# Prototype Behavioural FEM Model for Road Surfacing Seals

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## Summary

In many countries with large road networks serving widely separated developed industrial or agricultural nodes, road surfacing seals are widely used. Such seals may consist of a layer of bituminous binder in which a single layer of larger mineral aggregate (seal stone) is embedded.

At the ICCES conference of 2003 the development of the basic FEM model on road seal behaviour was reported. Since then, development in to the material constituents has occurred, and the progress is as follows:

-The development of seal component material constituents.

-Demonstration of the model to accommodate different environmental influences (tyre load and temperature).

-An indication of the potential to road pavement designers, and future research.

This model is a move towards the development towards a mechanistic design method for surfacing seals, as there are no definitive mechanistic design tools available and insight into seal behaviour is fully based on experience and empirical considerations.

## Introduction

In many countries with large road networks serving widely separated developed industrial or agricultural nodes, road surfacing seals are widely used. Such seals may consist of a layer of bituminous binder in which a single layer of larger mineral aggregate (seal stone) is embedded.

Functional, in-service requirements of the seal are:

-Protect the base from moisture, so that it retains its structural strength. A saturated pavement base will loose load bearing capacity, with resulting failure.

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-Protect the base from direct contact with tyres. The action of tyres results in local shear stresses, which if applied to the base directly loss of material will occur.

-Provide an all weather skid resistance and a smooth road surface.

With the modern trend in increased traffic loading, varying oil sources and related refining processes and the rapid introduction of new types of modified bitumen, it remains a strong belief of the authors that seal design may strongly benefit from a better insight into seal behaviour, specifically at micro-mechanic level. For that reason the University of Stellenbosch and the Delft University of Technology combined their human resources for the development of a Finite Element Model (FEM) that enables the examination of seal behaviour at a scale of individual seal stones (micro mechanics) (Huurman *et al*, 2003). In this second paper on the subject to be submitted to the ICCES, progress towards the development of such a model is discussed.

## Seal Behaviour

The behaviour of the seal is dependant on the design and construction, and the service environment. The seal is not considered a structural member of the pavement. From literature (Milne, 2004) it is known that the main causes of damage in a seal surfacing are:

-Deformation: punching of the stone in to the base and rotation of seal stone in the bituminous binder.

-Cracking: low temperature fatigue and cohesive cracking.

-Adhesion failure i.e. ravelling.

-Wear of the seal stone under the abrasive tyre loads.

As the aggregate is relatively inert when compared to the bitumen, wear is not considered at this prototype stage of the model. Punching and rotation of seal stones and adhesion failure are types of damage that develop on the scale of individual stones. Low temperature cracking is a damage that may either take place in the binder itself (lack of cohesion) or in the contact area between stone and binder (lack of adhesion).

## Seal Surfacing Model

In Figure 1 the basic layout of the model is presented. Various shades refer to different materials (blue are the stones, red the bitumen, separated by an interface). The model is comprised of modules that consist of an individual seal stone embedded in the bitumen binder. By adding modules together, the model can be made as large as can be handled by the available computers.

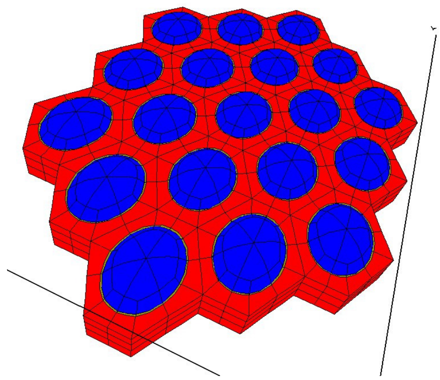

**Figure 1: Basic layout of the Prototype FEM Seal Behavioural Model**

Given the importance of the adhesion between stone and binder, for both cracking and ravelling damage, each stone is placed in a bowl of interface elements.

