A STUDY OF COMPUTER SIMULATION SYSTEM FOR RECONSTRUCTING CAR-TO-CAR COLLISION ACCIDENTS INVOLVING THE SECOND IMPACT

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Abstract: In this paper, based on the accident site information, a car-to-car accident reconstruction system is developed, which is used to simulate the impact velocity and trajectory of vehicles. The accidents concerned involve the second impact. Five collision tests involving second impact were used to evaluate the system. The simulation results are found to be in good agreement with real-world test results.

1. FOREWORD

In the field of traffic accidents authenticating, estimating the impact velocity and trajectory of vehicles is often the main goal of an accident analysis in order to establish accident course and transact accident responsibility justly in the light of the law. Car-to-car collisions are a common traffic accident form. Its impact analytical solutions have aroused the attention of the accident investigators. The authors published a car-to-car analytical impact model not involving the second impact and the animate reconstructing program three years ago. The video and data of sixteen collisions tests provided by Japan Automobile Research Institute (JARI) was used to test and verify its validity. The second impact was found in some videos of collision tests provided by JARI. And specifically this kind of accident was called car-to-car impact accident involving the second impact.

Car-to-car impact accident, as a special traffic accident form and its analytical simulation and reconstruction method has aroused great interest for the accident investigators. But, many real-world car-to-car collisions involve the second impact (It can be deduced by check the mark on the car body whether the second impact occurred or not). For this kind of accidents, the second impact center position in the ground coordinate system can't be obtained by investigating the accident site, besides, the instantaneous motion state and velocity during the second impact is unknown. It is therefore much more complex to simulate and reconstruct car-to-car impact accidents involving the second impact. Furthermore, it is difficult to verify through tests. The method used to simulate car-to-car impact accident involving second impact hasn't been found till now. This paper improves the algorithms [Lang, Hirotoshi and Takashi (1995)], [Lang, Yinsan, Takashi and Hirotoshi (1996)], [Hirotoshi (1995)], and develops the methods dealing with reconstruction of car-to-car collisions accidents involving the second impact, based on the analysis for a number of car-to-car collision tests. The video and data of five collision tests were used to test and verify its validity.

2.THE SIMULATION SYSTEM FOR CAR-TO-CAR IMPACT ACCIDENT INVOLVING THE SECOND IMPACT

The meaning of the notation and subscript is as follows:
(NOTATION)

X, Y: the centroid coordinate of vehicle in the ground coordinate system

τ, η: the centroid coordinate of vehicle in the second impact coordinate system($\tau k \eta$)

θ: the angle between the longitudinal central line of vehicle and x axle

m : vehicle mass V: velocity w: angular velocity ρ: radius of gytation

P: impact momentum

e : restitution coefficient L: wheel spacing B: axle spacing

L_f : distance from the centroid to fore axle

L_k : distance from the mark center of second impact to centroid (m) (It is positive in the front of the centroid; negative behind the centroid.)

L_z : the total length of vehicle (m)

μ : road friction coefficient

B_z: the width of vehicle (m)

ε_x, ε_y, ε_θ : the permitted error of the centroid position along x axle, y axle and θ angle .

(Subscript)

x , y , τ, η :the component of x axle, y axle, τ axle (tangential), η axle (normal)

k: the value at second impact center (or the second impact mark center)

so: (initial) the value at impact position
su: the value at rest position
q : pre-impact instantaneous value
g: post-impact instantaneous value
T: test value
S: simulation value
A, B: the value of vehicle A, vehicle B

The car-to-car accidents analytical impact model involving the second impact consists of the following subsystem:

1) The subsystem used to calculate the second impact center position.
2) The subsystem used to calculate the post-impact instantaneous motion variables.
3) The computation model at the second impact instant.
4) The computation model for estimating the initial impact velocity.

