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VEHICLE DYNAMIC SIMULATION USING A NONLINEAR FINITE ELEMENT ANALYSIS CODE

Y. S. YU[1)*], K. Z. CHO[1)] and I. B. CHYUN[2)]

[1)]Department of Mechanical Engineering, Chonnam National University, Gwangju 500-757, Korea
[2)]Commercial Vehicle Research Center, Hyundai Motor Company, Wanju-gun, Jeonbuk 565-904, Korea

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ABSTRACT–The 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, the Virtual Proving Ground (VPG) approach has been developed to simulate dynamic nonlinear events as applied to automotive ride & handling. The finite element analysis technique provides a unique method to create and analyze vehicle system models, capable of including vehicle suspensions, powertrains, and body structures in a single simulation. Through the development of this methodology, event-based simulations of vehicle performance over a given three-dimensional road surface can be performed. To verify the predicted dynamic results, a single lane change test was performed. The predicted results were compared with the experimental test results, and the feasibility of the integrated CAE analysis methodology was verified.

KEY WORDS : Ride and handling, Event-based simulation, Nonlinear finite element method, Driving conditions

1. INTRODUCTION

Accurate analysis results for the design and development of vehicle structure are extremely critical for the accurate prediction and optimization of the subsystems and full vehicle. The typical procedure for evaluating dynamic characteristics relies on the empirical method using measurements from predecessor vehicles or early prototype vehicles. While this provides a means of guiding preliminary design, errors in the data may add uncertainties to the prediction and the resulting design decisions that are made based on these results.

The FEA based simulation method provides a powerful tool for predicting dynamic characteristics for CAE engineers before a prototype is built. The method used in this current study, known as VPG, is a set of techniques used with an explicit, dynamic analysis program. The VPG method allows for the complete analysis of a mechanical system, including all joints, bushings, springs, materials, and geometric non-linearity using an event based analysis (Choi, 2000; Suh *et al.*, 2002). The design problems targeted for this method are those in which a mechanical system is to be analyzed in a dynamic sense. In other words, when a mechanical system is in use, displacement, forces, accelerations, and stresses occur in real time. This method provides an event based simulation solution for nonlinear, dynamic problems and overcomes the limitations of existing CAE analysis methods. Unlike the CAE analysis methods, the VPG approach is capable of producing all the possible necessary results with just one model, one program, and one process. Figure 1 shows the flow chart of analysis using the VPG approach. The key components of the technology required to perform these simulations are finite element code capability and the application of the finite element technology to vehicle simulations (Zhang and Tang, 1996). Challenges associated with the VPG method are currently focused on computing resources required to carry out these calculations. One drawback of this method is the computing resources required to carry out the calculations for the finite element code and the application of the finite element technology to vehicle simulations. However, this draw back is offset by more efficient and cheaper computing resources which are the result of the constant advances in computer technology.

**Corresponding author.* e-mail: taue@chol.com

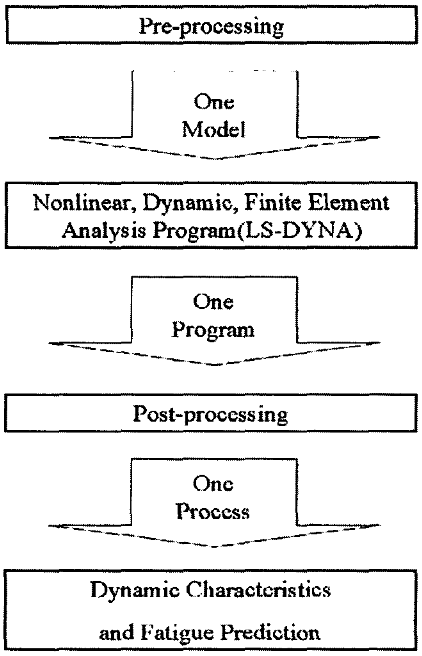


Figure 1. The routine for vehicle dynamic and fatigue strength evaluations using VPG approach.

2. DISTINCTIONS FROM PREVIOUS ANALYSIS APPROACHES

There are many difficulties associated with the use of finite element models which were constructed for stress, NVH and crash/safety analysis for vehicle dynamic analyses which use a rigid multi-body dynamic analysis program. However, a recently introduced flexible multi-body dynamic analysis can assign flexibility for each part through exchanges of data between the multi-body dynamic analysis program and the finite element program. Calculations still have to be performed in a separate program for both the finite element and dynamics analysis models (Bae *et al.*, 2000; Kim and Choi, 2003). Therefore, there exist two mathematical models that have different characteristics.