**Model Material Components**

The aggregate component of the seal has been modelled to enable smooth and rough stones to be assessed. An example of the different geometries is given in figure 2 below:

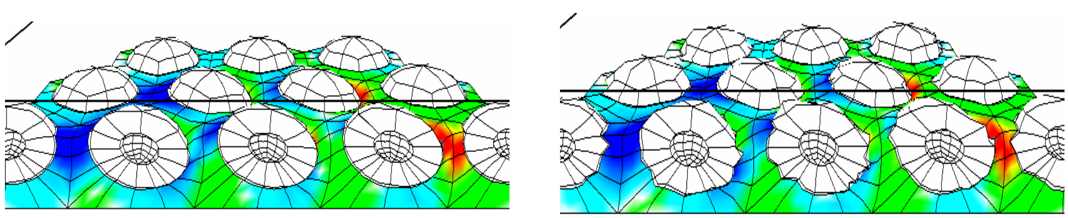

**Figure 2: Seal Stone Shape (Smooth; Bottom: Rough): Cross-section**

The binder parameters were chosen to enable modelling the difference in behaviour between the straight "penetration grade" bitumen, and a modified binder (in this case SBS rubber latex modified bitumen, which in practice improves adhesion, reduces temperature susceptibility and strength). The Burger's Model of visco-elasticity was utilised, with the "spring and dash-pot" parameters determined from reworking available data (Collop *et al*, 2003).

These parameters for the 25 ºC run are summarised in table 1:

**Table 1: FEM Burgers Model Bitumen Binder Parameters**

| Bitumen Material Parameters | | | | |
|---|---|---|---|---|
| Binder | Temperature | | | |
| | 25 °C | | | |
| | (Pa) $E_1$ | (Pa) $E_2$ | (Pa.s) $\lambda_1$ | (Pa.s) $\lambda_2$ |
| 70/ 100 pen | $2x10^8$ | $1,5x10^6$ | $8,67x10^4$ | $8,67x10^3$ |
| 3 % SBS (L) modified | $2x10^8$ | $2x10^5$ | $1,46x10^6$ | $2,61x10^4$ |

## Traffic Loading

A detailed analysis of available data and interpretation was undertaken to determine the time-load functions required to model a tyre on a textured surface. This analysis highlighted the limited information available to practice regarding the vertical, lateral and longitudinal stresses actually imposed by the elastic (rubber) tyre on the individual seal stones. By determining a load that varied with time, in all three axes, a dynamic load was simulated by applying global axes forces to the stone elements that were above the bitumen surface.

## Examples of Model Behaviour

Some examples of the model behaviour under load are given below.

