8. EXPERIMENTAL VALIDATION OF THE EFFECT OF BRAKING TORQUE TO BOGIE DYNAMICS: PART C. COMPARISON WITH THE SIMULATION

8.1. INTRODUCTION

This chapter reports the comparison between the experimental results and the results of the simulations using the RBD program developed as part of this thesis. The parameters considered were the longitudinal acceleration / deceleration, speed profile, angular velocity and slip. The input was the applied brake torque to the trailing wheelset. The wheel-rail friction coefficient used in the simulation was set as 0.18, which was the average value (of 0.15-0.20) obtained from the skid level forces measured from the experiments described in Chapter 7. This value of the friction coefficient was found to be the most representative capable of providing the best result of the simulation as indicated by a series of sensitivity studies..

8.2. MODELLING OF THE BOGIE USED IN THE EXPERIMENT

8.2.1. Bogie Properties

The bogie used in the experiment was modelled as a system containing two wheelsets and one mass (the bolster and the side frames were regarded as one sprung mass), the arrangement of which was the same as that of the model presented in Chapter 5. The mass properties and the dimensions of the bogie are presented in Table 8.1 and Table 8.2 respectively. The dimension and the mass of the bogie were the actual values measured from the bogie used in the experiment; the mass moments of inertia were calculated assuming even distribution of the body mass.

Table 8.1. Inertia properties of the bogie components used in the experiment

	Wheelset	Sprung Mass
Mass (kg)	1050	1480
Mass moment of inertia I_{xx} ($\mathrm{kg \cdot m^2}$)	450	2,000
Mass moment of inertia I_{yy} ($\mathrm{kg \cdot m^2}$)	90	1,500
Mass moment of inertia I_{zz} ($\mathrm{kg \cdot m^2}$)	450	2,500

Table 8.2. Dimensions of bogie used in the experiment

	Measured value (m)
Wheel base	1.675
Lateral distance between primary suspension	0.8
Nominal wheel radius	0.398

8.2.2. Wheel and Rail Profile

Prior to the execution of the experiment, the wheel and the rail profile were measured using the MiniProf tool (see Section 6.3). The rail profile was measured at every 1 m interval and the profile of each wheel was measured at four points (90 degree interval). Samples of measured profiles can be seen in Appendix III. For the purpose of the simulation the measured profile data were averaged. Fig. 8.1 shows the measured wheel profile (average) used in the experiment compared to the LW2 profile and Fig. 8.2 shows the measured rail profile (average) used in the experiment compared to the AS

60kg/m rail profile (LW2 profile and AS 60 kg/m rail profile were used for simulations reported in Chapters 4 and 5).