2.1 The Subsystem Used To Calculate The Second Impact Center Position

Finding the second impact center position in ground coordinate system is key to analyzing the car-to-car collision accident involving the second impact. The reason that second impact occurs after the first impact is the sharp rotation of impact vehicles. It can be inferred that second impact mainly occurred on the two sides of vehicle (including the end of the sides). Additionally, studying numerous data of collision tests, we can infer that the impulsive force of second impact is less than that of the first impact. In view of this, the method of asymptotic approximate which used to compute the second impact center position was presented. Firstly, under the condition of neglecting the second impact, on the basis of the method of reference [Lang, Yinsan, Takashi and Hirotoshi (1996)], the trajectory of the second impact mark center point can be computed in the light of the impact and rest position. Then, the approximate coordinate (X_k, Y_k) of second impact center can be obtained. The formula is as follows:

$$\begin{Bmatrix} X_k \\ Y_k \end{Bmatrix} = \begin{Bmatrix} (X_{kAj} + X_{kBj})/2 \\ (Y_{kAj} + Y_{kBj})/2 \end{Bmatrix} \tag{1}$$

$$j = i | \{\min(d_{ki} + \beta_i) \cup [\min d_{ki} \cap \min \beta_i] \quad , \quad (i = 1,2,\bullet\bullet\bullet,n)\} \tag{2}$$

Where

$$d_{ki} = \sqrt{(X_{kAi} - X_{kBi})^2 + (Y_{kAi} - Y_{kBi})^2} \qquad (i = 1,2,\bullet\bullet\bullet,n)$$

$$\beta_i = \begin{cases} |(\theta_{Ai} - \theta_{Bi})| & |\theta_{Ai} - \theta_{Bi}| < (\pi/2) \\ |[(\theta_{Ai} - \theta_{Bi}) - \pi]| & |\theta_{Ai} - \theta_{Bi}| > (\pi/2) \end{cases} \qquad (i = 1,2,\bullet\bullet\bullet,n)$$

2.2 The Subsystem Used to Calculate The Post-Impact Instantaneous Motion Variables

The subsystem used to calculate the second post-impact instantaneous motion variables mainly consists of the following computation models:

- iteration-convergence judge model
- kinematics model of impact vehicles
- tire-ground mechanics model(adopt G.Gim and P.E Nikavesh tire model [Gwanghun and Parviz (1990)], [Gwanghun and Parviz (1991)])

In this subsystem, the variables such as velocity and angular velocity can be obtained in the light of second impact center and the rest positions [Lang, Hirotoshi and Takashi (1995)], [Lang, Yinsan, Takashi and Hirotoshi (1996)]. Its computational flow diagram is shown in Figure 1.

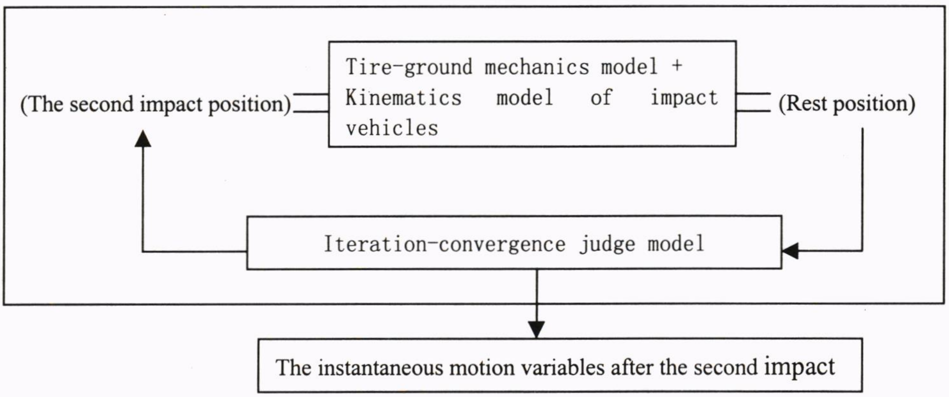

Fig. 1 The Computational Flow Diagram of Motion Variables after the Second Impact

2.3 The Computation Model at the Second Impact Instant.

This computational model is used to describe the relation of the motion variables between the instant pre-impact and post-impact. When the second impact center was obtained, the post-impact instantaneous velocity and angular velocity can be deduced from pre-impact velocity of the second impact. As shown in Figure 2, set the side of struck vehicle as the impact surface, and the second impact center k as origin. The τ -axle is tangential to the impact surface, parallel to the longitudinal central line of vehicle body, then the second impact coordinate system $\tau k \eta$ is built. The following instantaneous impact model is obtained based on the law of conservation of momentum.

