Vehicle Dynamic Analysis Using Virtual Proving Ground Approach

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Structural integrity of either a passenger car or a light truck is one of the basic requirements for a full vehicle engineering and development program. The results of the vehicle product performance are measured in terms of ride and handling, durability, noise/vibration/harshness (NVH), crashworthiness and occupant safety. The level of performance of a vehicle directly affects the marketability, profitability and, most importantly, the future of the automobile manufacturer. In this study, we used the virtual proving ground (VPG) approach for obtaining the dynamic characteristics. The VPG approach uses a nonlinear dynamic finite element code (LS-DYNA3D) which expands the application boundary outside the classic linear static assumptions. The VPG approach also uses realistic boundary conditions of tire/road surface interactions. To verify the predicted dynamic results, a single lane change test has been performed. The prediction results were compared with the experimental results, and the feasibility of the integrated CAE analysis methodology was verified.

Key Words: Ride and Handling, Noise/Vibration/Harshness (NVH), VPG Approach, Lane Change, Dynamic Characteristics

1. Introduction

In the vehicle development process, to improve a vehicle's dynamic characteristics, its fatigue intensity, and its NVH and crashworthiness, and expense are required to compete in the current market. With the recent rapid developments in computer CPU capabilities and application softwares, however, a dynamic analysis and durability design using CAE tools is now possible even before a prototype is developed. This reduces the time and cost required for testing.

In order to construct the perfectly integrated CAE environment, this study aims: (1) to develop a VPG Approach which is capable of producing the results required in a single process, a single model, a single program; (2) to propose a method which can dramatically reduce the time and manpower required to construct a model to analyze vehicle dynamics, quasi-static stress, and fatigue; and (3) to develop an analysis method

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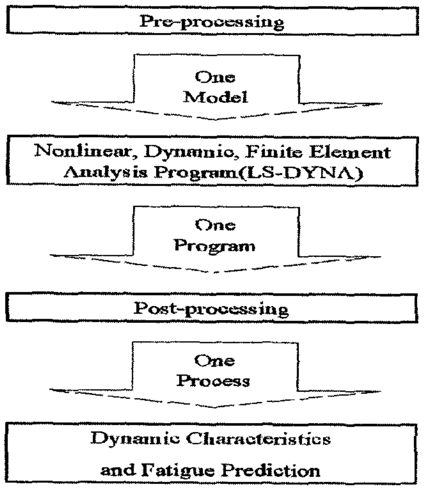


Fig. 1 The routine for vehicle dynamic and fatigue strength evaluation using VPG Approach

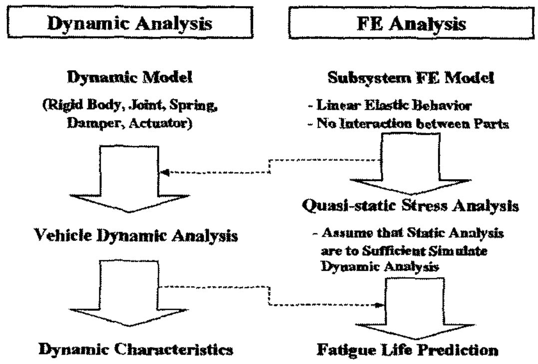


Fig. 2 Current methods and assumptions

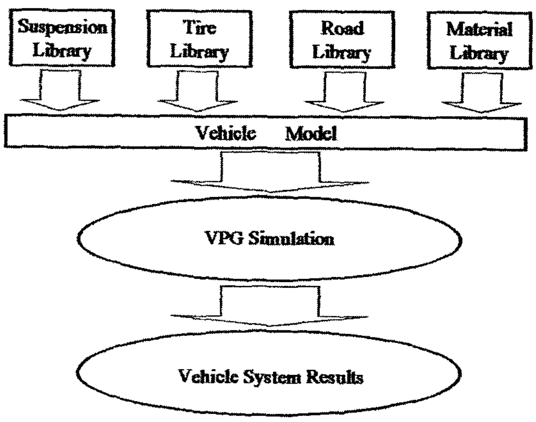


Fig. 3 The VPG concept

which enables an accurate vehicle dynamics analysis without changing the dynamic stress model by improving the existing VPG approach (Choi et al., 2000) Figure 1 shows the analysis routine using the VPG Approach.