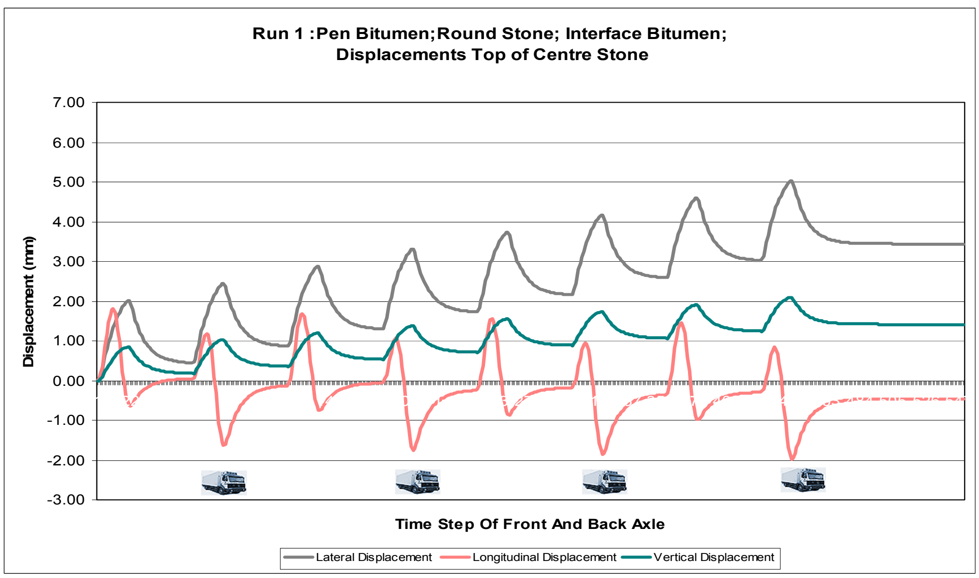


**Figure 3 (a): Penetration grade bitumen: Displacements under Load**

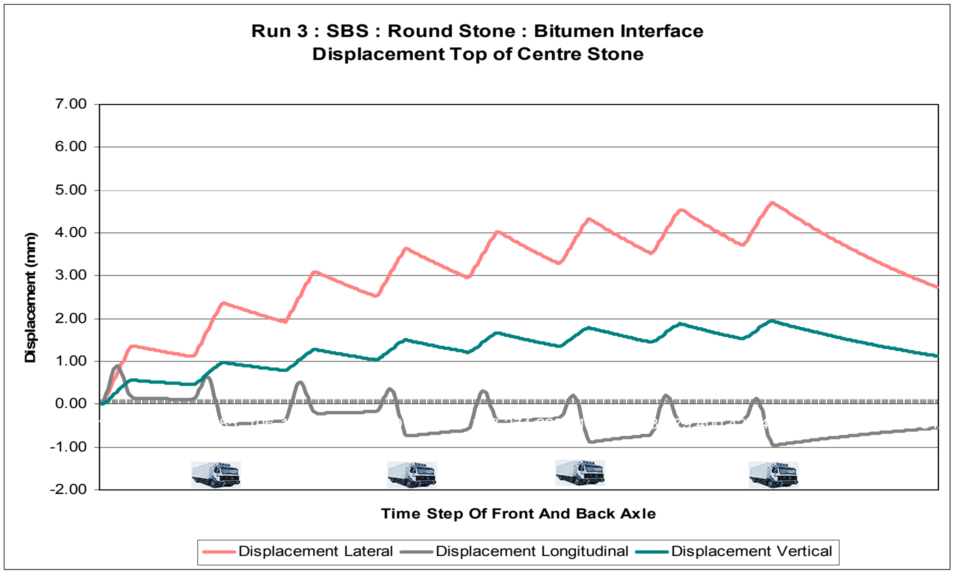


**Figure 3 (b): SBS modified Bitumen: Displacements under Load**

By comparing the behaviour of the two types of bitumen in figures 3 (a) and (b), it is evident that the model is able to distinguish between the two different binder types. The figure shows the displacement of the top of the central stone, under front and rear wheels of four truck passes. Of note is the better visco-elastic recovery of the SBS modified binder, during the final rest period, specifically when considering that the binder is still recovering after the computed rest period, while the pen grade bitumen's recovery is completed at end of load cycle.

Magnitudes of stresses in the seals are also able to be determined. Table 2 shows results analysed for 4 runs, with light and heavy traffic, and straight and modified binders.

**Table 2: Stresses imposed in Seals under light and heavy Traffic**

| Binder | Traffic | Transferred Stress (4th Truck, Driven Wheel, wheel on top of stone) | | | | | |
|---|---|---|---|---|---|---|---|
| | Type | Lateral XX | | Longitudinal YY | | Vertical ZZ | |
| | | Stress (MPa) | % of Pi | Stress (MPa) | % of Pi | Stress (MPa) | % of Pi |
| 1 Pen @ 25ºC | Heavy 800 | -3,78 | 473 % | -3,80 | 475 % | -4,27 | 543 % |
| 3 SBS @ 25ºC | Heavy 800 | -3,83 | 479 % | -3,85 | 481 % | -4,32 | 540 % |
| 13 Pen @ 25ºC | Light 200 | 0,945 | 473 % | -0,951 | 475 % | -1,07 | 535 % |
| 14 SBS @ 25ºC | Light 200 | -0,957 | 479 % | -0,963 | 481 % | -1,08 | 540 % |

In the above table '+': Tensile Stress, '-': Compressive Stress.

## Conclusions

It is concluded that a micro-mechanical model for seal surfacing is available. Different loading types and service temperatures were modelled. The model may furthermore be used in combination with more realistic material models and a granular base support.

On the basis of the linear calculations discussed here it is concluded the model will prove to give insight into seal behaviour and offers the following:

-Insight in to the complexities of load transfer on a textured surface.

-Distinction between different bituminous and modified binder type behaviour.

-Indication of magnitudes of stresses and strains in a seal.

This information will be of value to bitumen chemists and pavement designers.

## Future Work

Future work will include the addition of a base layer, to enable interaction between base and seal to accommodate punching of stones into the base, and to provide a more realistic support mechanism to the seal stones.

In addition, further refinement of the simulation capabilities of the material model will enable an even better understanding of the actual phenomena and processes involved.

## References

1 Huurman M, Milne TI, Scarpas A, *Development of a Structural FEM for Road Surfacing Seals,* Proceedings of ICCES Conference, Corfu, August 2003, ICCES.

2 Milne TI, *Towards a Performance related Seal Design Methods for Straight and Modified Binders,* Draft PhD Thesis, University of Stellenbosch, 2004.

3 Collop AC, Scarpas A, Kasbergen C, De Bont A, *Development of a non-linear viscoelastic constitutive model with damage*, ICCES 2003, Corfu, Greece.