Vehicle Turn Simulation Using FE Tire model

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Summary:

A simplified FE tire model has capability to solve a large deformation of a tire on a vehicle running simulation with acceptable computation time. We tried to simulate a vehicle cornering by using simplified FE tire models and a vehicle model which has a detailed kinematical structure of suspensions.

Keywords:

Tire, Vehicle, Cornering, Simulation, LS-DYNA

1 Introduction

Introduction of CAE in an automobile design is progressing in various fields, and, recently, to also make it run an automobile full model can be begun. CAE with high accuracy is effective in curtailment of a test vehicle, or the fault dissolution of a design early stage, and durability, driving stability, and a ride comfort are also becoming the object.

In order to perform the run simulation of vehicles, it is important to predict transfer of the load from a road surface with sufficient accuracy, and a highly precise tire model is needed first. Therefore, it becomes an effective means to carry out the structural analysis of the tire by FEM in a run simulation. However, if the tire has complicated structure containing a fiber, steel wires including rubber, etc. and tends to model these, it will become the model of a 100,000 element scale which is used for tire makers. Moreover, since a simulation so that the target revolution of this paper treats not the phenomenon of 100msec units like the crash simulation which LS-DYNA has so far treated but the phenomenon of a second unit, for the moment, the run simulation of the vehicles using the tire model of a 100,000 element scale is impossible by calculation time as a matter of fact.

Then, FE tire model simplified on a small scale so that a run simulation could be calculated in realistic time was developed[1,2,3]. Furthermore, improvement is added to this simplified tire model, and signs that a tire changes greatly on the curbstone riding raising problem which is equivalent to the shock on-the-strength problem of vehicles can be analyzed now with sufficient accuracy [4].

In this paper, improvement is further added to the simplified tire model, and the result which tried the rapid turn simulation of vehicles which changes a tire greatly according to the weight of vehicles, vehicle inertia, and friction with a road surface is reported.

2 FE TIRE MODEL

The type of a car developed in an automaker is usually plurality, and it is common that the tire sizes with which it is equipped also differ for every type of a car. For this reason, although the tire model used as a base is created and carrying out scaling and corresponding to the tire of other sizes is also performed, the tire is carrying out structure according to size or the profile, and the accuracy fall of the model by scaling poses a problem. The simplification tire model (FE TIRE MODEL LIBRARY) of many sizes was developed by making such a problem into a background.

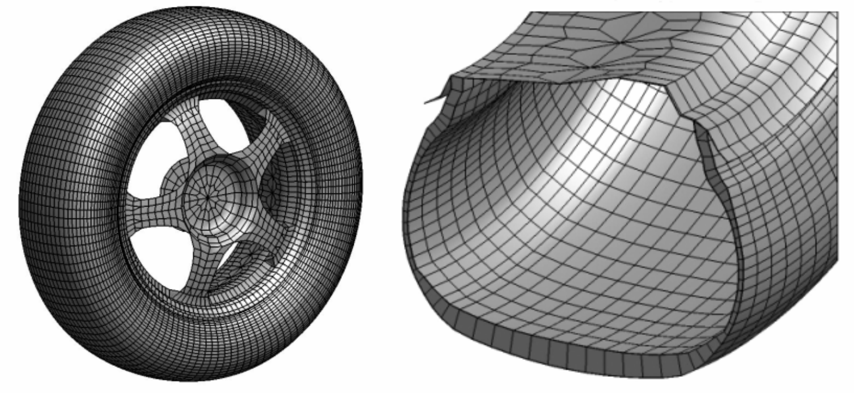


Fig. 1: Simplified FE Tire model (size:205/60R16)

It is checked that this simplification tire model is well in agreement with an experiment result on a static compression test and a dynamic cleat pass test, and the curbstone riding raising test of vehicles.