2. Differentiation from Existing Analysis Approaches

The object vehicle's front-wheel suspension has an independent form with double wishbone type ; the rear-wheel suspension has an axle suspension form with four links. For the model simulation, the vehicle drove straight at a speed of 80 km/h and then changed lanes from left to right at regular 30m intervals. The aim was to predict such dynamic response characteristics as lateral displacement and acceleration from the vehicle's centroid, the roll and yaw angle, as well as the roll and yaw rate. In Vehicle Dynamic Analysis (a multi-object dynamic program) which has been mainly used until now, it is difficult to determine a finite element, which is in turn used to analyze stress, NVH, crashworthiness, and so on.

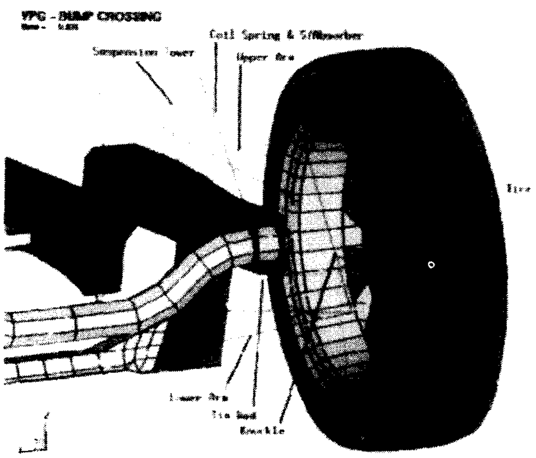
Recently, through a data exchange between the multi-object dynamic analysis program and the finite element program, a pliable multi-object dynamic analysis approach in which flexibility can be considered has been emerged (Yoo and Haug, 1985). Nevertheless, the finite element analysis model and the dynamic analysis model continue to be used as before, though in a different program, so that two mathematical models with different characteristics now exist.

For this analysis, it was impossible to analyze the existing vehicle dynamics and quasi-static stress using the same software as shown in Fig. 2. Too much time and money was needed for the data interface between softwares.

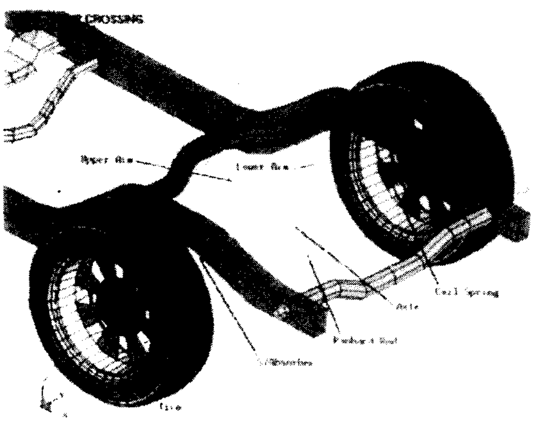
Using the VPG Approach, however, the cost for analysis can be reduced as both dynamic analysis and stress analysis can be carried out simultaneously using the same software (Zhang and Tang, 1996). The basic VPG concept is graphically shown in Fig. 3.

3. Vehicle Dynamic Analysis Model

The object vehicle is a jeep-type vehicle with a



(a) Front



(b) Rear

Fig. 4 Tire and suspension model

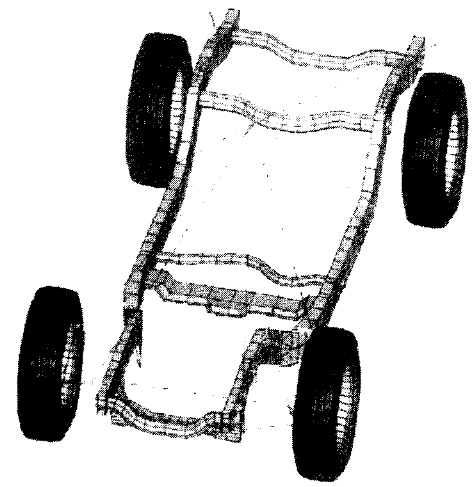


Fig. 5 80 km/h lane change simulation model

frame. It was assumed that all parts were rigid except the frame and tires. The tires, which were fixed to the rim of the wheel, played a role in absorbing percussion from the road surface and enabling better driving, direction-controlling and braking. In this study, thin shell and solid elements were used for modeling the most realistic tire (eta/VPG Manual, 1994 ; LS-DYNA Manual, 1994 ; Zhang, 1993).

Using DADS and ADAMS dynamic analysis programs, the suspension system was modeled by connecting the joint, spring, damper, and actuator. Fig. 4 shows the finite element models of the front and rear tire and suspension systems. The tire was made of simulated rubber ; the axle links and suspension system were modeled with rigid bodies (beam elements) (Tang et al., 1995 ; Zhang et al., 1997 ; Majcher et al., 1976). Fig. 5 illustrates the general analysis model.