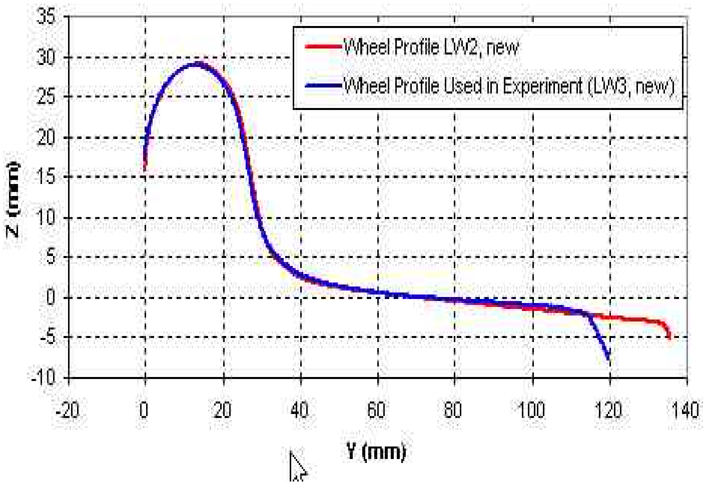

Figure 8.1. Wheel profile used in experiment (LW3) compared to LW2 profile

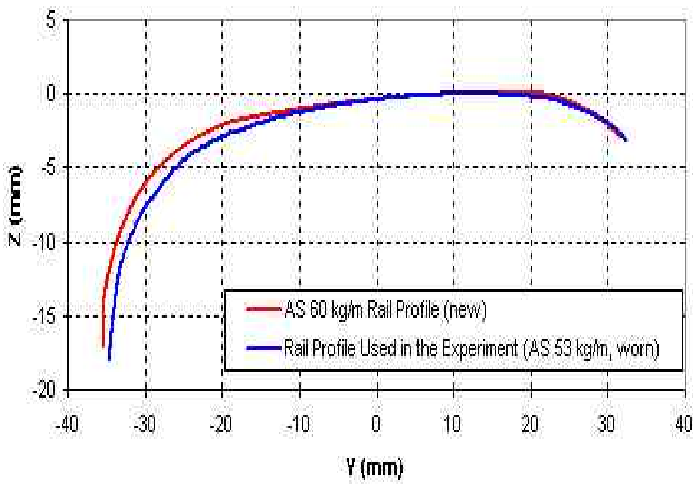

Figure 8.2. Rail profile used in experiment compare to UIC-60 profile

8.3. COMPARISON OF THE RESULTS

The simulation used the measured forces/torques from the experiments as the input. Because the experiments only measured the applied forces/torques of braking, thus the simulation was performed for the braking phase only. The initial speed input for the simulation was the nominal speed obtained during the coasting (steady state) phase before the brake was applied. To represent the actual condition of the test, a constant torque (65 kN.m) that represented the rolling resistance was required to be added to the input brake torque.

8.3.1. Simulation of Case #1 (Brake Pressure = 130 kPa)

Input brake torque

The input brake torque for the simulation of Case #1 is shown in Fig. 8.3. It is the average value of the brake torques gathered from the four trials of the experiments presented previously in Section 7.2.

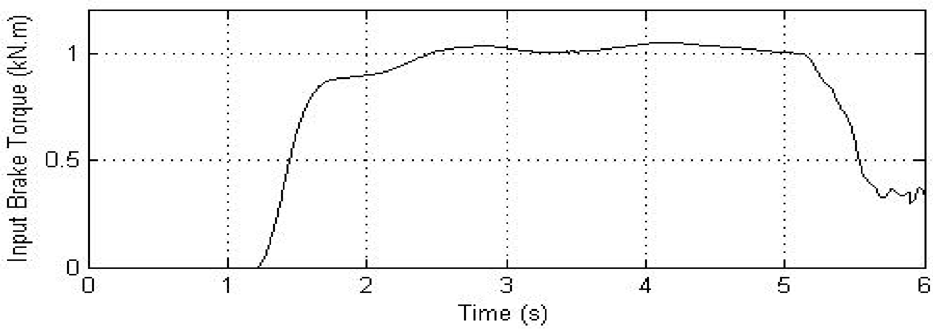

Figure 8.3. Input brake torque for simulation of Case #1

Output deceleration

Fig. 8.4 presents the calculated acceleration profile from the RBD simulation compared to the experimental results of Case #1. This figure reveals that the output acceleration profile of the simulation agrees very well with the measured experimental values, vindicating the accuracy of the formulation and the programming of the RBD program.

