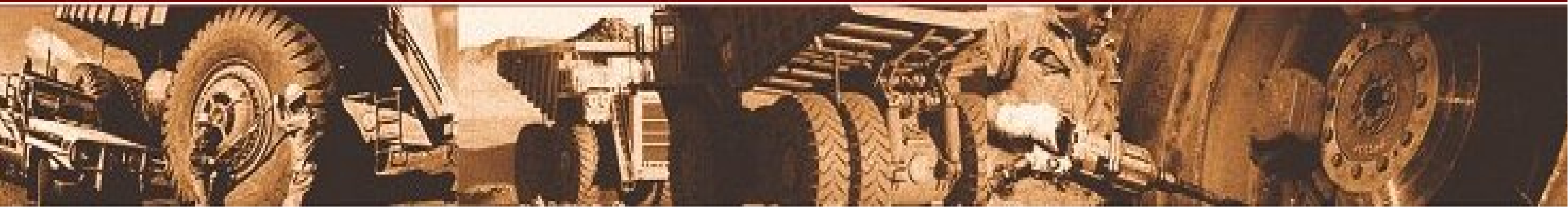
OTRACO GLOBAL TYRE MANAGEMENT



Technical Guideline

GUIDELINES

ON

HAULROAD DESIGN & MAINTENANCE

Version 6: September 2013

1 INTRODUCTION

This paper presents the basics of mine haulroad design and maintenance that Otraco has gleaned from various sources together with our experience of managing earthmover tyres on mines worldwide since the early 1970s.

Otraco's principal interest in having well designed and maintained haulroads is to maximise tyre life and minimise tyre operating cost. However haulroad quality has just as important an influence on other elements of haultruck operating cost – particularly in regards to chassis and suspension upkeep and fuel usage – plus productivity and safety.

Haulroad design and maintenance is not rocket science, but it is amazing how little effort is typically invested in planning and installing haulroads – huge benefits can usually be gained for relatively minor outlay.

This paper is not an in-depth study; it is designed to cover the basics in relation to haulroad geometry (width, camber, superelevation, gradient, etc), surfacing material and ongoing road maintenance. Hence it does not examine, in any detail, topics such as haulroad sub-base construction, dust suppressant technology[1], etc. If the reader wishes to pursue these areas more fully, we have recommended some reference material[2] below.

Survey control is essential when constructing haulroads, particularly in relation to road width, ramp gradient, crossfall and superelevation – do not rely on putting it in by eye. The quality of the grader operator is equally as important; a final-cut operator is worth his weight in gold.

We present the guidelines in two main sections:

- Haulroad Design Basics
- Haulroad Maintenance Basics

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[1] Otraco strongly supports the use of a good dust suppression system (eg. Dust A Side) to improve tyre life, reduce fuel consumption and minimise water usage.

[2] *Design of Surface Mine Haulage Roads – A Manual*, Walter Kaufman & James Ault (US Bureau of Mines)

Safety in Mines Research Advisory Committee (SIMRAC) Final Project Report COL467, RJ Thompson & AT Visser (Depts of Mining & Civil Engineering, University of Pretoria)

2 HAULROAD DESIGN BASICS

2.1 Road design issues

Typical haulroad design problems include:

1. Width - Insufficient
2. Crossfall - Too little or too much
3. Superelevation - Inadequate or negatively cambered
4. Corners - Too tight
5. Gradients - Excessive
6. Materials - Inappropriate type and size/distribution
7. Sub-Base - Inadequate strength

These road design inadequacies may lead to the following **operational problems:**

a. Trucks running up onto roadside windrows when road **width** is inadequate, causing:
   - Tyre shoulder, sidewall or casing damage,
   - Truck wheel bearing, suspension or chassis damage.

b. Water accumulating on road when **crossfall** is inadequate, causing:
   - Dramatically increased susceptibility to cutting of tyres,
   - Rocks being concealed by water,
   - Road surface damage leading to additional tyre/truck damage,
   - Reduction of road compaction strength,
   - Higher requirement for corrective road maintenance.

c. Uneven wheel load distribution when **crossfall** is excessive, causing:
   - Increased tyre loading leading to tyre heat damage,
   - Increased scrub angle resulting in excessive tyre wear,
   - Wheel bearing damage,
   - Higher loading of steering components,
   - Reduced control of the truck.

d. Rock spillage from truck body/tray, and excessive tyre loading when **superelevation** is incorrect, causing:
   - Tyre damage from rock spillage,
   - Increased tyre abrasion,
   - Wheel bearing/suspension damage.

e. Road surface damage and increased rock spillage arising from **switchbacks** or excessively tight **corners**, causing:
   - Tyre damage from rock spillage,
   - Tyre contact with windrows (tyre shoulder/sidewall and suspension damage),
   - Increased road surface damage due to high shear tyre/road contact,

- Subsequent tyre/chassis damage due to damaged road surface,
- Excessive truck pitching due to braking and accelerating through corner,
- Reduced control of the truck,
- Higher requirement for corrective road maintenance.

f. Increased wheel slip, braking force and rock spillage when **gradient** is excessive, causing:
- Dramatically increased tyre wear rate ,
- Excessive brake pad wear,
- Tyre damage from rock spillage (from back of truck body),
- Lack of control when ramp wet,
- Increased potential for water erosion of ramp,
- Increase fuel usage,
- Decreased vehicle speed (efficiency),
- Increased tyre loading (on downhill axle).