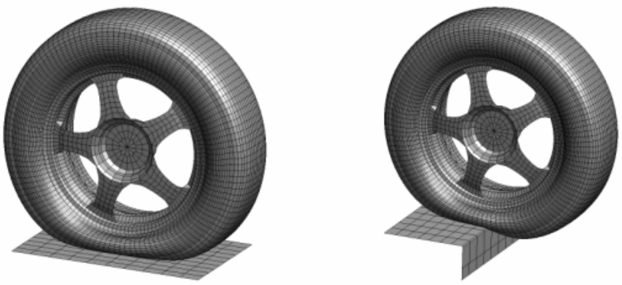


Fig. 2: static compression test (2 types)

Fig. 3: dynamic cleat pass test

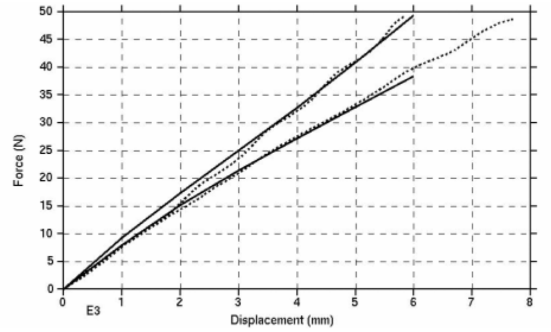


Fig. 4: static compression test result

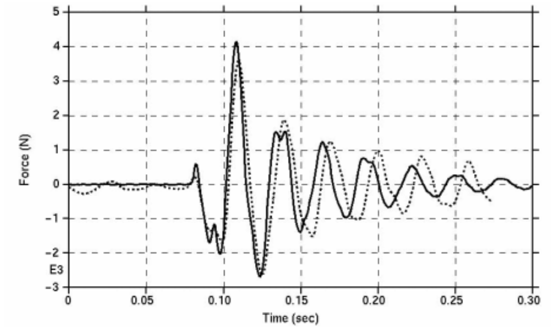


Fig. 5: dynamic cleat pass test result

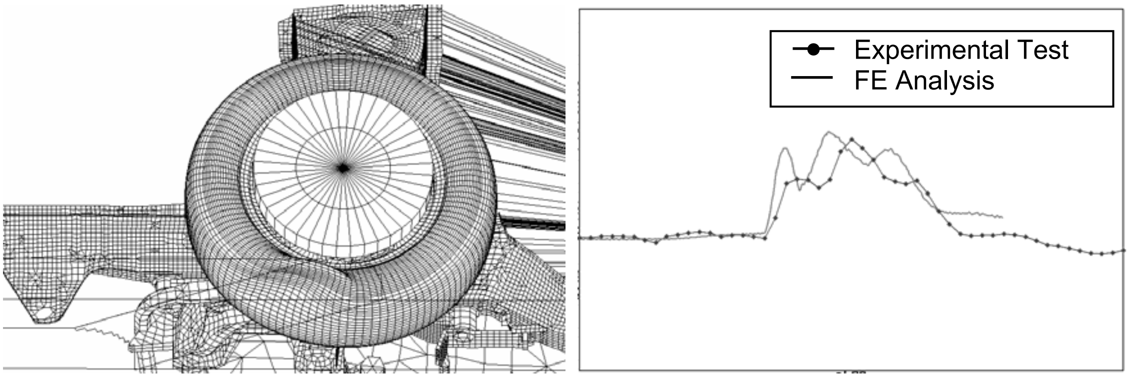


Fig. 6: curbstone riding raising test result

Then, in order to enable it to apply this simplification tire model to the rapid turn simulation of vehicles, the subject of three points was set up below as an improving point added to a tire model.

1. Enable it to analyze turn motion of the vehicles in the dryness road surface of asphalt.
2. Enable it to analyze marginal turn motion of the vehicles using the maximum of the horizontal force which a tire generates.
3. In order to analyze turn motion used as a second unit by the explicit method, make an old simplification tire model still more nearly small-scale, and shorten calculation time as much as possible.

However, in above 3, the rigidity of the metal parts of the body which is originally an elastic body, or a suspension is disregarded, and it is premised on limiting the deformation analysis of the vehicles under a tire deformation and the movement of a suspension. Improvement was added to the simplification tire model shown in Fig. 1 based on three points above, and it considered as the tire model used for the rapid turn analysis shown in Fig. 7.