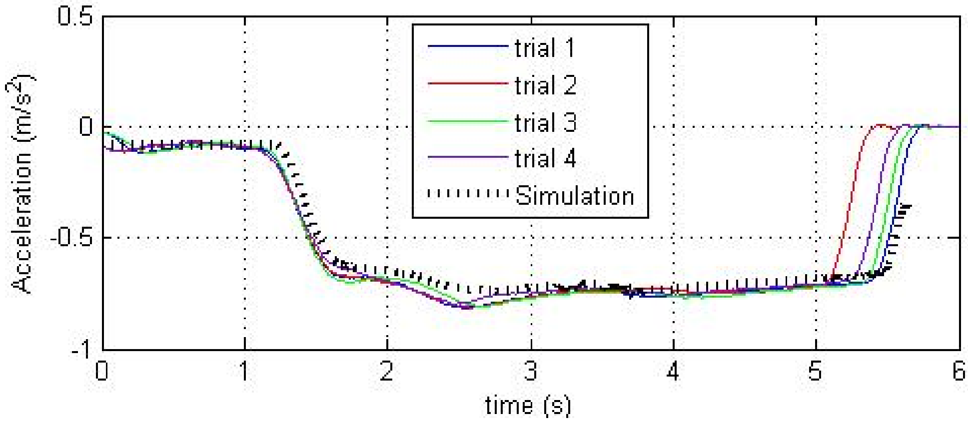

Figure 8.4. Simulation output of Case #1: deceleration

Output speed profile and angular velocity

The output speed profile and the angular velocity of both wheelsets for Case #1 is exhibited in Fig. 8.5.

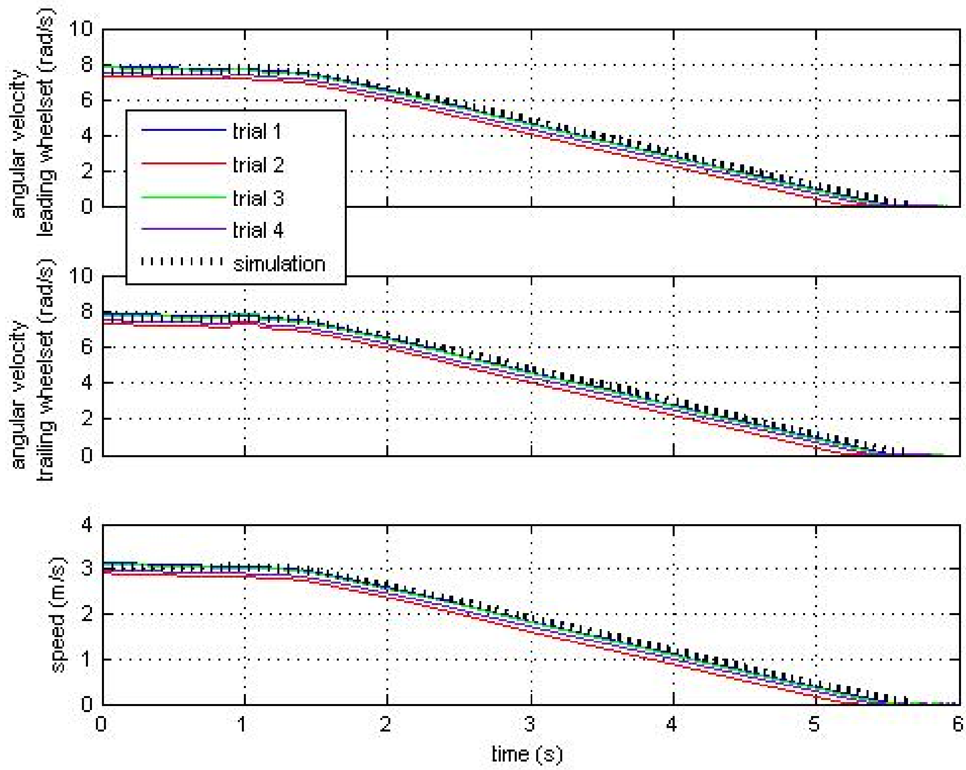

Figure 8.5. Simulation output of Case #1: speed profile and angular velocity

The input nominal initial speed for the simulation was set as 3 m/s. From Fig. 8.5, it can be seen that the RBD program calculates the speed profile and the angular velocity very well in comparison to the experimental results.

Output slip

Fig. 8.6 shows the comparison between the slip calculated by the RBD program and the experimental result for the Case #1. The maximum slip calculated by the RBD program was smaller than the experiment results. However the RBD program predicted the time of occurrence of the maximum slip comparable with the experimental results (around t=2.5s).