2.2 Road design goals

The operational problems discussed above can be minimised by targeting the following goals:

1. Adequate road **Width**
2. Minimum road **Crossfall** required for Drainage
3. Correct **Superelevation** of road Curves
4. Avoidance of tight **Corners** and **Switchbacks**
5. Appropriate road **Gradient**
6. Correct road **Alignment**
7. Appropriate road **Construction**

2.3 Road design parameters

The following parameters are covered in this guideline:

- Width
- Crossfall
- Curves/switchbacks
- Superelevation
- Gradient
- Intersections
- Transition zones
- Construction

2.3.1 Width

The following rule of thumb applies to mine haulroad width:

- One-way road
  - A one-way road should be twice the width of the largest haultruck operated on it; this applies to both straight sections of the road and to corners.

- Two-way road
  - Straight sections of a two-way road should be three-and-a-half times wider than the largest haultruck operated on it, while corners should be between three-and-a-half and four times the width of the haultruck (as the radius of the corner decreases, the road width should increase).

Table 1 shows the application of this rule of thumb for various widths of haultruck, and Figure 1 illustrates the case for a 5 metre wide haultruck on a straight section of two-way road.

Haultruck width (metres)	**One-way road width** ***Straights/Corners*** (x2) (metres)	**Two-way road width** ***Straights*** (x3.5) (metres)	**Two-way road width** ***Corners*** (x4) (metres)
3.0	6.0	10.5	12.0
4.0	8.0	14.0	16.0
5.0	10.0	17.5	20.0
6.0	12.0	21.0	24.0
7.0	14.0	24.5	28.0
8.0	16.0	28.0	32.0
9.0	18.0	31.5	36.0
10.0	20.0	35.0	40.0

Table 1 – Recommended haulroad width[3]

Notes:
1. Additional width must be allowed for drainage ditches, if used, and any run-off zone to these drainage ditches.
2. An additional 5 metres width should be incorporated into the road if road-centre "whopper stopper" windrows/dividers are used.
3. Design for the largest sized trucks that are likely to be used during the life of the mine.

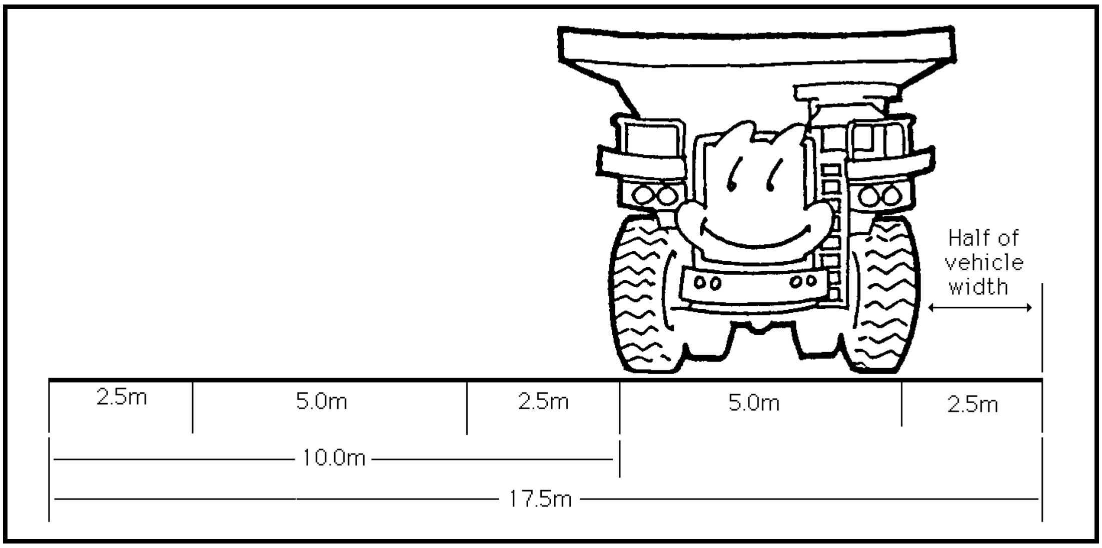

Figure 1 – Haulroad width (two-way straight-section) for a 5 metre width haultruck

[3] Source: *Design of Surface Mine Haulage Roads – A Manual;* US Bureau of Mines

2.3.2 Crossfall

Haulroad design should incorporate the minimum amount of crossfall necessary to maintain an adequate runoff of water to the side of the road. The other two main factors affecting runoff are the typical severity of local rainfall and the smoothness of the road surface – hence both of these need to be considered as shown in Table 2.