$$V_{qk\eta A} = V_{gk\eta A} - \frac{P_{k\eta}}{m_A} \quad (3) \qquad V_{qk\tau A} = V_{gk\tau A} - \frac{P_{k\tau}}{m_A} \quad (4)$$

$$\omega_{qkA} = \omega_{gkA} + \frac{P_{k\eta}\tau_{kA} - P_{k\tau}\eta_{kA}}{m_A \rho_A^2} \qquad (5)$$

$$V_{qk\eta B} = V_{gk\eta B} - \frac{P_{k\eta}}{m_B} \qquad (6)$$

$$V_{qk\tau B} = V_{gk\tau B} - \frac{P_{k\tau}}{m_B} \qquad (7)$$

$$\omega_{qkB} = \omega_{gkB} + \frac{P_{k\eta}\tau_{kB} - P_{k\tau}\eta_{kB}}{m_B \rho_B^2} \qquad (8)$$

Where

$$P_{k\eta} = \frac{-1}{(1 - M_{\eta\tau o} m_o)}\left[m_\eta R_{ds}(1 + \frac{1}{e_\eta}) + M_{\eta\tau o} R_{ss}(1 + \frac{1}{e_\tau}) \right]$$

$$P_{k\tau} = \frac{-1}{(1 - M_{\eta\tau o} m_o)}\left[M_{\eta\tau o} R_{ds}(1 + \frac{1}{e_\eta}) + m_\tau R_{ss}(1 + \frac{1}{e_\tau}) \right]$$

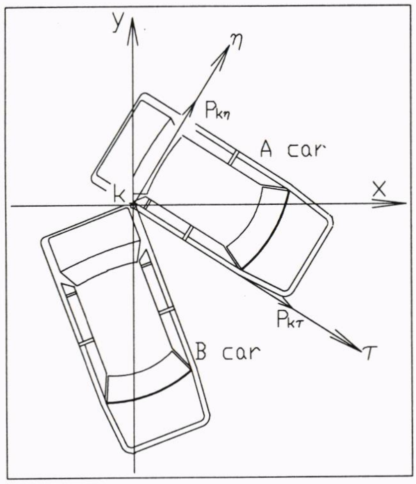

Figure 2. The Coordinate System of Second Impact Center Position

$$R_{ds} = V_{gk\eta B} - \tau_{kB}\omega_{gkB} - V_{gk\eta A} + \tau_{kA}\omega_{gkA}; \quad R_{ss} = V_{gk\tau B} + \eta_{kB}\omega_{gkB} - V_{gk\tau A} - \eta_{kA}\omega_{gkA}$$

$$M_{\eta\tau o} = m_\eta m_\tau m_o; \quad m_\eta = \frac{\gamma_{\eta A} m_A \gamma_{\eta B} m_B}{\gamma_{\eta A} m_A + \gamma_{\eta B} m_B}; \quad m_\tau = \frac{\gamma_{\tau A} m_A \gamma_{\tau B} m_B}{\gamma_{\tau A} m_A + \gamma_{\tau B} m_B}; \quad m_o = \frac{\tau_{kA}\eta_{kA}}{m_A \rho_A^2} + \frac{\tau_{kB}\eta_{kB}}{m_B \rho_B^2}$$

$$\gamma_{\eta A} = \frac{\rho_A^2}{\rho_A^2 + \tau_{kA}^2}; \quad \gamma_{\eta B} = \frac{\rho_B^2}{\rho_B^2 + \tau_{kB}^2}; \gamma_{\tau A} = \frac{\rho_A^2}{\rho_A^2 + \eta_{kA}^2}; \quad \gamma_{\tau B} = \frac{\rho_B^2}{\rho_B^2 + \eta_{kB}^2}$$

2.4 The Computation Model for Estimating the Initial Impact Velocity

In this subsystem, post-impact velocity and angular velocity of the first impact can be gained through the first and second impact center position. Furthermore, on the basis of impact velocity computational model, pre-impact velocity and angular velocity of the first impact can be obtained [Lang, Hirotoshi and Takashi (1995)], [Lang, Yinsan, Takashi and Hirotoshi (1996)]. Its computational flow diagram is shown in Figure 3.

3. THE SIMULATION SYSTEM FOR RECONSTRUCTING CAR-TO-CAR COLLISIONS INVOLVING SECOND IMPACT

The flow diagram of the animated simulation system for reconstructing car-to-car collisions involving second impact is shown in Figure 4. The program automatically read and input the post-impact velocity and angular velocity calculated in the former section. After the computations, it can display the instantaneous motional state at every time step and the second impact position, which shows the entire process of impact accident. Simulation can be visualized with the continuous animate.