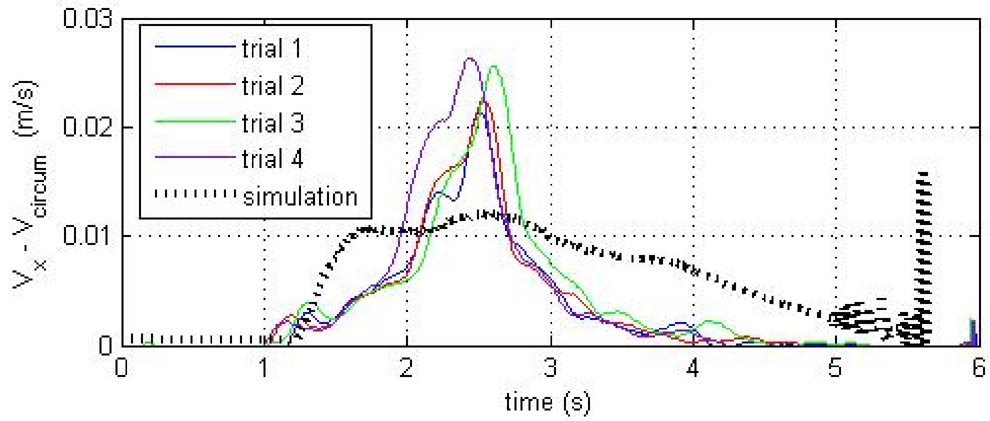

Figure 8.6. Simulation output of Case #1: slip

The areas under the slip curves that represents the energy dissipated due to braking are comparable to each other. Fig. 8.6 shows that the RBD program calculated instantaneous peak of the slip differed to the experimental prediction. In spite of this disagreement at micro-level, the RBD program in general calculates the global behaviour such as the acceleration (Fig. 8.4) and the speed profile (Fig. 8.5) correctly. It seems that the creepage-creep relationship used in the RBD program (the standard

Polach method) was able to generally model the overall dynamics but not the wheel-rail contact detail accurately especially for low values of slip. Future research opportunities exist to improve the creepage-creep force relationship during braking. Another issue that requires consideration is the maximum magnitude of slip for this case, which is very small (≈ 0.025 m/s in Fig. 8.6) and can be regarded as micro-slip. Creepage-creep force relationship due to the slip of such small magnitudes will be more likely affected significantly by the surface condition (tribological properties), which are considered beyond the scope of this thesis.

8.3.2. Simulation of Case #2 (Brake Pressure = 150 kPa)

Input brake torque

The input brake torque for the simulation of Case #2 is shown in Fig. 8.7. It is the average value of the brake torques gathered from the four trials of the experiments presented previously in Section 7.3.

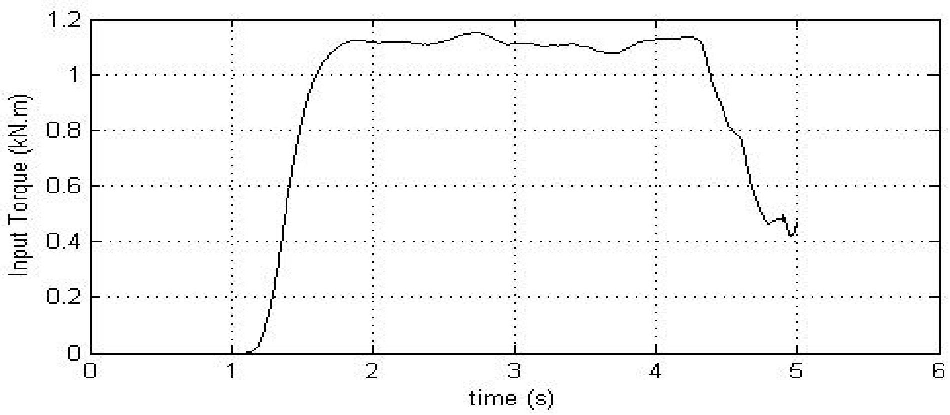

Figure 8.7. Input brake torque for simulation of Case #2

Output deceleration

Fig. 8.8 presents the calculated deceleration from the RBD simulation. The experimental results of Case #2 are also shown in the figure. The output of the simulation agrees very well with the experimental results, once again re-assuring the accuracy of the formulation and programming of the RBD program.