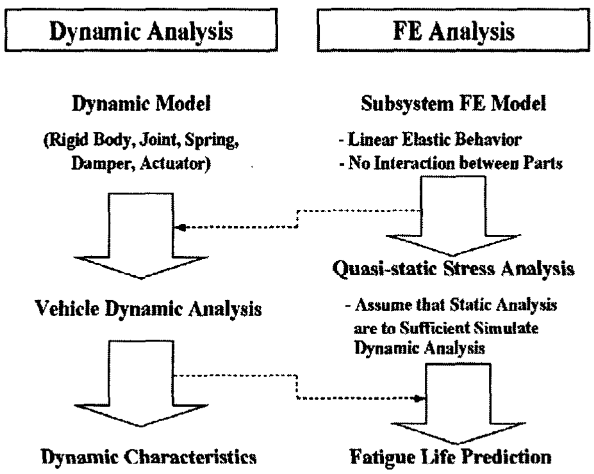


Figure 2. Current methods and assumptions.

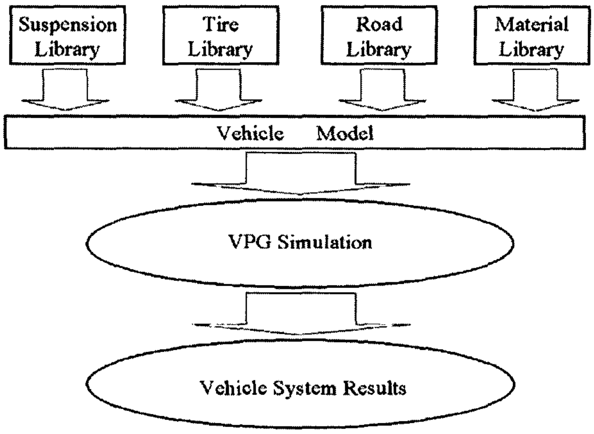


Figure 3. The VPG concept.

Figure 2 shows that with the FEA based method of performing the analysis it is impossible to perform an analysis using the same software for vehicle dynamics and finite element analysis, because the cost and time consumed for the data interface between two different software programs is very high.

In the VPG analysis approach, the dynamic analysis and stress analysis considering structural flexibility can be performed simultaneously which can reduce the cost of analysis. Figure 3 shows the basic concepts in the VPG analysis approach.

The VPG approach makes use of component finite element models, assembled using joints, and spring elements. This approach has the advantage of accounting for component flexibility and allows for the calculation of stresses during the analysis event. An additional advantage of inclusion of the flexible bodies is that it may provide the basis for a true full vehicle model, collecting real time stress data for each of the proving ground events. Inclusion of the flexibility has been shown to provide higher levels of correlation when compared to a rigid body modeling approach.

Once the full vehicle model is assembled, the analysis is carried out using a dynamic nonlinear finite element analysis approach. The commercially available program LS-DYNA is used as the general solver for this study. The LS-DYNA program has the ability to simulate component contacts, and allows the transmittal of forces between these components (Zhong, 1993). This ability allows for the analysis of large displacement events, such as a vehicle driving over an uneven road surface, traveling at operational speeds. The methodology used to analyze the proving ground events requires that the appropriate tire be added to the vehicle model. A frictional contact is defined between the road surface and the tire, accounting for tire dynamic friction. For purposes of most analyses, a typical value is used. However, the frictional coefficient may be altered to simulate a specific driving condition.