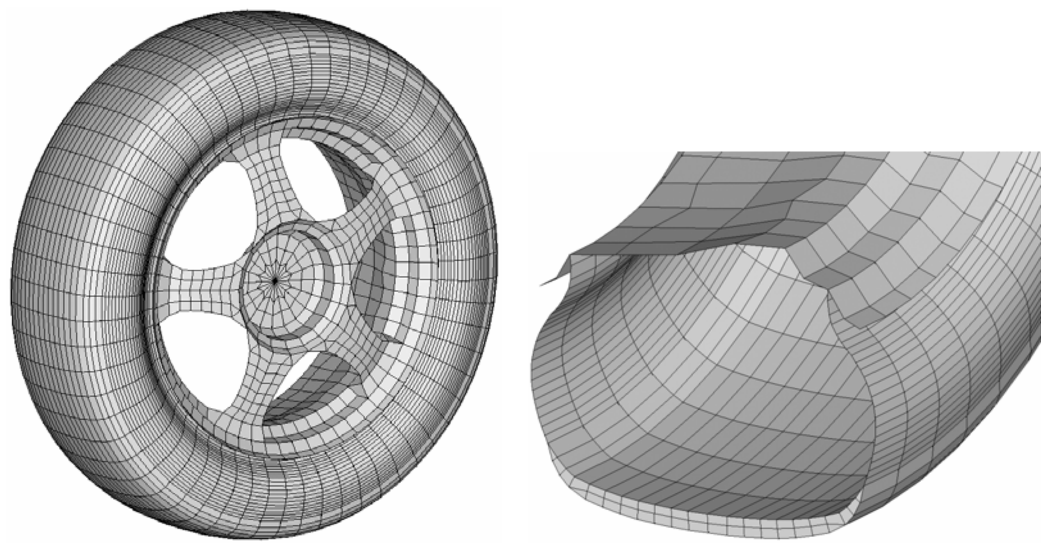


Fig. 7: FE Tire model used for vehicle rapid turn analysis

In this improved simplification tire model, the number of element division of the direction of a circumference was reduced, or the laminating structure of a sidewall part was compounded to the SHELL element of one layer, and the number of elements was cut down below in the half compared with FE tire model library shown in Fig. 1. However, the structural feature of a tire reproduced using a SOLID element and rubber material for a tread part, and using a SHELL element and ortho-tropic material for a case and a breaker part etc.

Next, in order to use the simplification tire model shown in Fig. 7 for the rapid turn motion of vehicles,we measured cornering forces using flat belt examination machine and correlated the tire model with the test results. In the rapid turn motion of these vehicles, in order to target even marginal movement using the maximum of the horizontal force which a tire generates, the range of the vertical load to the tire in the horizontal force characteristic by the flat belt examination machine, a camber angle, and a slip angle was defined as follows.

Vertical load:	2-6kN
Campber angle:	0-5 deg.
Slip angle:	0-15deg.

In order to have made the horizontal force characteristic in agreement with a measurement result, the friction coefficient of a tire and a flat belt needed to take into consideration the characteristic of changing with contact force and slip speed of a tire tread part, and included these in the simplification tire model. Consequently, a nonlinear change of the horizontal force by the grounding load of the time of a slip angle exceeding 6 degrees, as shown in Fig. 8, or a tire came to be in agreement with the measurement result in general.