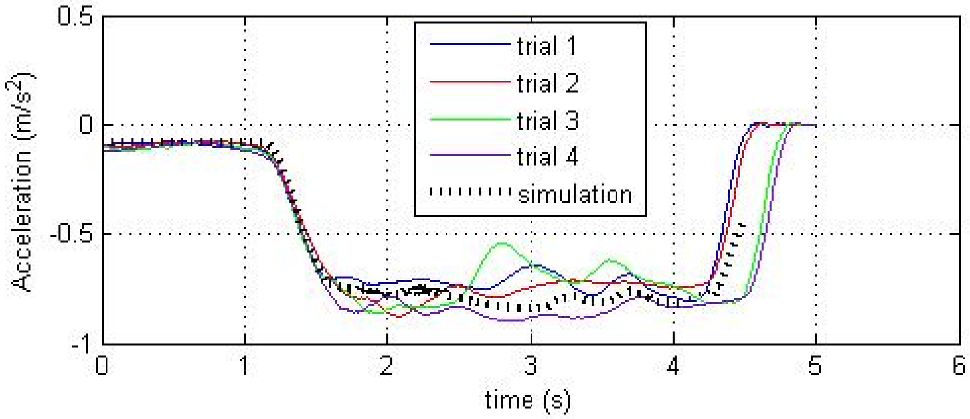

Figure 8.8. Simulation output of Case #2: deceleration

Output speed profile and angular velocity

The output speed profile and the wheelset angular velocity of the simulation are presented together with the experimental results of Case #2 in Fig. 8.9.

The nominal initial speed was set as 2.5 m/s. From Fig. 8.9, it can be seen that the RBD program predicted no skid condition has agreed well with the experimental results of trials 2 and 4. Without having detailed creepage formulation allowing for tribological surface parameters, it was not possible to predict skid that happened in trials 1 and 3 of the experiment. In other words, from the parameters considered in the simulation, for the wheel and rail profile and the friction coefficient used, and the initial speed specified, prediction is that the bogie will experience no wheelset skid. The trials that exhibited skid in the experiment could be regarded as some special cases where some parameter has slightly varied unfavourably.

