Evaluation of Event Data Recorder Based on Crash Tests

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Abstract – Event Data Recorder (EDR) is an additional function installed in airbag control module (ACM) to record vehicle and occupant information for a brief period of time before, during, and after a crash event. EDRs are now being installed in ACMs by several automakers in the USA and in Japan. The aim of this study is to understand the performance of EDRs for the improvement of accident reconstruction with more reliable information.

In the first report of the study, data obtained from EDRs of seven vehicle types were evaluated using 2006-2007 J-NCAP (Japanese new car assessment program) full-lap frontal barrier crash tests and offset frontal deformable barrier crash tests data.

For more practical standpoint, we conducted thirteen crash tests reconstructing typical real-world accidents such as single vehicle accidents with barriers or poles, car to car accidents and multi rear-end collisions focusing on Japanese typical accident types. Data obtained from EDRs are compared with data obtained from optical speed sensor, instrumented accelerometers and high speed video cameras. The velocities determined from pre-crash data of EDRs and the maximum change in velocity, delta-V, and delta-V time history data obtained from post-crash data of EDRs are analyzed.

The results are as follows:

- Pre-crash velocities of EDRs were very accurate and reliable. An average difference between the EDR recording values and reference speeds was 4.2% and a root mean square of the differences was 9.2%. Only two cases resulted large differences for the pre-crash velocity. Both of them were cases with braking prior to the collision. However, another test with braking resulted less difference. The braking condition may influence accuracy of pre-crash velocities.
- Maximum delta-Vs obtained from the EDRs showed uncertainty of measurement in several cases in comparisons with the reliable delta-V data. The differences in maximum delta-V were more than 10% in five of twenty-five events data and more than 20% in two of twenty-five events data. An average of the all differences was about 4% and root mean square of the differences was about 11%. Especially large deformation at narrow area may influence accuracy of post-crash delta-V.
- Multiple rear-end crash tests were reconstructed using EDRs data as case studies. Some EDRs recorded two events and a time gap between two events, so that these reconstruction case studies were very accurate and reliable.
- If though only one of three vehicles in multiple rear end crash was equipped EDR, overview and velocities of all cars may be reconstructed using these limited EDR data. In this case study, leading car's EDR data and middle car's EDR data were valuable. However if only following car was equipped EDR, the reconstruction was not accurate.

INTRODUCTION

Event Data Recorder (EDR) is an additional function installed in airbag control module (ACM) to record vehicle and occupant information for a brief period of time before, during, and after a crash event. In January 2008, National Highway Traffic Safety Administration (NHTSA) in the USA published a revised final rule on EDRs [1]. In March 2008, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (J-MLIT) decided on the technical requirements for the application of EDRs to light vehicles (3500 kg GVWR or less) [2]. This rule - the so called J-EDR technical requirement [3] - is comparable to the US regulation (49 CFR Part 563). EDRs are now being installed in ACMs by several automakers in the USA and in Japan.

EDRs are promising for accident reconstruction since they generally record delta-V, indicated vehicle speed, engine speed, driver seat position and driver safety belt status. Furthermore, they verify whether or not the service brake was applied, to what extent the accelerator pedal was depressed (or engine throttle percentage). However, if EDRs are to be utilized for accident investigation, it is first necessary to examine the reliability and accuracy of data read out from EDRs. The aim of this study is to evaluate the characteristics of EDRs and to understand the performance of EDRs for the improvement of accident reconstruction.

In the first report of the study [4], data obtained from EDRs of seven vehicle types were evaluated using 2006-2007 J-NCAP (Japanese new car assessment program) full-lap frontal barrier crash tests and offset frontal deformable barrier crash tests data. These results were evaluated as standardized crash test. For more practical knowledge, crash tests reconstructing typical real-world accidents must be conducted. In this report, data from thirteen accident reconstruction crash tests including six single vehicle crash tests (with barrier, block and poles), five car to car crash tests (head-on collisions and side impacts) and two multiple rear-end collision tests were evaluated.

GENERAL DESCRIPTION OF ANALYSIS METHOD

Laboratory crash test data are used for the comparison of the EDR data. (See Figure 1) According to the test procedures, four accelerometers are attached to the cars used for the accident reconstructing crash tests, and high-speed video cameras are employed. The acceleration data obtained from the sensors are integrated to obtain the change in velocity, delta-V, during the collision. The displacement of the target marks on the cars captured by a high-speed video camera is differentiated to obtain the delta-V. An external optical speed sensor is employed to obtain the impact velocities of the cars. Car models installed with EDRs are used for the analysis.