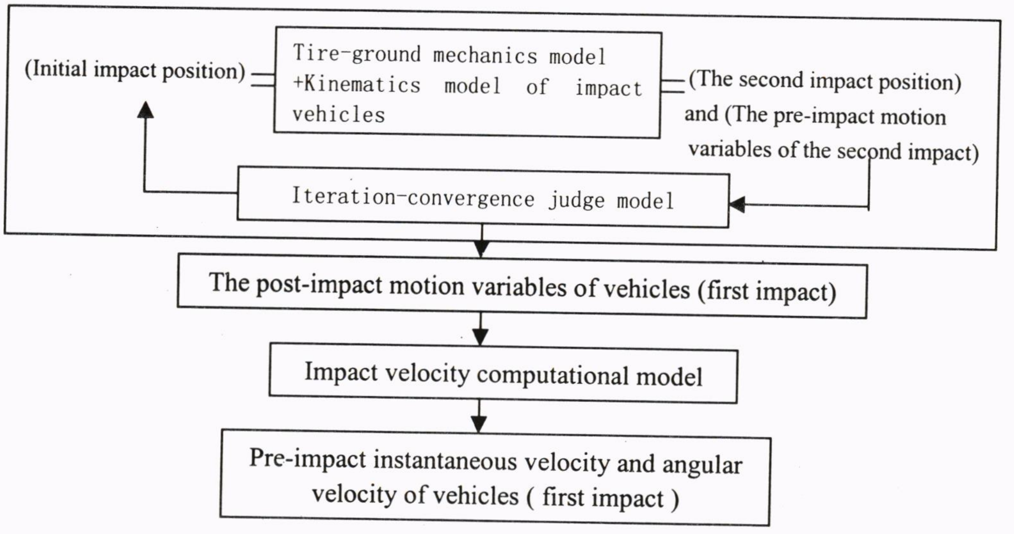

Fig. 3 The Computational Flow Diagram of Impact Velocity

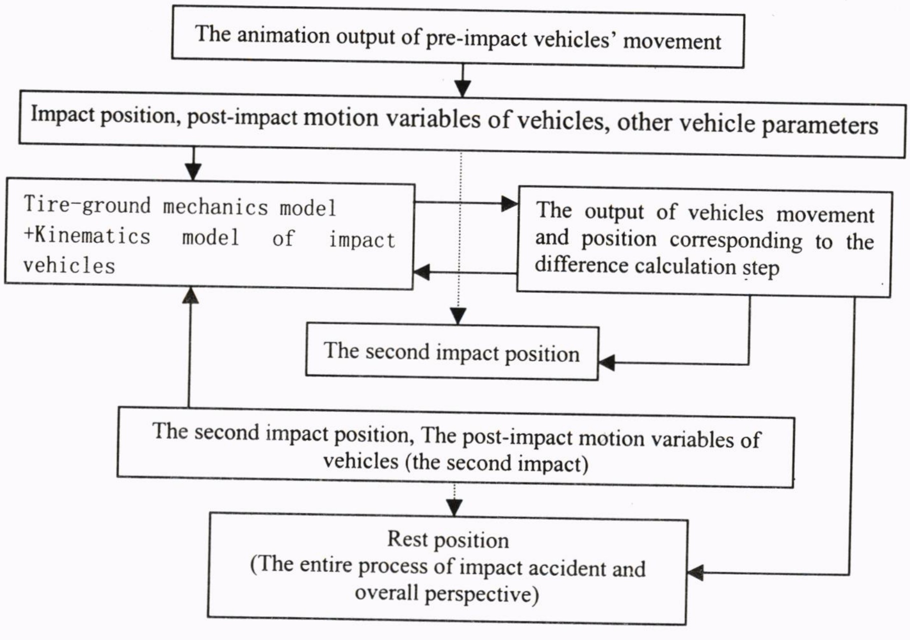

Figure 4. The Flow Diagram Of Simulation System for Reconstructing Car-To-Car Collisions Involving Second Impact

4. EVALUATION OF THE SYSTEM USING THE TESTS

Under the common conditions, the data measured at the real-world accident site, especially the impact velocity from accident investigation, is not suitable to verify the validity of the simulation model. In this paper, under the accurate control and test conditions, five car-to-car collision tests involving second impact (see Table 1) were used to verify and assess the simulation system.