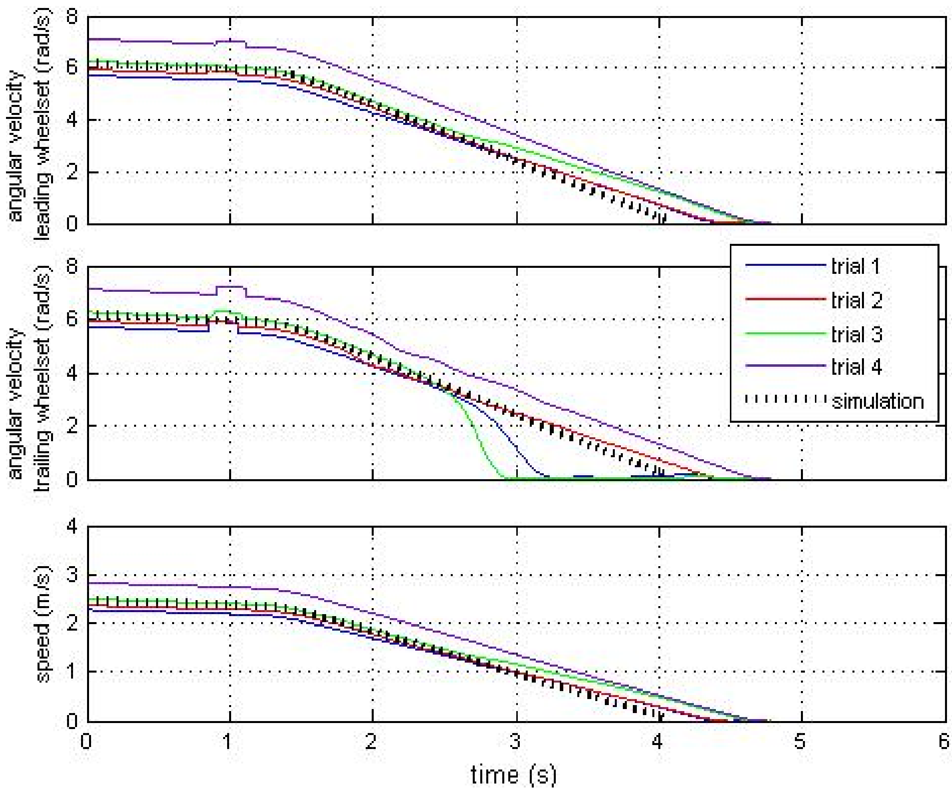

Figure 8.9. Simulation output of Case #2: speed profile and angular velocity

Output slip

Fig. 8.10 shows the slip calculated by the RBD program and the experimental result for Case #2. The maximum slip calculated by the RBD program, which predicted no skid, was smaller than the experiment results of trials 1 and 3 where the skid occurred. However compared to the experimental trials 2 and 4 where no skid occurred, the slip calculated by the RBD program was marginally larger. It should be noted that the vertical axis of the graph shown in Fig. 8.10 represents 50 times larger slip compared to the vertical axis of the graph in Fig. 8.6 (Case#1).

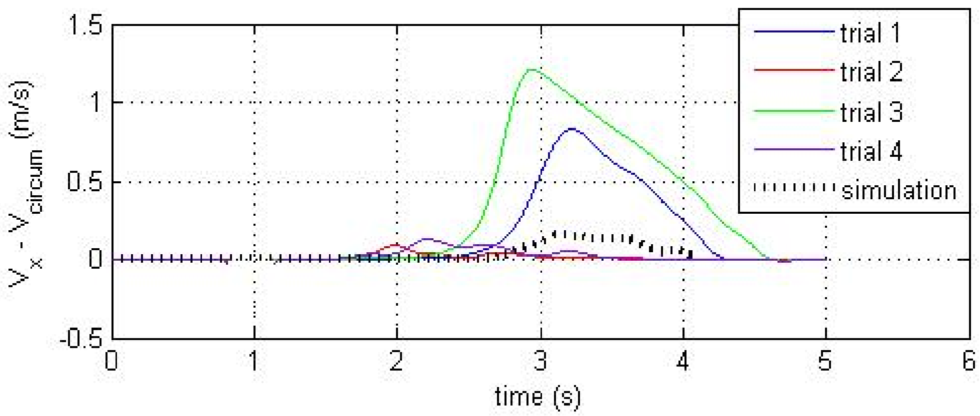

Figure 8.10. Simulation output of Case #2: slip

8.3.3. Simulation of Case #3 (Brake pressure = 180 kPa)

Input brake torque

The input brake torque for the simulation of Case #3 is shown in Fig. 8.11. It is the average value of the brake torques gathered from the four trials of the experiments presented previously in Section 7.4.

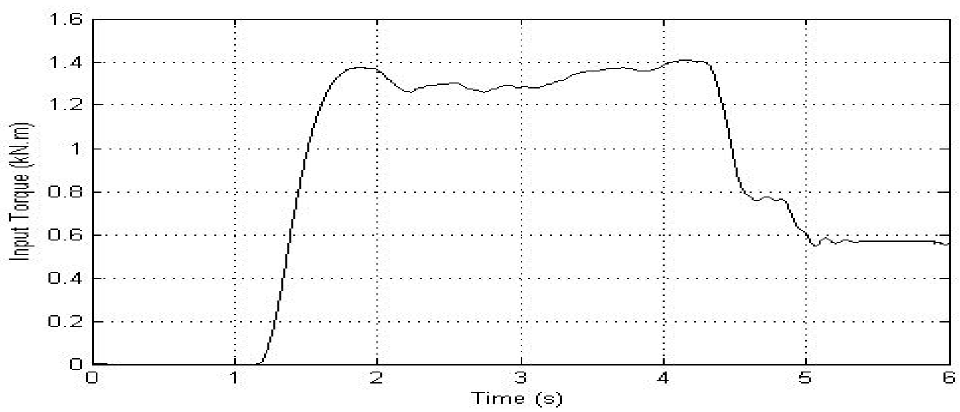

Figure 8.11. Input brake torque for simulation of Case #3

Output deceleration

Fig. 8.12 presents the calculated deceleration from the RBD simulation and the experimental results of Case #3. The output deceleration of the RBD simulation was found to compare very well with the experimental values. Once again, the ability of the RBD program to deal appropriately with such severe dynamics cases is illustrated through this case.