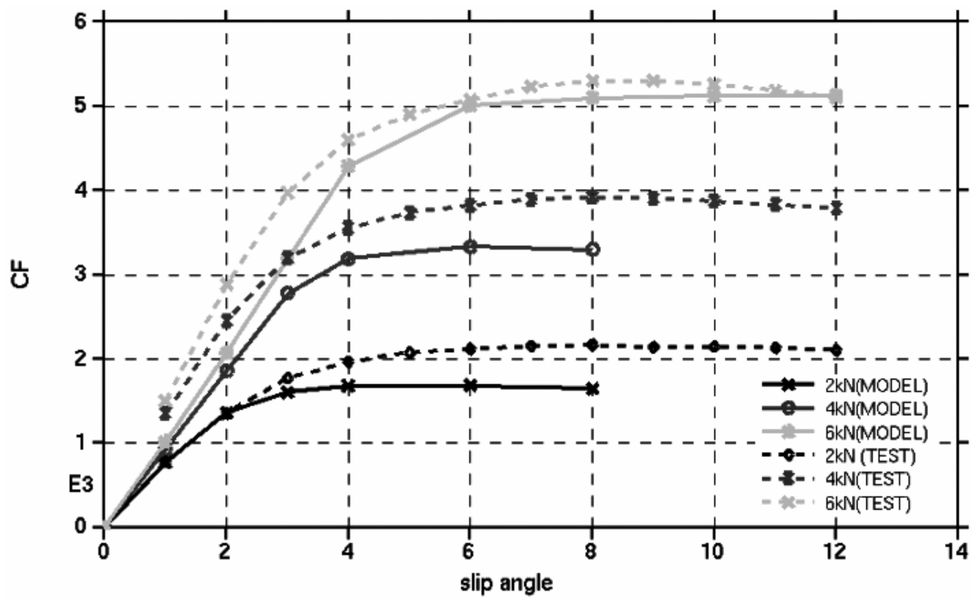


Fig. 8: FE Tire model cornering force correlation result (Camper angle=0 deg.)

The rapid turn motion of vehicles was tried using the simplification tire model which was in agreement with the horizontal force characteristic by this flat belt examination machine.

3 Vehicle Model

We decided to try the rapid turn simulation of the medium size sedan car shown in Fig. 9 using the simplification tire model shown in Figs. 7 and 8.

Fig. 9: medium size sedan car used for the rapid turn simulation

In order to analyze rapid turn motion of the vehicles used as a second unit as mentioned above, compared with the real vehicle of Fig. 9, the vehicles model was simplified sharply, and only the tire was mostly set as the target of the deformation analysis under rapid turn motion. A vehicles model expresses the following characteristics.

1. Suspension and steering parts
2. Reaction force properties for spring,shock absorber, vamp rubber, and bush including stabilizer
3. Inertia properties for body, interior, engine, drive train equipped to suspension parsts.

We defined body and metal parts including suspension system as rigid body, and assume the only parts above 2 are deformation parts. This made the calculation speed fast. A vehicles model is shown in Fig. 10.