4. 80 km/h Lane Change Simulation

This simulation was carried out under the assumption that the vehicle was driving at a speed of 80 km/h on a level asphalt-paved road and then changed lanes from left to right at regular intervals of 30 m. The lane changes were marked by rubber cones. For the simulation, the occupant capacity was at its full driving capacity. The vehicle's standard air pressure was adapted to its tires' air pressure, and it was assumed that the road surface was dry. The steering angle input, which is one of the most critical factors for analysis, was controlled not from the steering wheel directly, but from the gear box outlet to the knuckle itself. That is for analytic convenience, the section from the steering wheel to the inlet of the gear box was not considered.

Figure 6 shows the vehicle's route through the simulated 80 km/h land change course using the VPG Approach. Figure 7 to 10 illustrate the lateral displacement and acceleration from the vehicle's centroid, the roll and yaw angles, the roll and yaw velocities, as well as the wheel center load histories. In all of the above figures, the lane changes begin after a 1 second period, so that no analysis results before 1 second are shown.

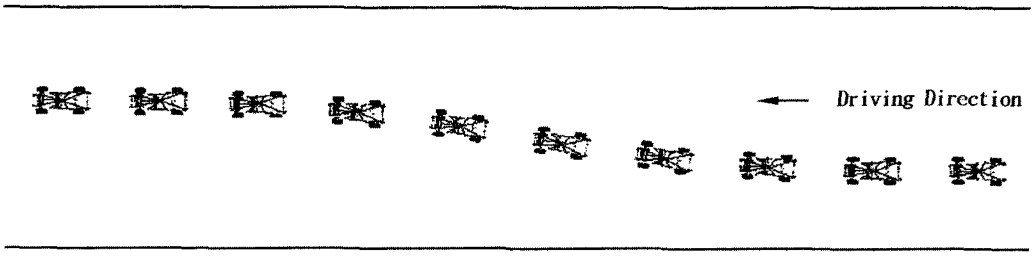
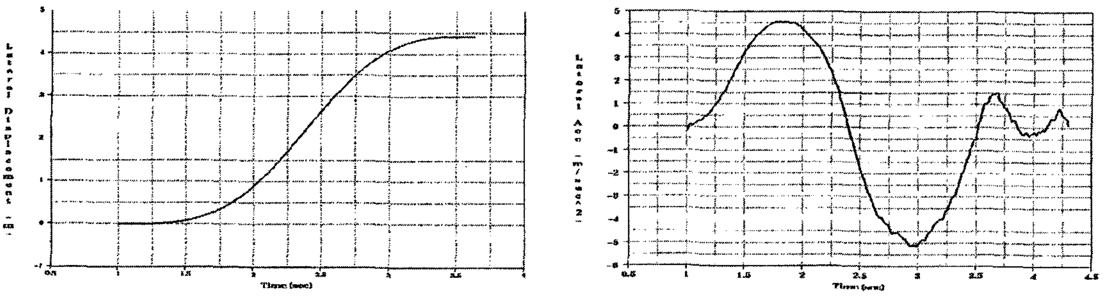
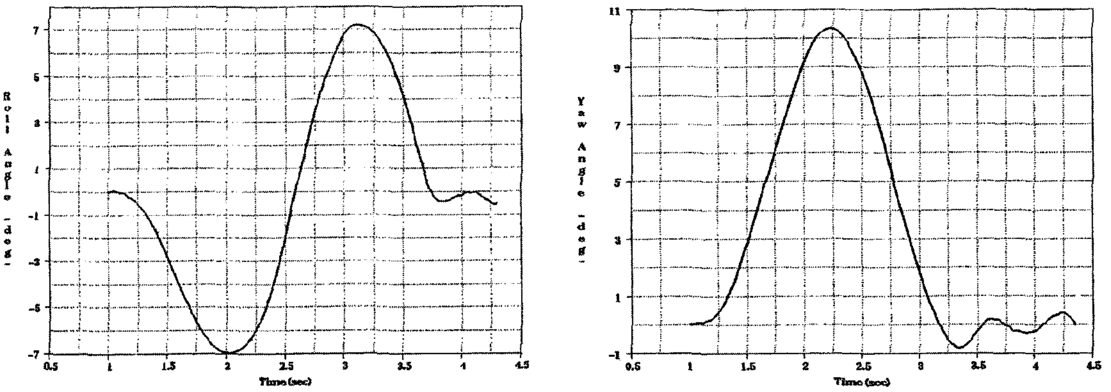