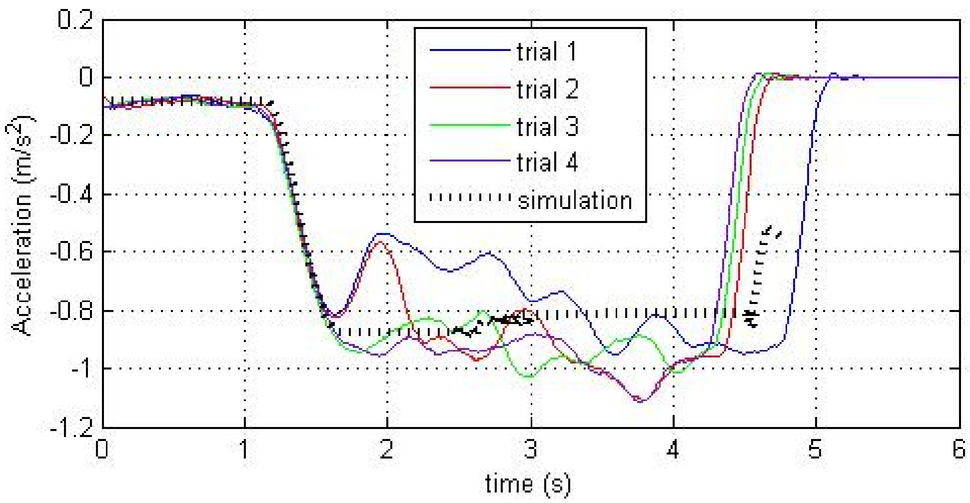

Figure 8.12. Simulation output of Case #3: deceleration

Output speed profile and angular velocity

The output speed profile and the wheelset angular velocity of the simulation and the experimental results of Case #3 are exhibited in Fig. 8.13. The nominal initial speed was set as 2.9 m/s in the simulation. From Fig. 8.13, it can be seen that the RBD program calculated speed profile and angular velocity agree very well with the experimental results. The RBD program has also predicted the occurrence of skid due to large brake torque applied, which is appropriate and consistent with the experimental observations.