Table 1. The Data of Real World Collision Tests Involving Second Impact

Test	Car	M (kg)	ρ (m)	L_f (m)	L (m)	B (m)	X_{so} (m)	Y_{so} (m)	θ_{so} (°)	X_{su} (m)	Y_{su} (m)	θ_{su} (°)	μ	L_k (m)
T1	A	1073	125	1.12	255	1.46	0.00	-1.60	90	-4.70	5.76	130	0.65	(L)1.35
	B	1070	125	1.17	255	1.46	-0.90	0.56	180	-7.10	3.46	353		(R)1.65
T2	A	901	120	1.08	241	1.32	0.00	-1.48	90	-3.55	41.02	86	0.65	(L)1.25
	B	1108	124	1.02	255	1.46	-0.10	0.68	180	-7.60	6.02	345		(R)1.65
T3	A	1113	124	1.10	255	1.46	-1.82	0.00	0	2.65	0.41	3	0.65	(L)1.45
	B	1109	123	1.06	255	1.46	0.64	0.67	90	4.55	3.40	215		(R)1.65
T4	A	1041	124	1.10	255	1.46	-1.75	-0.24	0	531	-8.44	-225	0.60	(L)-2.0
	B	1081	124	1.10	255	1.46	0.58	1.02	-75	11.81	-11.68	-70	(rain)	(R)-1.6
T5	A	991	123	1.15	255	1.46	0.30	-1.70	90	12.7	4.90	20	0.65	(L)-2.1
	B	1004	123	1.16	255	1.46	-0.85	0.70	0	123	15.10	50		(R)-2.1

Notes: Hm, Mm, Hg and Mg present the motion state of left-front wheel, right-front wheel, left-rear wheel and right-rear wheel respectively. Appoint: the value was set to 1 when the locked wheel can't roll, the value was set to 0 when the wheel can roll freely.

4.1 Verification of Simulation Computation

The observed value V_T and calculated value V_S of initial impact velocity, observed value and calculated value of the second impact center position are shown in Table 2. The absolute error of velocity is within 7.4km/h, and the relative error is within 12.21% except for the car B in T2 case (22.11%) and car B in T3 case (28.83%).

Table 2 Impact Center Position and Velocity Comparison between Test and Simulation Value

Test	Car	ε_x(m)	ε_y(m)	ε_θ(°)	X_{kT}(m)	Y_{kT}(m)	X_{ks}(m)	Y_{ks}(m)	V_T (km/h)	V_s (km/h)	absolute error (km/h)	relative error (%)
T1	A	0.25	0.25	5	-3.80	2.40	-4.06	2.30	40.7	41	0.3	0.74
	B	0.25	0.25	5					40.4	44	3.6	8.98
T2	A	0.25	0.25	5	-1.59	3.52	-1.71	2.84	60.6	68	7.4	12.21
	B	0.25	0.25	5					30.3	37	6.7	22.11
T3	A	0.25	0.25	5	2.27	1.95	2.04	1.69	49.7	47	2.7	5.43
	B	0.25	0.25	5					16.3	21	4.7	28.83
T4	A	0.25	0.25	5	0.96	-0.29	1.12	-0.15	49.8	47	2.8	5.62
	B	0.25	0.25	5					51.1	49	2.1	4.11
T5	A	0.25	0.25	5	0.80	0.30	0.93	0.46	45.0	40	5.0	11.11
	B	0.25	0.25	5					45.0	44	1.0	2.22

4.2 The Contrast Verification for Simulation Reconstruction

The trajectory comparison between the simulation and collision tests are shown in Figure 5～Figure 9. The second impact simulation trajectories were found to be in good agreement with real-world test results.