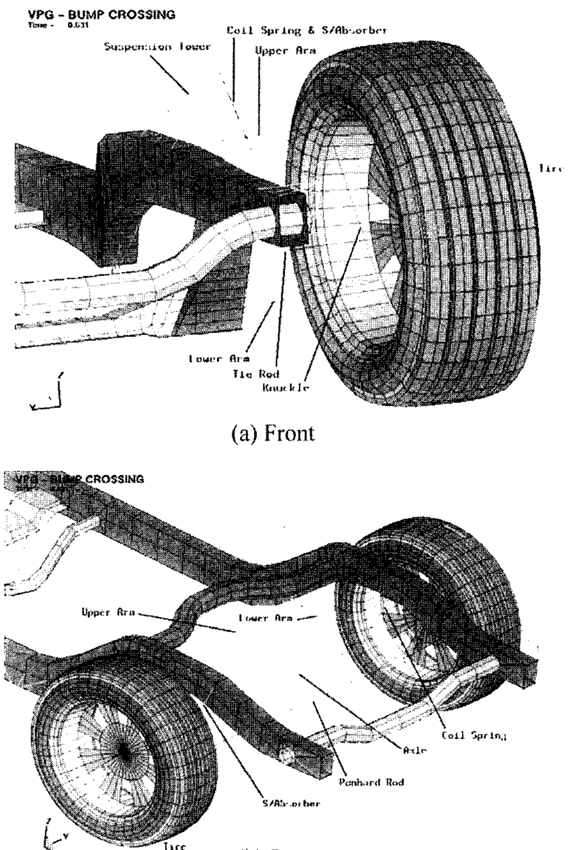
3. VEHICLE DYNAMIC ANALYSIS MODEL

The target vehicle was a jeep type passenger vehicle with a frame included. The suspension model was developed from component durability models for the various suspension components. The front suspension consists of a lower control arm, a upper control arm, a steering knuckle, a strut, and a tie rod. These components are attached as an assembly by means of joints and bushings. This assembly is then attached to the vehicle structure through bushings to the frame. The four link type rear suspension is composed of component models, assembled into a system. The rear suspension is made up of an axle, four links, a coil spring, a knuckle (hub), and a shock absorber. As with the front suspension, the rear suspension is attached through joints and bushings to the vehicle structure (Tang *et al.*, 1995).

Bushings are created by means of spring elements. For each bushing, a series of springs are defined. These elements have a stiffness value defined in a local coordinate system which corresponds to the orientation of the bushing.

To reduce the computation time, all other parts except the tires and frame are assumed to be rigid bodies. The tires attached to the wheel rim are rotating, absorbing impact energy from the ground and creating friction to enable the vehicle to drive, steer, and brake. In this study, thin shell and solid elements were used to make a much more realistic tire. Since the tire is the primary load transfer mechanism between the road surface and the vehicle, it is a vital component for performing VPG simulations. Efficient but accurate models of tires must be implemented, which have the ability to accurately transmit the road profiles with the correct amplitude and frequency content. The tire model used in this methodology was developed using published test data for radial and lateral stiffness, as well as the dynamic behavior of the tire/wheel combination. This data was incorporated into the model, providing a tire stiffness which correlates to an actual tire and empirical data.

In the VPG methodology, vehicle structure models are constructed in much the same manner as traditional durability finite element models. These models contain sufficient detail to predict stress levels in local areas of the structure, while maintaining a somewhat overall constant mesh density. Lumped masses are added to the



(a) Front

(b) Rear

Figure 4. Tire and suspension model.

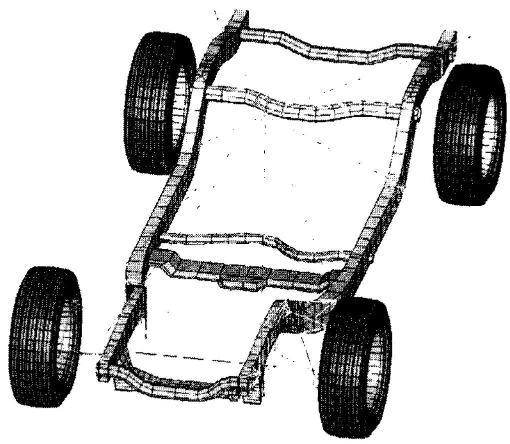


Figure 5. 80 km/h lane change simulation model.

model to account for all non-structural masses, as well as BIW, powertrain components, fuel tank, spare tire, tools, etc. Since the analysis technique used is based on explicit nonlinear finite element techniques, the use of small elements is discouraged in order to speed the analysis. The use of small elements results in increased computation requirements, which will increase the overall solution time.

Figure 4 shows the front and rear suspension systems, as well as the tire FE model. Rubber characteristics have been considered in the tire, and the links in the axle and suspension system have been modeled as rigid beams (Zhang and Tang, 1997; Majcher *et al.*). Figure 5 shows the entire model.