Crossfall should be applied at a constant slope – not with a curved profile – to ensure that the inner position tyres on a four-tyred rear axle are not overloaded relative to the outer position tyres (refer the bottom illustration of Figure 5 in the Addendum to this paper).

Road Gradient	Minimum Crossfall *(Light rainfall area / Smooth road surface)*	Maximum Crossfall *(Heavy rainfall area / Rough road surface)*
0-3%	2%	5%
4-6%	2%	3%
> 6%	1%	2%

Table 2 – Recommended haulroad crossfall[4]

Notes:
1. Crossfall should be evenly sloped from the road centre-line out to the road shoulder. Uneven crossfall – eg. curved crossfall with zero slope at the road centre-line increasing to maximum slope at the road shoulder – will result in uneven tyre loading, with the inside rear tyres carrying substantially more load than the outside tyres.
2. Where mud or ice is a problem, excessive crossfall can cause trucks to slide sideways.
3. Crossfall of 2% (two units of vertical fall per 100 units of horizontal width) is barely visible to the naked eye. If crossfall is evident, then it is usually excessive (apart from for regions of heavy rainfall).

2.3.3 Curves/switchbacks

Curves pose a number of potential problems including spillage from trucks, excessive/uneven loading of tyres, tyre contact with roadside windrows, and tyre and road surface damage due to cornering shear forces – the tighter the curve (smaller the curve radius) the greater the potential for operational issues.

Important points to consider with curves are to:
- Increase roadway width on a curve,
- Super-elevate the curve,
- Incorporate transition zones between straight sections and a curves,
- Avoid locating road intersections on curves or corners.

[4] Sources: *Design of Surface Mine Haulage Roads – A Manual*, US Bureau of Mines; *The Evolution of Current Mine Design for Off Highway Truck Haulage*; Bougainville Copper Limited (Newman Truck Haulage Seminar, 1982)

These elements are covered in the width, superelevation and transition zone sections of this paper. There is one type of curve though that deserves special mention – the switchback; it is discussed in more detail below.

Switchbacks

A switchback is the single biggest road related problem for haultruck tyres and road maintenance workload, and its inclusion in a mine road layout should be avoided wherever possible. The main problem zone of a switchback is its inside corner which becomes damaged by a combination of steering slip of the tightly turning front tyre and shear drag of the mated-dual tyres on the inside corner side of the truck. This causes road rutting/gouging and tyre damage, with the former increasing the likelihood of spillage further exacerbating damage to the road and tyres.

Where a switchback is deemed necessary, the following design aspects should be given proper consideration:

- Minimum turning path capability of haultrucks,
- Required superelevation,
- Reduction or elimination of switchback gradient on ramps,
- Maintenance/strengthening of the road surface on the problematic inside corner,
- Windrow management on the inside corner (constructed of fine material with regular upkeep),
- Tracking/traffic management of the truck around the switchback.