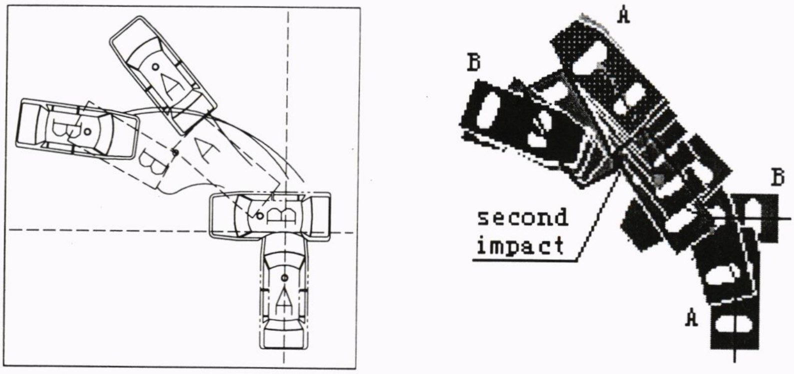

Fig. 5 T1 Test Result (Left) and Simulation Result (Right)

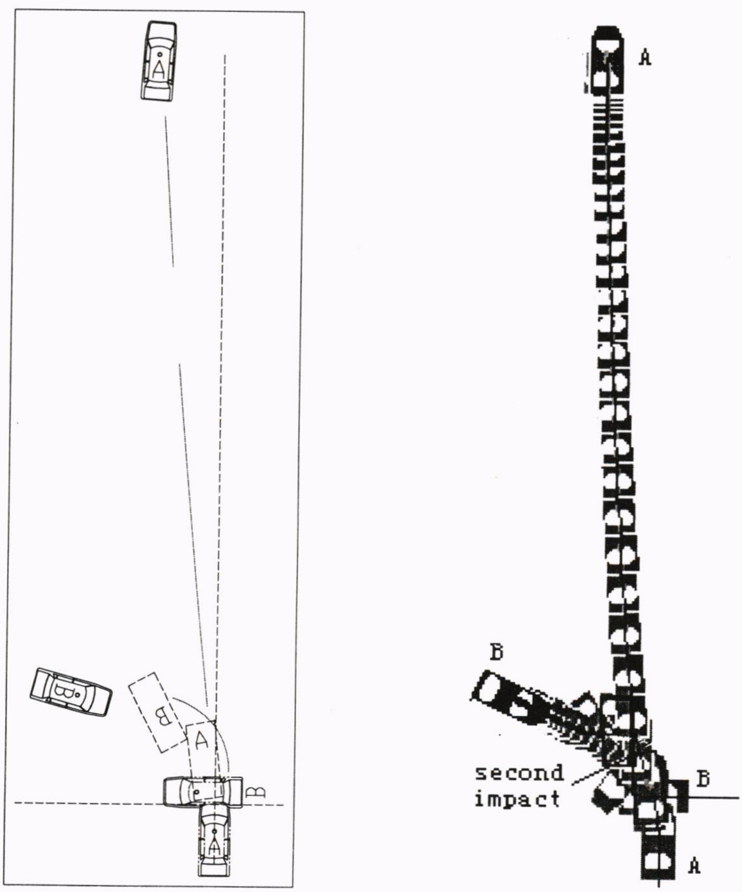

Fig. 6 T2 Test Result (Left) and Simulation Result (Right)

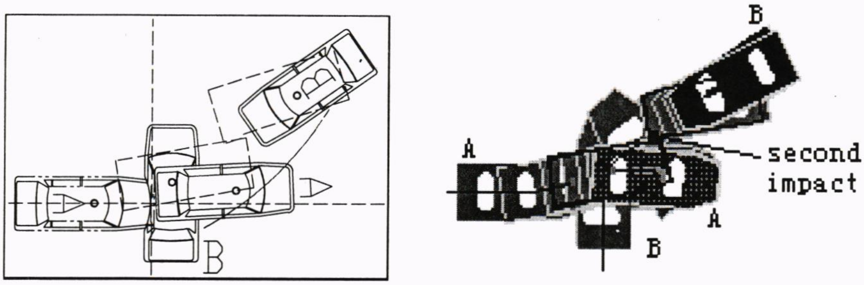

Fig. 7 T3 Test Result (Left) and Simulation Result (Right)