4. SIMULATION FOR LANE CHANGE AT 80 KM/H

This simulation assumes the following situation: A vehicle, having a velocity of 80 km/h, is driving on a flat paved road with a couple of pylons lying on the road at a distance of 30m intervals. The vehicle changes lanes through the rubber cones. This type of simulation is used to predict the dynamic response characteristics such as lateral displacement, lateral acceleration, roll angle, yaw angle, roll velocity and yaw velocity at the point of the

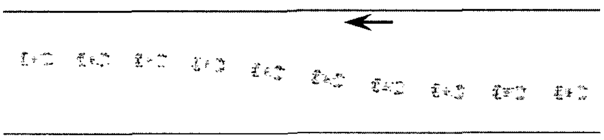
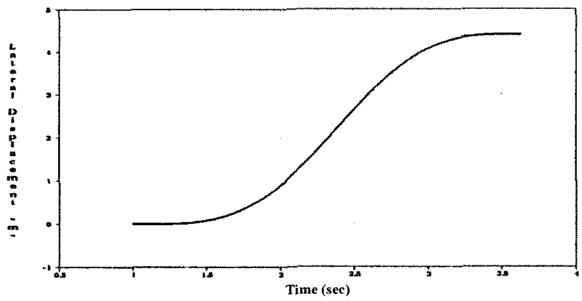
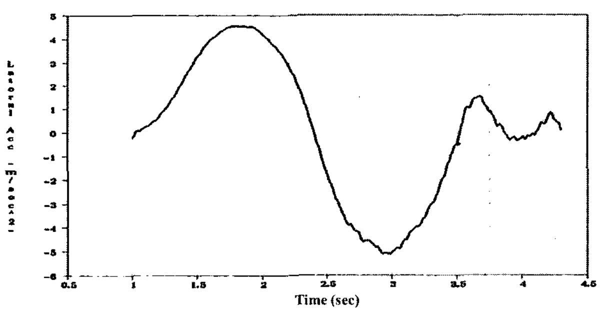


Figure 6. Graphic animation of 80 km/h lane change simulation.