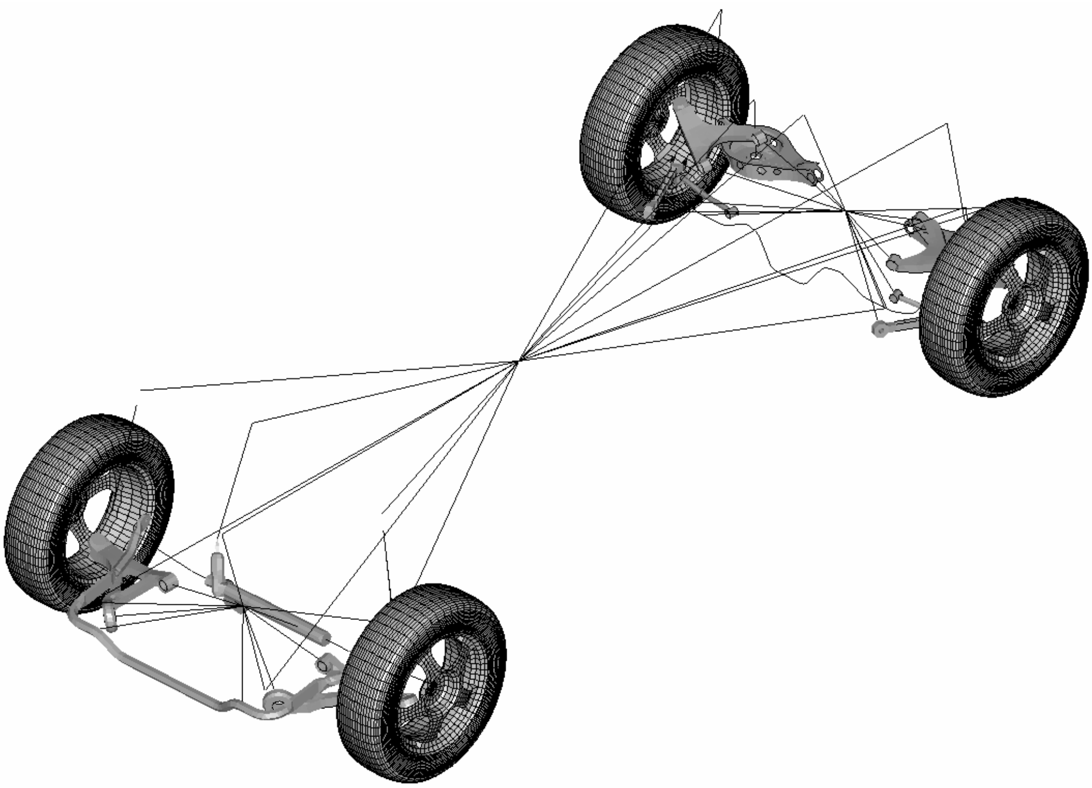


Fig. 10: Vehicle model with 4 FE tire models

In the model of the front suspension shown in Fig. 11, we modelled a RACK & PINION type steering gear system. To steer the vehicle front tires, the rack was moved using prescribed motion definition. With respect to the vehicle model shown in Fig. 10 and 11, inertia properties and reaction forces on axle and wheel alignment changes dependent on suspension stroke were confirmed to have an agreement with the measurement result of the real car shown in Fig. 9.

4 Vehicle rapid turn simulation

The rapid turn simulation was performed using the vehicles model of the medium size sedan shown in Fig. 10, and it compared with the experiment result of these conditions.

1. analysis condition

According to the following conditions, even if it increased rotation angle of steering wheel, the state of understeering beyond the limit of vehicles movement of being hard to circle in vehicles was analyzed.
- Road surface: Dryness asphalt way
- Vehicle velocity at the time of a revolution start: 68 km/h (vehicle speed in front of the turn start obtained in the vehicles experiment conducted applicable to comparison)
- Steering: The left was made to rotate 180 degrees of steering wheels in 0.7 seconds, and rotation angle was fixed as it was.
- Braking: Nothing
- Gearbox position: Neutral

As the analysis conditions corresponding to the above-mentioned conditions
- Vehicle velocity before a steering start:68 km/h (measured by experimental test)
- steering: the rack was moved using prescribed motion definition. The displacement was measured from experimental test.
- Braking: Nothing
- Gearbox position: Neutral

2. analysis results

The action figure of the vehicles obtained in the revolution simulation is shown in Figs. 11 and 12.