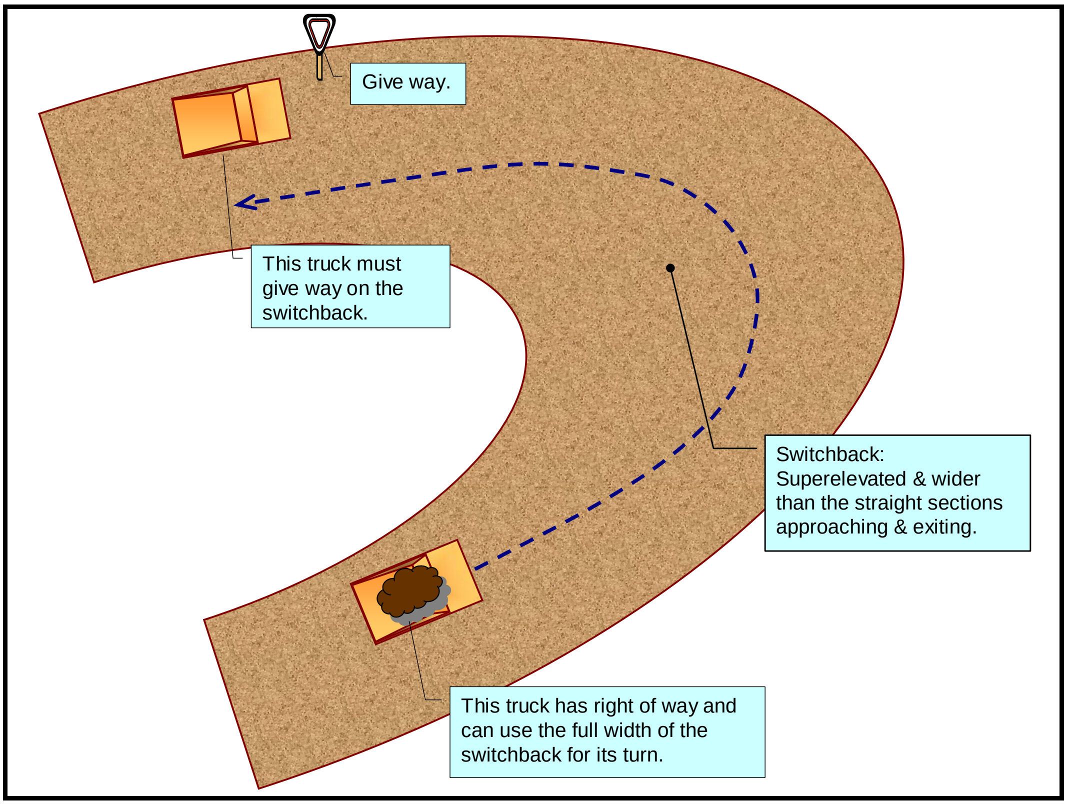

Figure 2 – Switchback traffic management option

Options that should be considered are to strengthen the switchback surface (eg. by mixing cement or some other bonding agent into the road surface) and/or to utilise a system whereby the truck negotiating the inside corner has right of way enabling it to make full use of the switchback road width (refer Figure 2).

2.3.4 Superelevation

Superelevation should be built into all curves, corners or switchbacks where vehicle speed exceeds 15 kph. It counteracts the effects of centripetal force on the truck, payload (and driver), as the truck negotiates the corner, by tilting the road towards the centre of the curve so that centripetal forces are largely offset by the corner crossfall. This minimises spillage from the truck, unequal load distribution on the tyres, and shear contact damage to the tyre tread and road surface. Superelevation also increases driver comfort.

Superelevation should be limited to a maximum of 10% (ie. 10 units of vertical rise per 100 units of horizontal width) to prevent sideslip of a slow moving or stationary vehicle in muddy or icy conditions. A transition zone, from the crowned straight road section (with its crossfall) to the superelevated circular curve, must also be considered. Transition is covered in a following section.

Table 3 shows superelevation for various combinations of road curve radius and haultruck speed around the curve. The curve radius refers to the radius of the **centreline** of the road **lane** on the **inside** of the curve.

Road curve radius* (metre)	**Haultruck speed** (kilometre per hour)							
	15 kph	20 kph	25 kph	30 kph	35 kph	40 kph	45 kph	50 kph
50	4%	6%	10%					
60	3%	5%	8%	12%				
70	3%	5%	7%	10%				
80	2%	4%	6%	9%	12%			
90	2%	4%	6%	8%	11%			
100	2%	3%	5%	7%	10%			
125		3%	4%	6%	8%	10%		
150		2%	3%	5%	7%	9%	11%	
175			3%	4%	6%	7%	9%	11%
200			2%	4%	5%	6%	8%	10%
250				3%	4%	5%	7%	8%
300				2%	3%	4%	5%	6%

Limit superelevation to a maximum of 10%; therefore avoid curve radius/truck speed combinations in grey shading.

* This is the radius of the **centreline** of the road **lane** on the **inside** of the curve or corner.

Table 3 – Superelevation in relation to curve radius & truck speed[5]

Notes:

1. The superelevation table is based on the curve radius of the centreline of the road lane on the inside of the curve; the radii of the inside shoulder, centreline and outside

[5] Source: Michelin – *Maintenance Guide for Earthmover Tyres*

shoulder of the curve may be readily determined by incorporating relevant haultruck and road width values.
2. There is a practical limit (in the order of 10%) to the rate of superelevation, eg. where mud or ice is a particular problem because slow travelling vehicles could slide down the cross slope.
3. Adequate distance should always be provided prior to and after a superelevated corner for transition from the normally cambered section of straight road to the superelevated curve. If the transition zone is inadequate, excessive pitching will occur.

2.3.5 Gradient

The gradient of a ramp is measured as the number of units of vertical rise per 100 units of horizontal length. A 10% gradient ramp has 10 metres of vertical rise per 100 metres of horizontal distance (typically measured along the centreline of the roadway).

Gradient is usually a trade off among overburden mining tonnage, haultruck productivity and haultruck operating cost (tyres, fuel, chassis, suspension and braking). Steeper gradients usually require less overburden to be mined while increasing haultruck operating cost. There is typically an optimum gradient, for each particular haultruck model, at which productivity is maximised.

Sustained grades should preferably be set at 8% (although 10% has become the industry standard – influenced largely by truck haulage efficiency); higher gradients will result in a dramatic drop in tyre wear out life. Maximum gradient should never exceed 12%.