Fig. 6 Graphic animation of 80 km/h lane change simulation



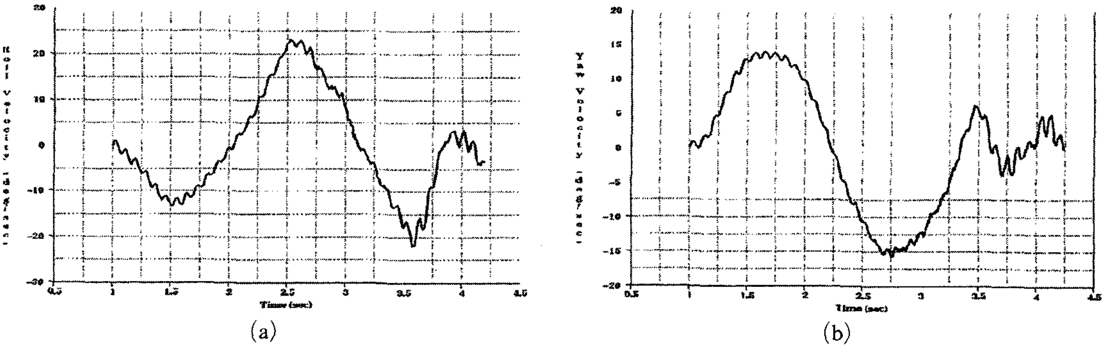
(a) (b)

Fig. 7 Lateral displacement and acceleration of 80 km/h lane change simulation



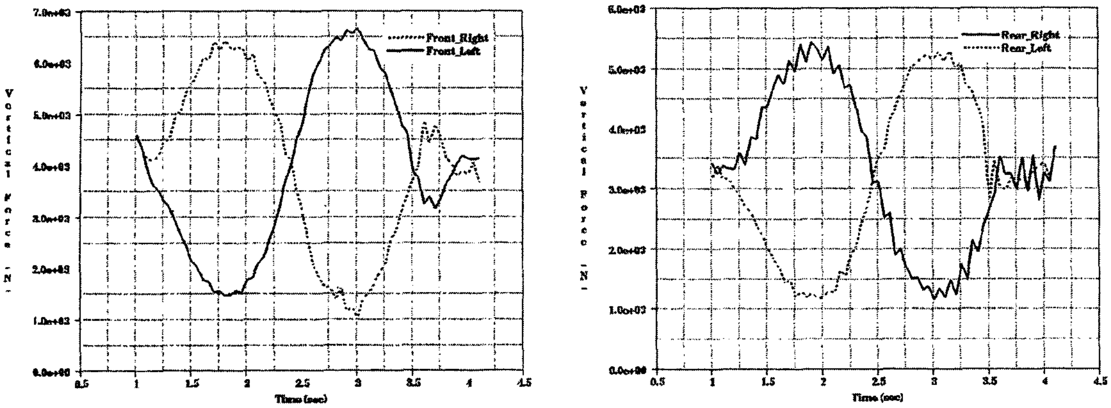
(a) (b)