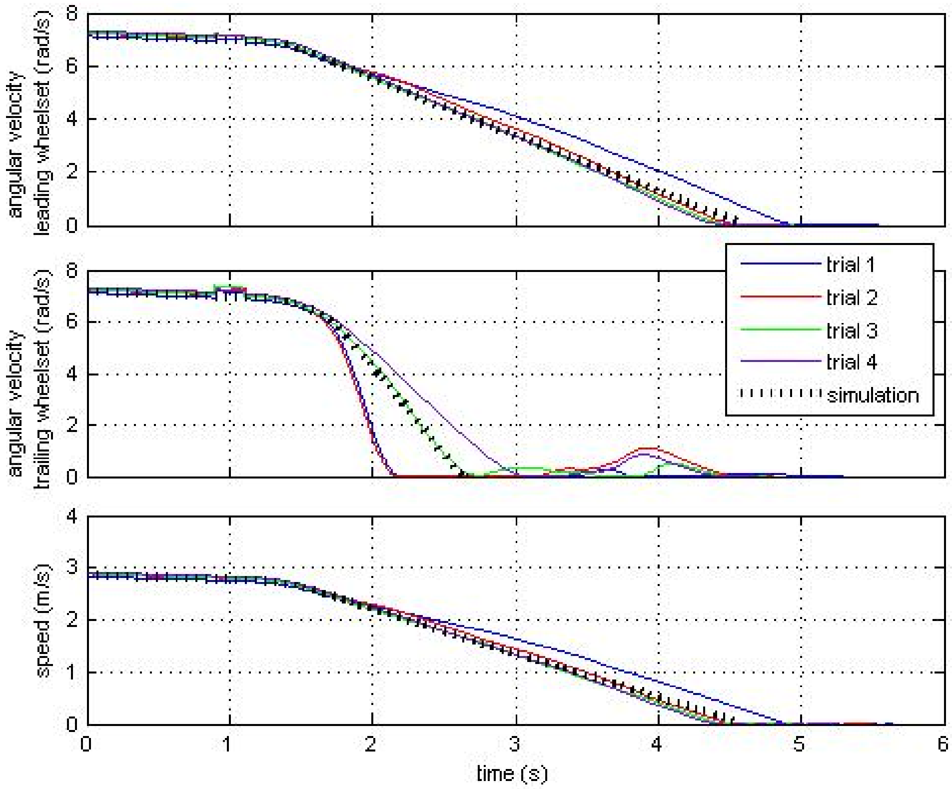

Figure 8.13. Simulation output of Case #3: speed profile and angular velocity

Output slip

Fig. 8.14 shows the slip calculated by the RBD program and the experimental result for Case #3.

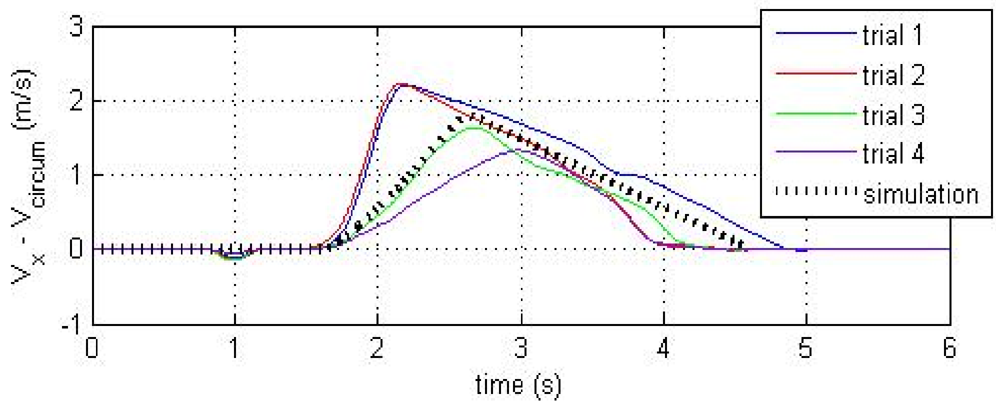

Figure 8.14. Simulation output of Case #3: slip

The RBD program predicted one hundred percent slip (skid) occurring at the speed of 1.8 m/s, at t=2.7s, very close to the values obtained during trial 3 of the experiment Case #3. The order of magnitude of the slip which occurred in this case is approximately 70 times larger than the trials in Case#1. For such larger cases of slip, the creepage – creep force relationship used in the RBD program (standard Pollach method) appears appropriate.

8.4. SUMMARY AND CONCLUSION

Computer simulation of the experiment using the RBD program has been performed and the simulation results have been compared to the data gathered from the experiment. Important conclusions drawn are as follows:

- RBD program simulates the longitudinal dynamics of the bogie used in the experiment under the application of brake very well. The results of the simulation are generally very close to the data obtained from the experiment.

- Although the RBD program did not calculate the instantaneous peak of the slip during the application of the brake without skid, especially for very low values of slip, the program can generally calculate the acceleration and the speed profile correctly. It seems that the creepage-creep relationship used in the RBD program (the standard Polach method) was able to generally model the overall dynamics but not the detail of wheel-rail contact (creepage-creep forces relationship) for such conditions. This observation opens the possibility for future research opportunities to improve the creepage-creep force relationship during braking, where large instantaneous longitudinal creepage occurs.

- The RBD program could now be regarded as being validated for most practical conditions including severe dynamics/skid.