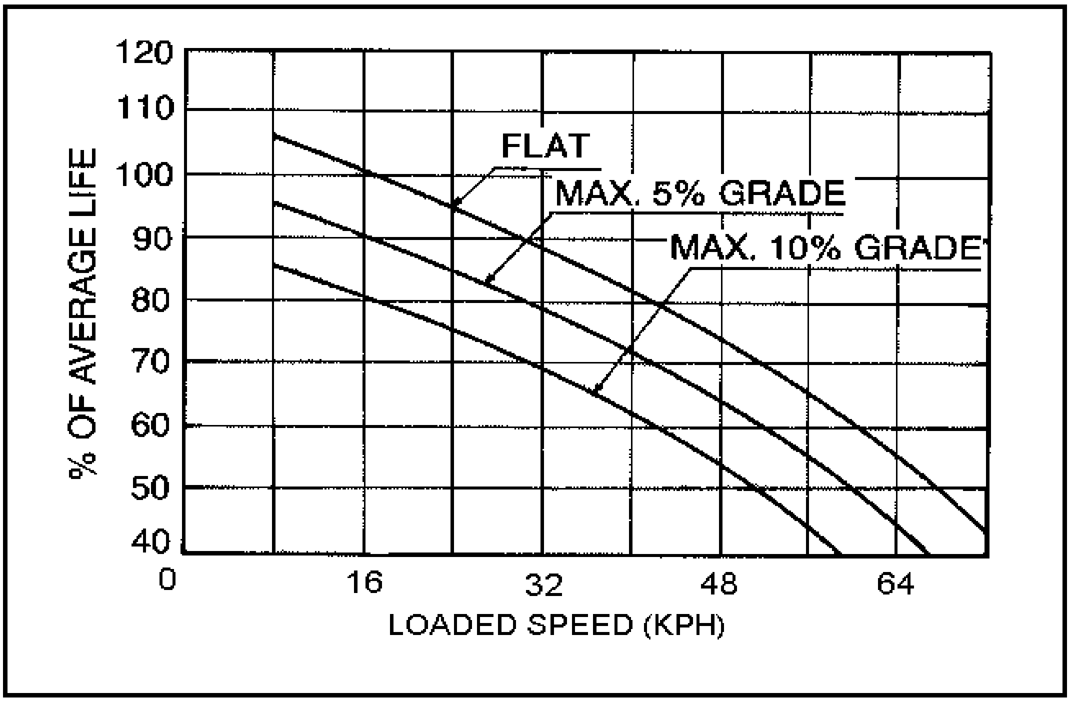

Figure 3 – Effect of ramp gradient and truck speed on tyre life (wear rate)

Severe gradients should be avoided wherever possible because of the influence they have on tyre wear rate and life. The increase in tyre wear rate, and a subsequent reduction in tyre life, becomes substantial as road gradient and truck speed increase (refer Figure 3). Tyre wear is mainly due to tyre slip – under traction when travelling uphill, and under braking when travelling downhill. Surprisingly, downhill haulage has a more adverse effect on tyre wear than uphill haulage, while some of the highest wear rates are sustained by the tyres of unloaded haultrucks on grade.

In addition, road gradient is a factor in front to rear wheel weight distribution and can lead to heat separation failure of tyres which are operating close to their TKPH (work rating) limits on long, steep ramps.

2.3.6 Intersections

Intersections tend to be the most hazardous areas of the mine road network. They are associated with an increased risk of vehicle collision, traffic disruption and damage to roadway surface and tyres. They typically require constant maintenance to rectify road surface degradation.

General guidelines for intersections are:

- Ensure adequate visibility from all directions and have clearly defined right-of-way rules or signage – to minimise the risk of vehicle collision.
- Avoid the intersection of more than two roads at one point (including cross roads) – it causes traffic confusion and road surface degradation.
- Avoid intersections on a ramp or at the crest or bottom of a ramp – it causes visibility problems at the crest, and vehicle braking and road degradation problems partway along or at the bottom of the ramp.
- Allow adequate turning radius – to minimise road and tyre damage.
- Ensure adequate drainage – for the same reasons.
- Ensure roadside windrows/berms are composed of fine material and that rock spillage that collects in windrows is regularly removed – to minimise tyre sidewall and shoulder damage.
- Encourage drivers to brake gently when approaching an intersection, and to accelerate smoothly and use the largest practicable turning radius when exiting it – to avoid road and tyre damage.

2.3.7 Transition zones

Transition zones should be considered for any change in road alignment; in particular:

- between a straight section of road and a superelevated curve,
- between a section of level road and a ramp,
- at the intersection of an access road and a ramp.

Straight to superelevated curve transition

Figure 4 shows a crowned straight section of road transitioning into a superelevated curve and back to a crowned straight. The transition distance, on each of the entrance to and exit from the curve is designated Le (**circled** on the diagram).