Fig. 8 Roll and yaw angles of 80 km/h lane change simulation



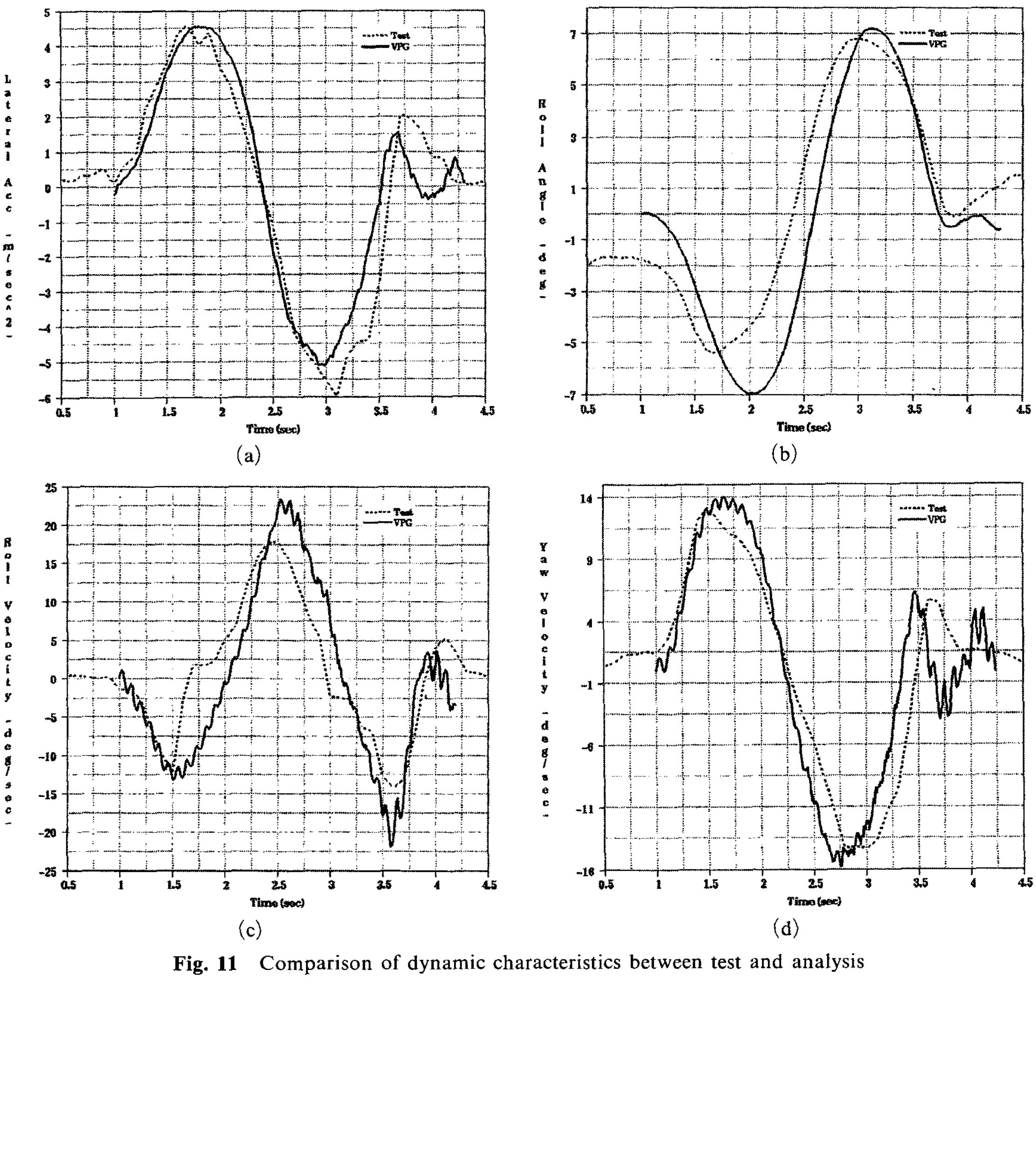
(a) (b)