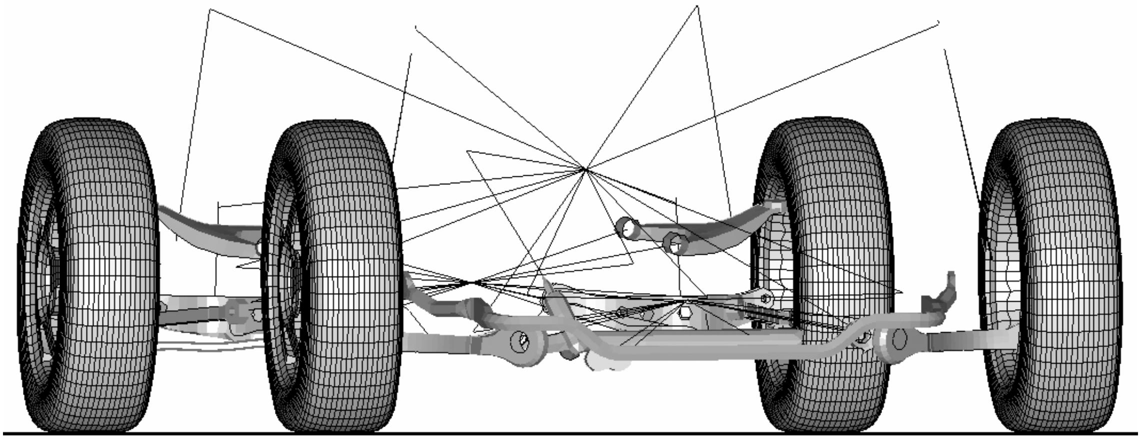


Fig. 11: Vehicle motion while running straight

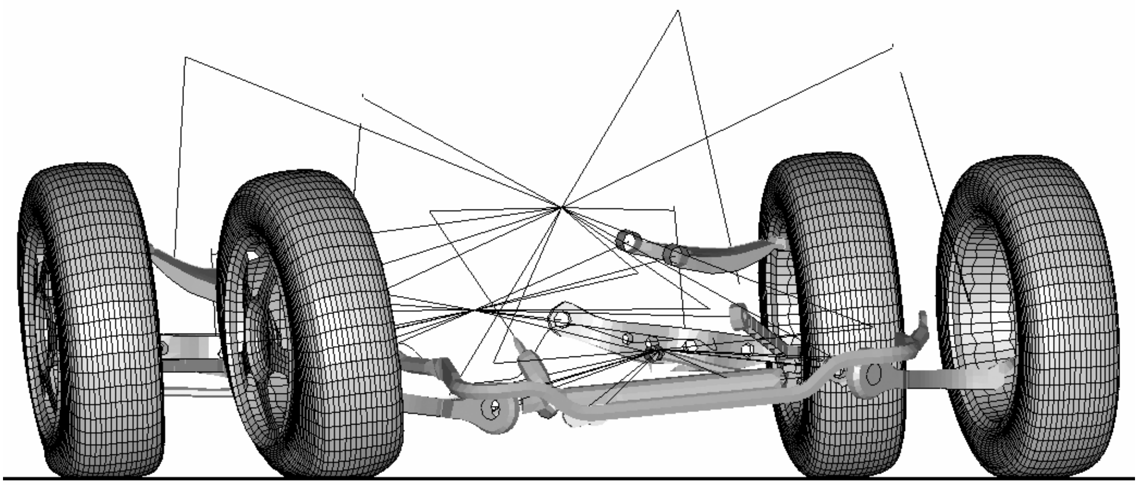
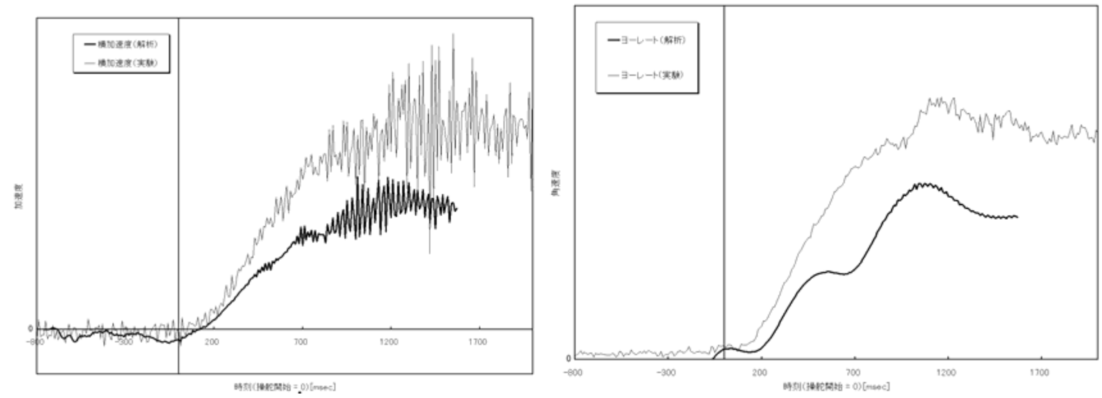


Fig. 12: Vehicle motion while rapid turn

If Fig. 11 and Fig. 12 are compared, while the amount of spring upper part will incline leaning forward by turn of vehicles, it turns out that it leans also to the right-hand side (left-hand side of a figure) of vehicles. Deformation of the vertical direction near sidewall and the right-and-left direction is the most remarkable with a forward right ring.