The transition distance (Le) will depend upon the change in cross-slope between the crossfall of the crown section of road leading into (or exiting) the superelevated curve, and also upon the anticipated speed that a haultruck will negotiate the curve. The percentage change in cross-slope is the difference between the percentage of crossfall and the percentage of superelevation.

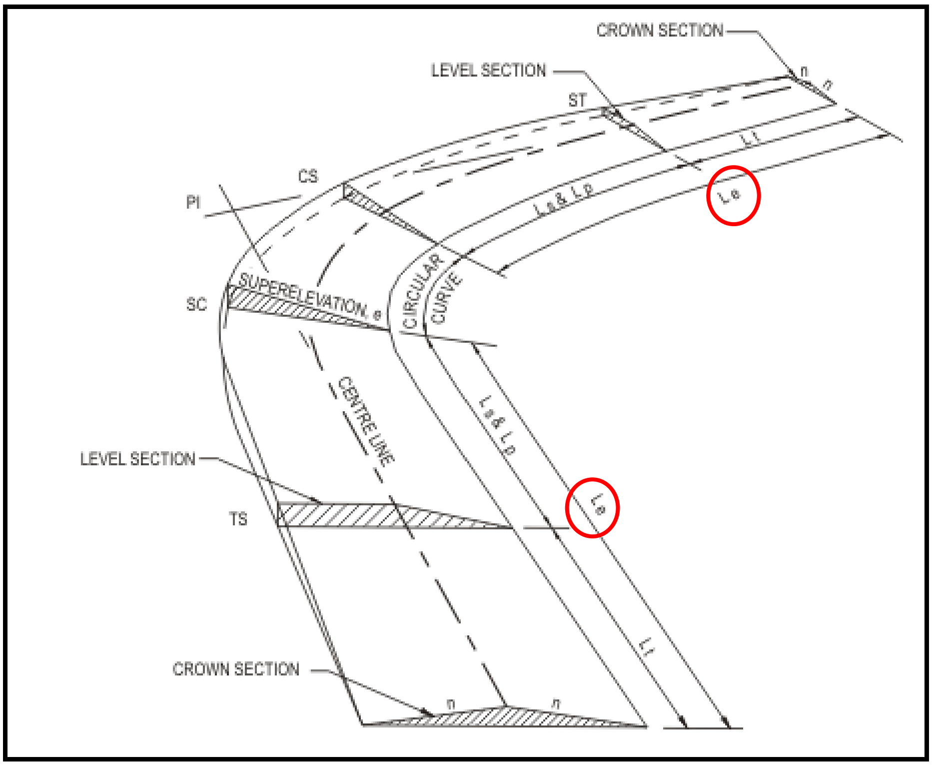

Figure 4 – Transition from a crowned to a superelevated section of road

Assuming that the straight section of road leading into (and exiting) the curve is crowned (with crossfall from the road centreline to each shoulder as shown in Figure 4), then we add the magnitude of crossfall to the magnitude of superelevation to determine the change in cross-slope.

The transition zone length (in metres) is calculated as follows:

Transition distance (Le) = Cross-slope change ÷ Rate of cross-slope change x 100

(One-third of this length should be placed on the curve and two-thirds on the tangent)

The rate of cross-slope depends upon anticipated haultruck speed as shown in Table 4.

Truck speed on curve (kph)	30 kph (or less)	40 kph	50 kph
Rate of cross-slope change per 10m of road	2.0%	1.6%	1.3%

Table 4 – Superelevation transition length determinants

Example:
If the crossfall of the crown section of straight road is 2% and the superelevation of the curve is 6%, then the change in cross-slope is: 2% + 6% = 8%.[6]

From Table 4, if the speed of a haultruck on this curve is 50 kph then the recommended rate of cross-slope change per 10m of road is 1.3%.

The transition distance (Le) is calculated as 8% ÷ 1.3% x 10m = 62m of required transition leading into (and exiting) the superelevated curve. One-third (20m) of this length should be on the curve and two-thirds (42m) should be on the straight section approaching (or exiting) the curve.

Level road to ramp transition (vertical curve)

There should be a transition zone of adequate length to allow for a smooth change in gradient of the roadway between a level section and a ramp. The recommended minimum rate of change in gradient through the vertical curve is in the order of 1.0% per 10 metres of road.

Example:
We need to determine the vertical curve transition length for a ramp gradient of 9%.

The transition distance is calculated as 9% ÷ 1.0% x 10m = 90m of required vertical curve transition from the flat section of roadway leading into (and exiting) the ramp.

Avoid the formation of a dip at the bottom of the ramp or a hump at the top of a ramp. Both create inefficiencies in haulage productivity, increase effective ramp length, and exacerbate tyre and suspension loading and wear. Dips also collect water – a major cause of damage to tyres and road surfacing.