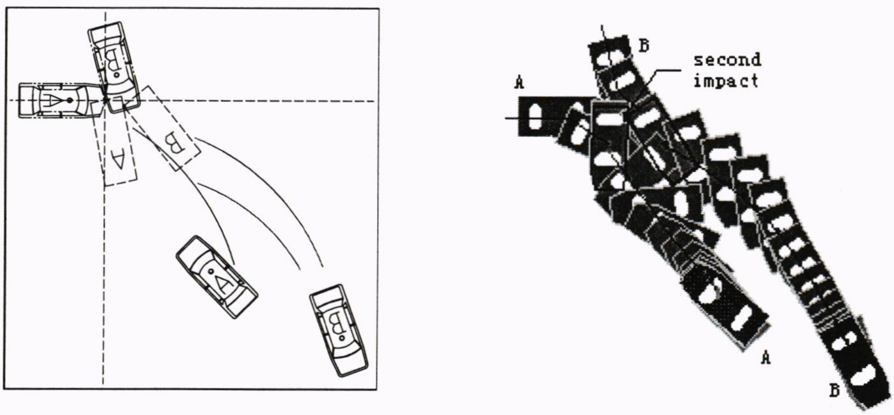

Fig. 8 T4 Test Result (Left) and Simulation Result (Right)

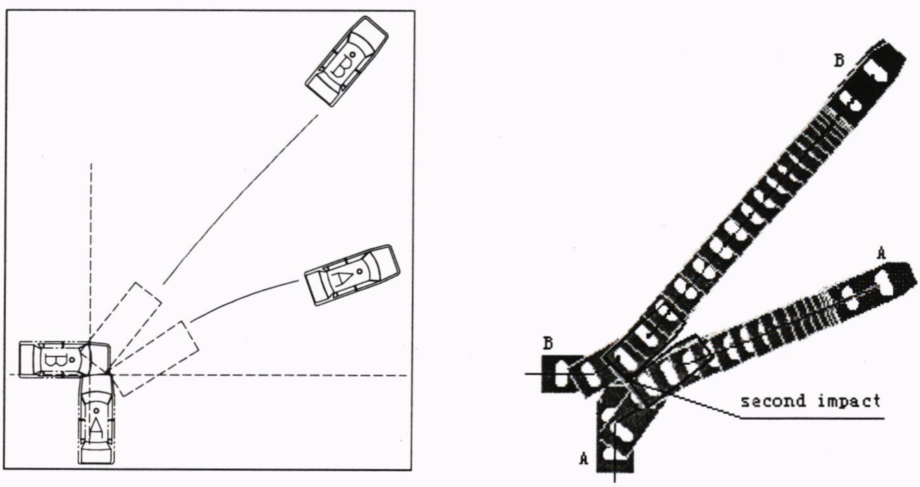

Fig. 9 T5 Test Result (Left) and Simulation Result (Right)

5. CONCLUSIONS

Based on the simulation model for car-to-car single impact accidents and quoted normal and tangential restitution coefficients in this paper, the simulation system for reconstructing car-to-car collisions involving second impact is described. Using the field data such as impact position, rest position, impact marks on the car body, this system can obtain the kinematic state of accident vehicles, the second impact position and impact velocity. Five collision tests involving second impact were used to evaluate this system, and the simulation results were found to be in good agreements with the real-world test results.

REFERENCES

Lang Wei, Hirotoshi Ishikawa and Takashi Nakatsuji (1995) A Study on Accident Reconstruction Model, **Automobile-Research**, 17-10.

Lang Wei, Yinsan Chen, Takashi Nakatsuji and Hirotoshi Ishikawa (1996) A Study of Computer Simulation System for Reconstructing Car-to-car Collisions Accidents, **China Journal of Highway**, Vol.9 No.4, 14-21.

Hirotoshi ishikawa (1995) Restitution Coefficients in Car-to-car Collisions, **Automobile-Research,** 17-1.

Lang Wei and Takashi Nakatsuji (1995) A Study on Accident Animate Reconstruction Model, **30th Anniversary of JCTS**, Tokyo,Japan,86-89.

Gwanghun Gim and Parviz E.Nikravesh (1990) An Analytical Model of Pneumatic Tyres for Vehicle Dynamic Simulations. Part 1:Pure Slips, **International Journal of Vehicle Design**, Vol.11, No.6, 589-618.

Gwanghun Gim and Parviz E.Nikravesh (1991) An Analytical Model of Pneumatic Tyres for Vehicle Dynamic Simulations. Part 2:Comprehensive Slips, **International Journal of Vehicle Design**, Vol.12, No.1, 19-39.