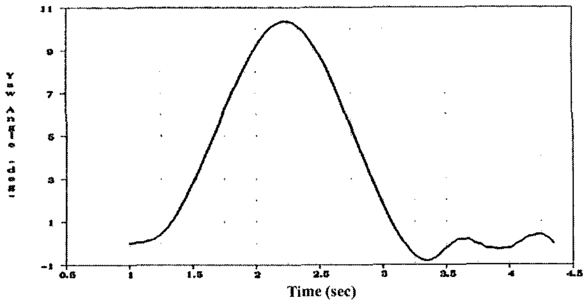


(a) Lateral displacement

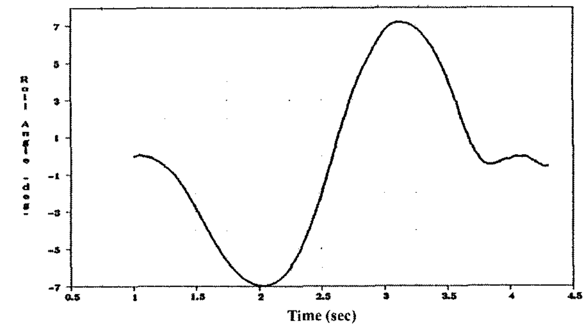


(b) Lateral acceleration

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

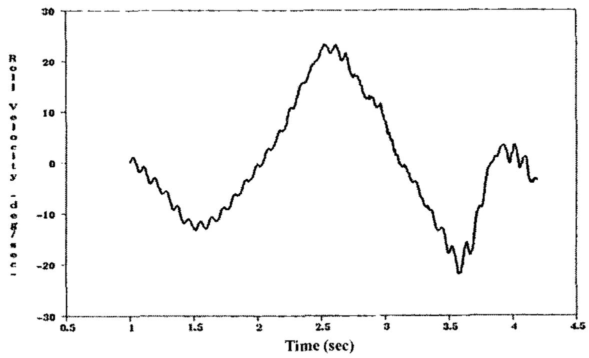


(a) Roll angle

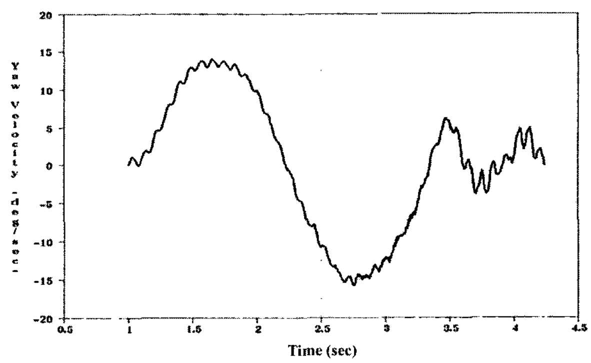


(b) Yaw angle

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

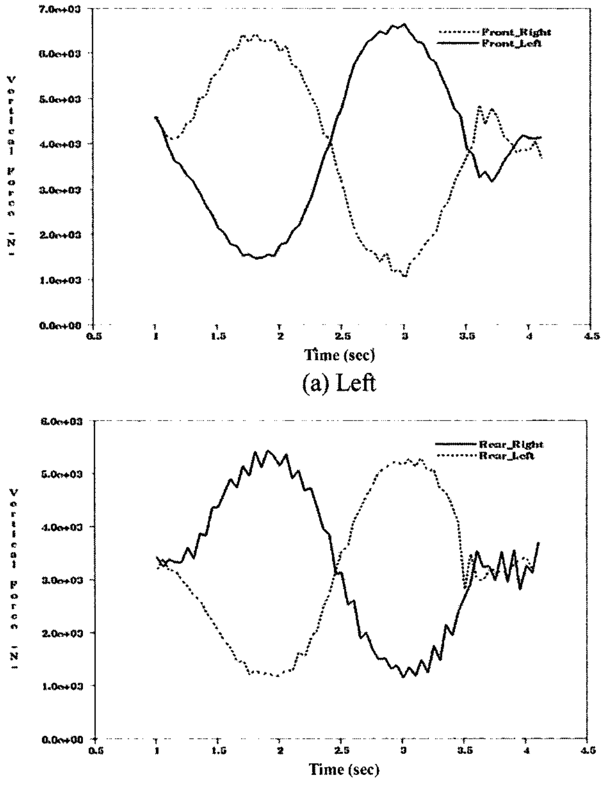


(a) Roll velocity



(b) Yaw velocity

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



(a) Left

(b) Right

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

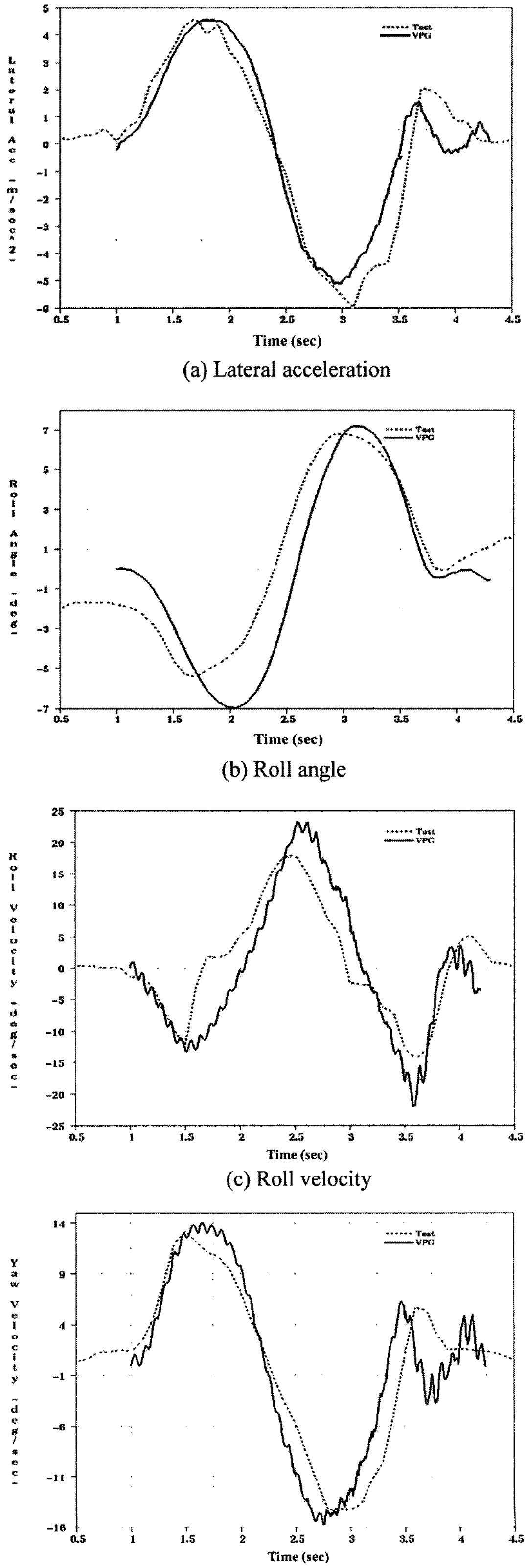
vehicle's mass center of gravity while it is changing lanes from left to right.

It was assumed that the vehicle has the maximum amount of passengers and tire pressure was given as a standard value of a target vehicle for dry road conditions. The steering angle, which is the most important parameter, was not given directly to the steering wheel. The angle was inputted to the gearbox and then transferred to the knuckle to steer the wheel. Figure 6 shows the output vehicle path through 80 km/h lane changes using the virtual proving ground approach.