[6] If the straight sections of road leading into (and exiting) the superelevated curve are not crowned but have a constant crossfall from one shoulder of the road to the other, and if this crossfall is in the **same** direction as the superelevation of the curve, then subtract the smaller from the larger (of crossfall and superelevation) to determine the change in cross-slope, eg. in this case the calculation is: 6% - 2% = 4% (rather than 8% when crossfall and superelevation are in **opposite** directions). The transition distance (Le) in this case would be 4% ÷ 1.3% x 10m = 31m, with 10m of this on the curve and 21m on the straight approach (or exit).

Access road intersection with ramp transition

Otraco is a strong proponent of maintaining a constant gradient on ramps, with the possible exception of a switchback (discussed earlier) or where a medium-to-high traffic haulage access road intersects with a haulage ramp. It these cases it may be preferable for the ramp to transition from grade to level at the intersection and then back to the ramp gradient – thereby avoiding some of the road maintenance issues associated with an intersection on a gradient.

2.3.8 Construction

Sub-base

A stable roadbase is essential for the safe operation of equipment. The road must be able to support the heaviest equipment utilised. Road construction should not be confined to the immediate short term requirements. Roads should be built with sufficient strength for the duration of planned operations, not simply so that operations can begin.

Failure to provide adequate roadbase strength during construction will lead to many future problems. These include:

- Road restrictions (speed)
- Rework
- Clearing
- Levelling
- Cleaning

Common problems with road construction include:

- Incorrect particle sizes and distribution
- Low bearing strength
- Flow under load
- Scouring
- Sinking
- Dust

Sub-base design and material guidelines are discussed in detail in *Design of Surface Mine Haulage Roads – A Manual*, US Bureau of Mines.

Surface sheeting

Whereas a properly designed sub-base will minimise problems such as road subsidence and potholing – major contributors to tyre casing and truck chassis/component fatigue – the choice of road surface material will have an immense effect upon tyre tread wear.

An ideal surface mixture is a competent rock or gravel material sized at a maximum of 25-30mm[7] with a good distribution of smaller material to promote binding of the surface under compaction, and to minimise the

[7] For very high rainfall areas such as in the tropics (eg. Indonesia), material size of up to 50mm may be appropriate for the surface course, provided that the material does not have sharp cutting edges.

generation of dust and susceptibility to water erosion. Large (> 30mm), hard, sharp-edged material should be avoided as it will lead to a dramatic increase in tyre tread wear and cutting, especially in wet conditions.

Treatment such as a dust palliative can be very effective in producing a smooth, competent road surface that has the following benefits:[8]

- Increased safety (reduced dust generation)
- Increased tyre life (reduced wear and cutting),
- Increased truck component life (reduced dust generation),
- Reduced road water usage and delivery infrastructure,
- Increased haulage productivity and reduced fuel burn (lower road rolling resistance).

Haulroad surfacing and dust palliative treatment are discussed in detail in *Safety in Mines Research Advisory Committee (SIMRAC) Final Project Report COL467*, University of Pretoria.

General

The haulroad profile should be such that roads are level and ramp gradients are constant (as discussed earlier) without undulations, dips and unevenness. As haultrucks become larger, the potential cost of fatigue related damage to tyres, chassis and other truck components increases dramatically. Smooth roads minimise these costs while providing other substantial benefits in relation to fuel usage and haulage productivity.

[8] In Otraco's experience, a properly implemented dust palliative management system (rather than just the application of additives to water used for wetting roads) is required to achieve these benefits on an ongoing basis.

3 HAULROAD MAINTENANCE BASICS

3.1 The right balance

Once the mine road system has been built, it then needs to be maintained. Road maintenance standards will be largely influenced by the size and deployment of the road maintenance fleet; nevertheless a proper road maintenance system will ensure that the maximum benefit is achieved from the available fleet.

There is a balance between the potential savings for tyres and truck components and other haulage costs associated with a well maintained mine road system, and the cost of additional cleanup equipment, manning and infrastructure costs necessary to achieve these savings. That is where constructing roads properly in the first place pays such big dividends in the long term.

3.2 Good practices

Good road maintenance practices will improve the efficiency of any fleet.

1. Regular **pit inspections** should be carried out to identify problem areas.
2. **Spillage** is the main cause of tyre damage; **grader and dozer operators** should be continually encouraged to clean it up whenever they see it. Cleanup equipment should be regularly deployed to spillage prone areas.
3. The **wear** on virtually **every component** of a haultruck is increased significantly when the haultruck travels rapidly over a rough surface,
4. Use of properly sized (**maximum of 25-30mm)** material with a good distribution of fines and coarser components, preferably compacted, for the surface course, will result in a **tightly bound pavement** requiring less maintenance than a loose rock surface. Compaction is strength.
5. Grading should not be carried out immediately after **heavy rain** as it tends to slurry the fine material in the road surface causing scouring of the surface.
6. When **corrugations** appear in the road surface, grading alone will not correct the problem. The section of corrugated road should be **tyned to a minimum depth of 165mm**, regraded and then preferably compacted.

