8. OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

In this chapter an indication of the contribution of the thesis to the state of knowledge is first provided. This is followed by the main observations, conclusions and recommendations from this thesis.

The thesis focuses on providing practical guidelines to characterising vehicle-pavement interaction from a pavement design viewpoint. The objectives of this study focus on a practical systems framework populated with various models and data sets for the analysis of the transient response of pavement structures to dynamic tyre loads. The stated objectives of this study were met by developing such a framework and a practical approach for analysis of vehicle-pavement interaction, and by verifying this approach using existing analysis techniques. The overall scope of this thesis was the field of vehicle-pavement interaction, focussing on the effect of vehicle-pavement interaction specifically on pavement design.

8.2 Contribution to the State of Knowledge

The aim of this thesis is to contribute to the state of knowledge in the general field of vehicle-pavement interaction, with a focus on the effects on pavement design. The main areas where this thesis contributes to the state of knowledge are:

a. Development of a method for predicting the moving dynamic tyre load on a pavement based on relevant vehicle and pavement parameters;
b. Development of a method for estimating the dynamic pavement response parameters based on the static pavement response parameters for certain pavement structures;
c. Definitions for the type of loads on pavements and the technological analysis types available for vehicle-pavement interaction studies, and
d. A better understanding of the issues relevant to vehicle-pavement interaction from a pavement design viewpoint in South Africa.

The *method for prediction of the moving dynamic tyre loads on pavements* is based on the knowledge that tyre load populations form a normal distribution, and that the average and Coefficient of Variation of this normal distribution can be predicted based on certain vehicle and pavement properties (Equations 5-1 and 5-2).

These equations contribute to the practice of pavement engineering in South Africa in that it can be used to develop moving dynamic tyre load populations for existing pavements in South Africa to aid the process of pavement management and rehabilitation. Individual tyre load populations can be developed for each section of pavement, ensuring optimum managerial decisions on maintenance and rehabilitation options and strategies.

The *method for estimating the dynamic pavement response parameters based on static pavement response parameters* is based on empirical relationships between the static and dynamic pavement response parameters calculated using an axi-symmetric finite element analysis method (Tables 6.13 and 6.14). It can be used to obtain indications of the effect of speed on pavement response for certain pavement types.

These equations contribute to pavement design in providing a tool to the general pavement engineer to evaluate the possible effects of load speed on the population of possible pavement bearing capacities for a specific structure. Although these equations are empirically derived (and therefore unique for the conditions for which they were derived) it forms the beginning of a better understanding of the issue of load speed in pavement design.

The *definitions for load types and technological analysis for vehicle-pavement interaction studies* assist in the understanding of the primary issues concerning vehicle-pavement interaction issues. It can be used to base further investigations into detailed aspects of vehicle-pavement interaction on. It also assists in focussing the pavement engineer on the relevant issues in vehicle-pavement interaction.

The analyses and discussions contained in this thesis add to the current knowledge of vehicle-pavement interaction from a pavement design viewpoint in South Africa, by highlighting dominant and important issues in such analyses. The examples in Section 7.3 form the basis of indicating the need for incorporating vehicle-pavement interaction issues into normal pavement design and analysis. The effect of inadequate pavement maintenance and the resultant effect of inadequate pavement roughness on moving dynamic tyre loads necessitate a new appreciation of issues such as quality control and pavement management to ensure prime pavement quality for the life of the pavement.

It was stated in Chapter 1 of this thesis that it is the purpose of this study to contribute to the state of knowledge in terms of:

a. Establishment of a holistic system approach to vehicle-pavement interaction in which the connections between the various components are defined;
b. Provision of a simplified method for estimating the moving dynamic tyre load on a pavement, and
c. Provision of a practical approach to transient pavement-structure response analyses for evaluating specifically South African pavement structures.

It is the author's view that these objectives have been met and that an improved understanding of vehicle-pavement interaction for pavement design exists due to the contribution of this study. However, much still needs to be done to improve this understanding and it is also the plea of the author that the recommendations in this thesis be taken further to ultimately aid in the economic development of South Africa by ensuring a high-quality pavement network.

8.3 Observations

The following primary observations are made based on the information in this thesis. These observations may in some cases confirm existing knowledge, but are highlighted as they are seen to be vital for a clear understanding of the effects of vehicle-pavement interaction in pavement design. The chapter on which the specific observation is based is shown in brackets:

a. Difficulties were experienced in obtaining valid information on both vehicle and pavement components (Chapter 2);
b. The vehicle-pavement interaction process can be classified into various components that interact with each other in specific manners (Chapter 4);
c. Load magnitude shows good relationships with the stresses in the upper part of the pavement structure, while load speed shows good relationships with the strains in the pavement structure (Chapter 6);
d. Higher load frequencies affect calculated stresses in the pavement less than calculated strains. Higher load frequencies affect calculated strains in the deeper parts of the pavement less than lower load frequencies (Chapter 6);
e. Analysis of response parameters indicated that the deeper parts of the pavement are less affected under moving constant loads (MCL) than under static loads (Chapter 6);
f. A distance lag exists with speed between the position of maximum load application and the positions of maximum response at the surface and lower down in the pavement (Chapter 6);
g. Running finite element analyses is a time-consuming process that requires detailed input data and data reduction techniques not normally required for static response analyses. More complicated material models affect the time required for an analysis (Chapter 6);
h. Similar trends were observed in both the static pavement response and transient pavement response analyses for all parameters at the different load levels (Chapter 6), and
i. The equations for converting static response parameters to equivalent dynamic response parameters appear to provide good relationships (Chapter 7).