Figures 7~10 show the lateral displacement, lateral acceleration, roll angle, yaw angle, roll velocity, yaw velocity and wheel center load histories of the vehicle. In all figures, lane change started after 1 second. Results prior to 1 second are not presented.

5. COMPARISON BETWEEN TEST AND ANALYSIS RESULTS

The results show that the dynamic response characteristics from the CG of the vehicle, while changing lanes at a speed of 80 km/h, was similar in its trend and magnitude with no large significance. To verify the



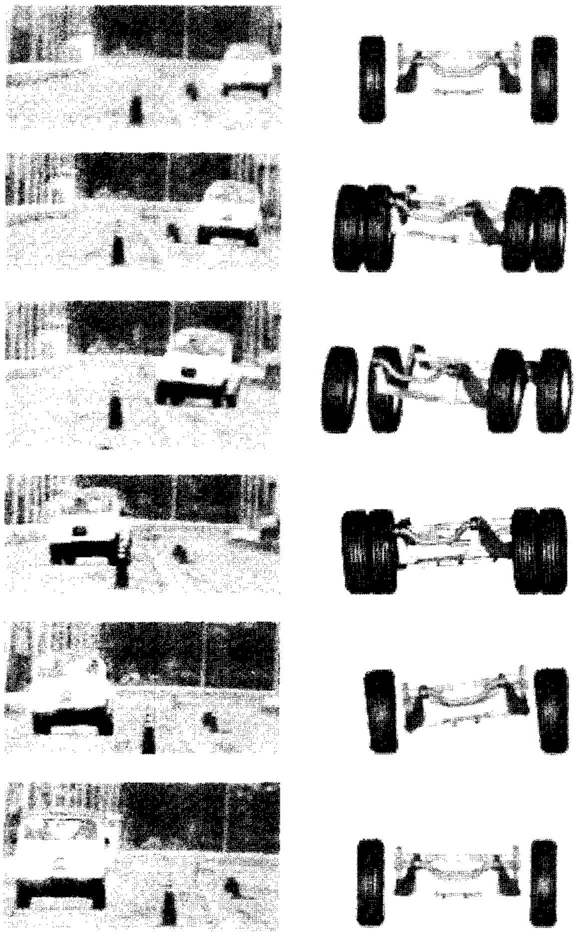
(a) Lateral acceleration

(b) Roll angle

(c) Roll velocity

(d) Yaw velocity

Figure 11. Comparison between test and analysis.



(a) Test (b) Analysis

Figure 12. Comparison of vehicle motion between test and analysis.

analysis results, we tested the same vehicle with the same conditions as the target analysis vehicle. Figure 11 shows the comparison between the test and analysis (lateral acceleration, roll angle, roll velocity, yaw velocity, etc.). There is a significant deviation in the roll velocity compared to the other results. It seems that the paved road test performed was not flat, so the vehicle initially had some inclination and started changing lanes. In the figure of roll velocity and yaw velocity, the difference between the driver's action and the simulation made the analysis result appear more irregular than the test result. If the time interval in the test was the same, as in the analysis, the test curve would result in an irregular pattern similar to the curve in the analysis results. Figure 12 shows the comparison of front view of the test and simulation while changing lanes. In Figure 12, it can be seen that the vehicle motion of the test and analysis are similar.

6. CONCLUSIONS

Through the advanced simulation method we were able to simulate real driving conditions, and to set up a standard analysis method to predict the dynamic characteristics of a vehicle using a finite element analysis code. The results show that the VPG simulation method can simulate contact problems between vehicle components, the relation between structural flexibility, and ride/handling, as well as various kinds of 3 dimensional road profiles. This could be used to save time and costs in developing new vehicle models. In addition, if the analysis method is combined with optimization technology based on its structural flexibility, this could make the analysis method a much better design tool.

The main contents and characteristics of this research were as follows:

(1) The VPG approach developed in this research can reduce costs and the number of engineers required for vehicle design compared with existing dynamic analysis techniques.

(2) Due to the benefit of being able to use the crash analysis FE model, modeling time was reduced by up to 70%.

(3) The proposed VPG analysis can be utilized not only in the vehicle dynamics and kinematic analysis, but also in the fatigue analysis of the suspension system and body structure.

(4) This method also allows the engineer to study the complete behavior of the vehicle, considering the nonlinear dynamic behavior, more accurately simulating the real world conditions of vehicle usage.

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