7. When grading a properly prepared road, very little material needs to be taken from the road surface, and hence large **grading windrows** should not eventuate.

8. **Roadside windrows** should consist of **fine material**, which can be spread evenly across the pavement surface during grading, and which does not damage tyres if trucks run up onto the windrow.

9. Avoid the use **road dividers** or "whopper-stoppers" (earthen windrows placed in the centre of the road to divide traffic or to be used as an emergency stop buffer). Dividers reduce road width and tend to become a depository of rocks (as spillage from trucks is graded or dozed into their base).

10. Uncontrolled **surface water** is the most **efficient destroyer** of a gravel haulroad surface. It is therefore of utmost importance that drainage is taken into account when designing new roads.

11. **Potholes** should be filled as soon as they develop.

Refer to Figure 5 in the Addendum to this paper to see the effect of road surface disparities such as potholes, depressions and humps, and circular (rather than even, constant slope) road crown upon tyre loading and hence tyre life.

Correct haulroad design and construction will dramatically reduce the need for maintenance. Haulroad construction cost is usually a fraction of haulroad life-of-mine cost. Therefore the emphasis should be on getting the road right at construction rather than relying solely on maintenance to keep it at the required standard.

ADDENDUM – EFFECT OF ROAD DISPARITIES ON TYRE LOADING

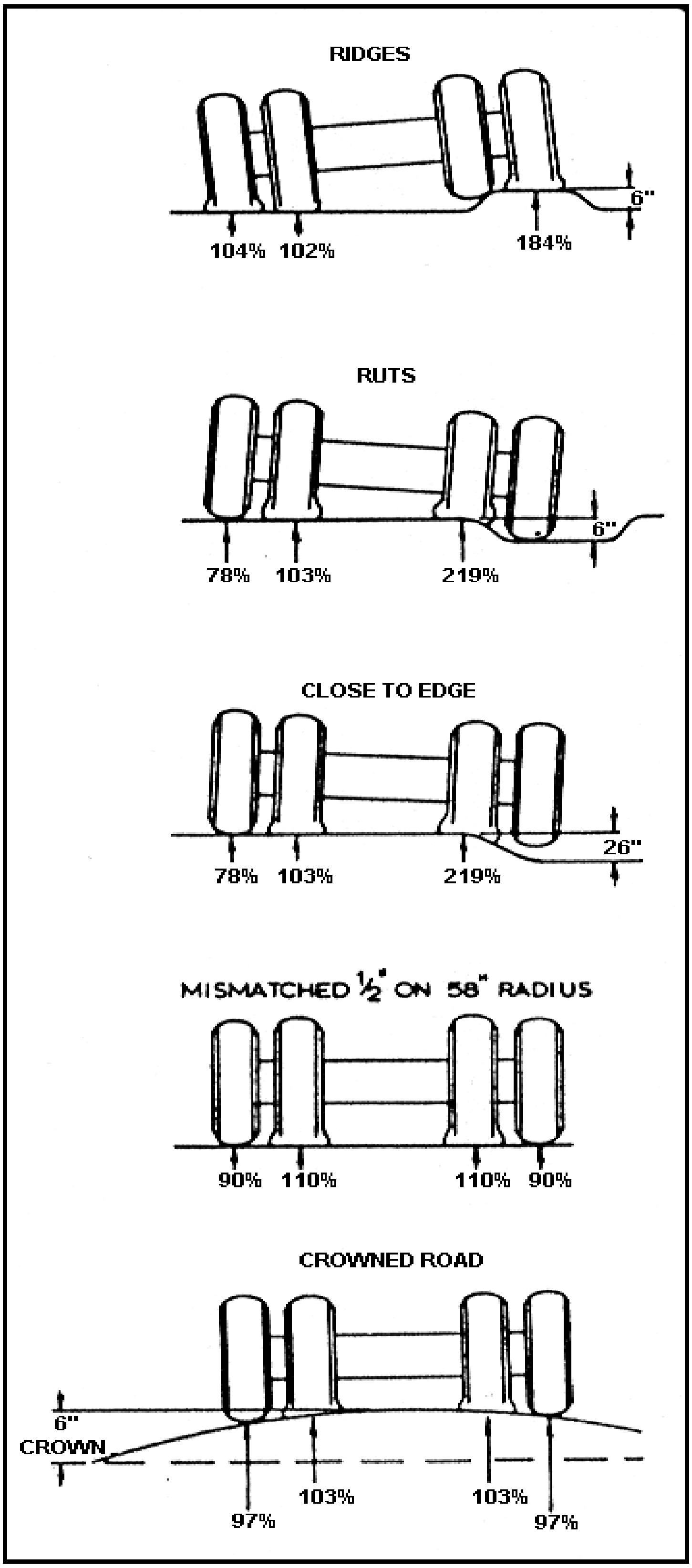

Figure 5 – Common tyre problems related to road surface disparities