8.4 Conclusions

The following primary conclusions are drawn based on the information in this thesis. More conclusions of a general nature can be found at the end of each chapter. Some of the conclusions may confirm existing knowledge, but are highlighted as they are seen to be vital for a clear understanding of the effects of vehicle-pavement interaction in pavement design. The chapter on which the specific conclusion is based is shown in brackets:

a. Pavement roughness is the main cause for dynamic tyre loads (Chapter 2);
b. The main vehicle components identified as important in vehicle-pavement interaction are the tyres, suspension, vehicle dimensions, configuration and load (Chapter 2);
c. A thorough fingerprinting of the important pavement and vehicle issues should be performed on a regular basis to ensure availability of valid data to industry (Chapter 2);

d. Vehicle speed, stress level and environmental conditions were identified as the major factors in influencing transient pavement response (Chapters 2, 5 and 6);

e. A good understanding of material properties is needed if a transient pavement response analysis is attempted (Chapter 6);

f. All tyre loads can be classified as Static, Moving Constant, Dynamic or Moving Dynamic Loading (Chapter 4);

g. All pavement responses to tyre loading can be classified as either Static or Transient Response (Chapter 4);

h. The static tyre load component is directly related to the Gross Vehicle Mass (GVM) of the vehicles that use the pavement, while the dynamic load component is directly related to and dependent on the vehicle speed, vehicle type, GVM, load and pavement roughness (Chapter 5);

i. The control of tyre load levels on roads is the joint responsibility of the road authority (through control of pavement roughness and vehicle speed) and the vehicle owner (through control of GVM and vehicle speed) (Chapter 5);

j. Load magnitude has a dominant effect on the calculated stresses using moving constant load analyses, especially in the surfacing and base layers of the pavement, while load speed has a dominant effect on the calculated strains and deflections in the pavement (Chapter 6);

k. The positions of maximum load application and maximum stress response at the different depths in the pavement are not similar when the load is moving, and it increases with increased load application speeds (Chapter 6);

l. This distance lag indicates that a relative principal axis rotation occurs between the upper and the lower parts of the pavement when a load is moved over a pavement (Chapter 6);

m. Use of the transfer functions developed for static conditions together with data from a moving constant load analysis do not provide the same estimates of pavement life than when static load analysis are used exclusively (Chapter 7);

n. The use of percentile values of the dynamic tyre load population, rather than an equivalent static 80 kN axle load in pavement response analyses cause significantly different pavement responses which ultimately can be used to develop a population of possible pavement responses (Chapter 7);

o. The use of moving dynamic loads and equivalent dynamic pavement response parameters in pavement analyses is possible and can provide adequate estimates of the expected pavement life (Chapter 7), and

p. Moving constant and moving dynamic loads can affect pavement response analyses significantly and should be applied with good engineering judgment (Chapters 6 and 7).

8.5 Recommendations

The following primary recommendations are made based on the information in this thesis. The chapter on which the specific conclusion is based is shown in brackets:

a. A sensitivity analysis of the effect of variations in vehicle and pavement component characteristics on pavement response analysis should be performed (Chapters 2, 5 and 6);

b. A study should be performed to determine the mechanistic relationship between vehicle characteristics (i.e. combination, and component types) and pavement roughness to develop mechanistic equations for predicting the tyre load populations of vehicles (Chapter 5);

c. The effect of accelerating, decelerating and cornering on dynamic tyre loads should be investigated (Chapter 5);

d. The effect of different suspension systems on dynamic tyre loads should be investigated (Chapter 5);

e. The effect of actual (non-uniform) contact stresses between tyres and the pavement during dynamic tyre loading should be investigated (Chapter 5);

f. An investigation regarding improvement of current transfer functions to incorporate moving dynamic loads and non-linear elastic material models on South African pavements should be performed (Chapter 6);

g. The effects of non-linear (and other) material models on vehicle-pavement interaction should be investigated (Chapter 6);

h. A study should be performed to develop a simple 3-dimensional transient vehicle-pavement interaction model that can be used to model the moving dynamic load transient response of a pavement structure (Chapters 6 and 7), and

i. A mechanistic relationship should be developed between the static and dynamic response parameters of various pavement materials to enable a mechanistic (and not empirical as in this thesis) conversion between static and dynamic response parameters (Chapters 6 and 7).