Next, the acceleration of the vehicles center of gravity and the history of yaw rate which were fixed to the body compared movement of the vehicles in this analysis result with the experiment result. The time history of the acceleration of the vehicles center of gravity and yaw rate is shown in Fig. 13.

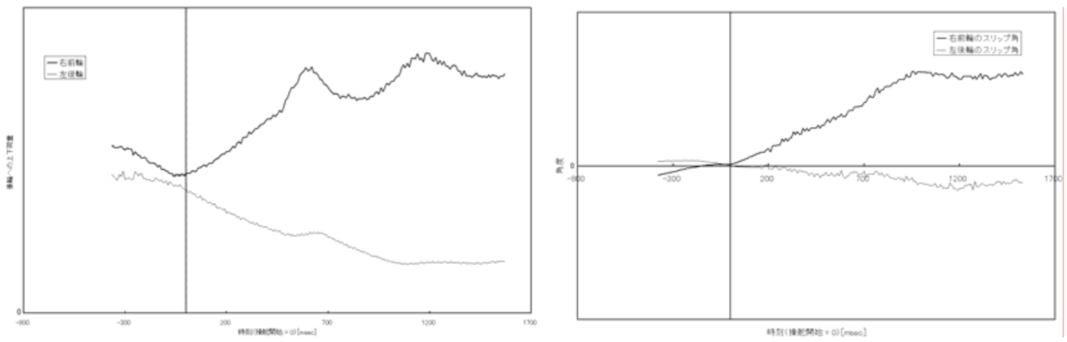


lateral accelaration yaw rate

Fig. 13: the motion of vehicle gravity center

Although the analysis result differed from the experiment result at each maximum as shown in Fig. 13, the tendency for the horizontal acceleration from after a steering start and yaw rate to become large, and to serve as maximum after 1.2 seconds was in agreement.

Next, in order that horizontal acceleration and yaw rate might guess a greatly different cause from an experiment result, the history of the vertical load of a wheel and a slip angle in a turn simulation was investigated.



vertical forces on axle slip angle

Fig. 14: the status of right front tire and left rear tire

Fig. 14 shows vertical forces and slip angles with respect to right fornt tire and left rear tire. We can see that vertical force of left rear tire is only 25% of right front tire. In comparison with the measurement result of the horizontal force by the flat belt examination machine shown in Fig. 8, signs that the change of horizontal force to a slip angle becomes remarkably small in the domain where a slip angle is large, and signs that horizontal force changed with vertical loads became the same tendency as a measurement result. However, as for the value of horizontal force itself, vertical loads differed the slip angle about 10 to 20% from the measurement result except for the domain exceeding 6 degrees by 6kN(s). This simplification tire model was developed tuning up some parameters so that it may be in agreement with the measurement result of the horizontal force by the flat belt examination machine in input values, such as a physical-properties value of structure material, the slip speed dependability of a friction coefficient, and grounding contact pressure dependency. However, since it is in the way which calculates the optimal value of the parameter to input, it is thought that the difference arose between the simulation result, and the measurement result of a flat belt examination machine and a vehicles experiment result.

5 Summary

Improvement was added to the simplification tire model applicable to the run simulation of vehicles, and the rapid turn simulation of the vehicles used as the phenomenon of a second unit was tried. This simplification tire model was developed so that it could respond to the horizontal force characteristic that it can respond to marginal motion of vehicles with a large slip angle and the large difference for every wheel of vertical load which acts on a wheel.

Although the horizontal acceleration of the vehicles center of gravity and the maximum of yaw rate differ from the turn experiment result of vehicles, since change of a time history became the characteristic corresponding to an experiment result, it is expectable that the analysis result approaching a vehicles experiment result is obtained by tuning up the characteristic of a friction coefficient with the physical-properties value and road surface which are given to a material model.

6 Literature

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