Fig. 9 Roll and yaw velocities of 80 km/h lane change simulation



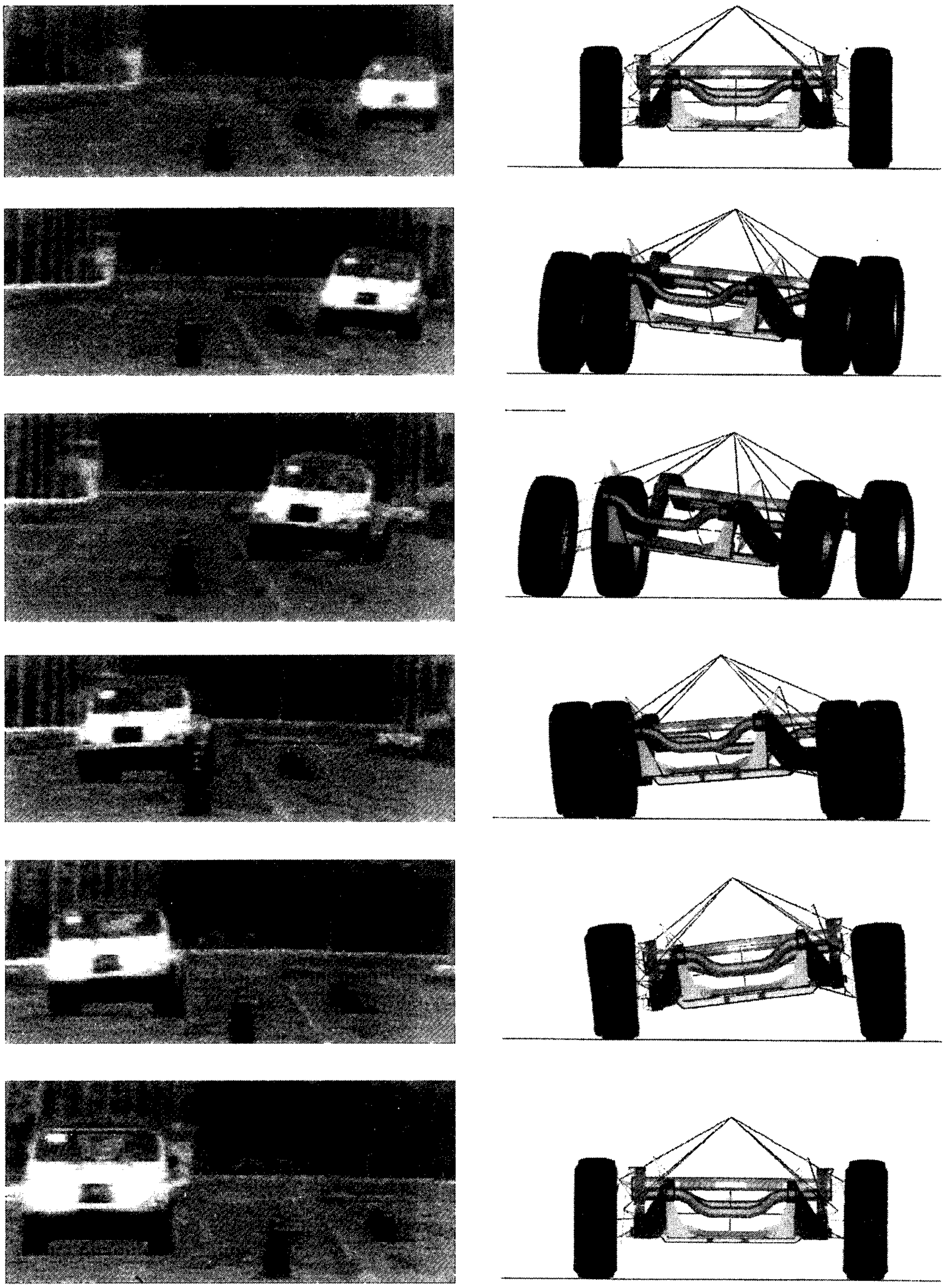
(a) (b)

Fig. 10 Wheel center load histories of 80 km/h lane change simulation



(a) (b) (c) (d)

Fig. 11 Comparison of dynamic characteristics between test and analysis



(a) Test (b) VPG Analysis

Fig. 12 Comparison of vehicle motion between test and analysis

5. Comparison Between Analysis and Experimental Text Results

After the 80 km/h lane change test, there were few differences between the analysis results for the vehicle's centroid dynamic charcteristics and the experimental results. These differences are shown in Fig. 11. The results for the lateral acceleration from the vehicle's centroid, the roll angles and velocities, as well as the yaw velocities, were obtained from the vehicle lane change test. This test was carried out under the same conditions as the vehicle analysis.

In case of the roll angle, there were relatively large differences between the experimental and the analysis results, as compared to other factors. It seems that, as the test road was not perfectly flat, the vehicle traveled in an yawing state before changing lanes. There were also somewhat irregular results in the comparison between the roll and yaw velocities, as compared to the real test results. This is because the data recording time interval was different in each one. If the time interval between the real test and the analysis had been identical, the real test results indicated by the dotted line might also have been irregular, as were the analysis results indicated by the solid line.

Figure 12 shows the test vehicle's front pictures at the regular time interval during the land change test, as well as the animation cuts of the test analysis. It should be noted that the graphic animation cuts of the analysis results and the real test vehicle's front pictures demonstrate similar behavior patterns.

6. Conclusion

In this study, using the VPG Approach to simulate real road driving conditions, an integrated CAE environment was used to test vehicle's performance, ranging from crashworthiness to dynamics and fatigue analysis, using a single analysis model and application software. The results obtained were as follows :

(1) A better dynamics analysis has been developed using the VPG Approach, which reduces the manpower and cost required as compared to existing methods of analysis.

(2) The time required to model the vehicle's dynamic analysis can be reduced because single crash analysis model can be used for all vehicles.

(3) A foundation has thus been constructed to carry out the crashworthiness, dynamics and fatigue analysis of a vehicle's development under the perfectly integrated environment.

(4) The VPG Approach which is presented in this study can be utilized to analyze not only dynamics and fatigue, but also NVH, or the kinematicism of the suspension system.

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