Pre-crash velocity recorded in each EDR (V_{EDR}) was compared with the data from an optical speedometer placed in front of the barrier (V_{OP}). If V_{OP} was not available, image analysis data from high-speed video cameras were used as reference. Post-crash maximum delta-V and delta-V versus time history data recorded in EDRs were compared with the EDRs data from accelerometers - on ACM (A-EDR), the left-side sill (A-L), right-side sill (A-R), and centre floor (A-C). If these reference data were not available, image analysis data from high-speed video cameras (Video) were used as substitution.

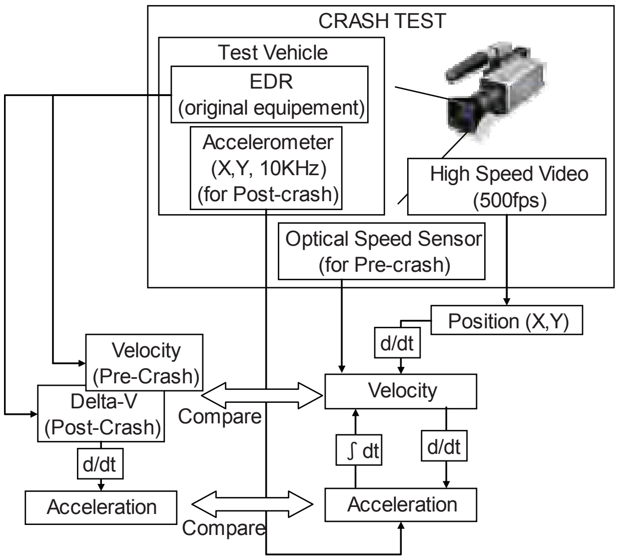
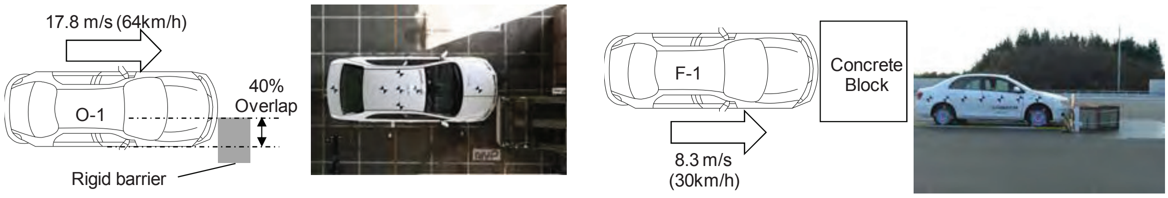


Figure 1. Diagram of data analysis

CRASH TESTS CONDITIONS

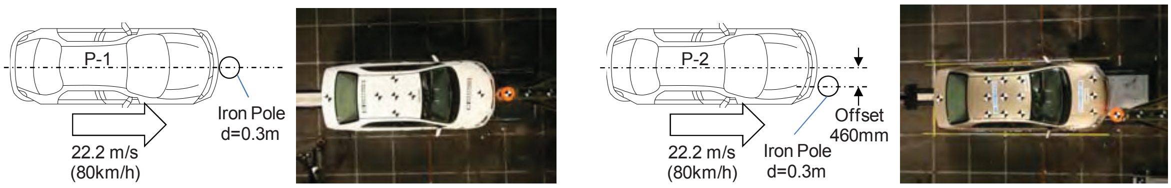
Figure 2, Figure 3, Figure 4 and Figure 5 shows conditions of crash tests reconstructing typical real-world accidents. Figure 2 shows frontal barrier/block crash tests and Figure 3 shows car to pole crash tests. These tests reconstructed single vehicle accidents with road facilities. Figure 4 shows car to car crash tests so that these tests reconstructed head-on collisions and accidents at intersections. Moreover two multiple rear-end collisions were reconstructed (Figure 5). In some cases, impact speeds and/or impact positions deviated from objective conditions. However these deviations were not so large that they had little effect on analysis and consideration of results.

Toyota Corolla (NZE140, 141) equipped with an EDR and front, side and curtain airbags (model year 2007 - 2009) was mainly used for the tests. In Table 1, most of test cars were Toyota Corolla (NZE140, 141) except following four test cars. Cars (R-1 and R-4) used for the multiple rear-end collisions in the front-most position were Toyota Progress (JCG10) equipped with an EDR and front, side, and curtain airbags. A bullet car (A-3) used in the car-to-car side impact test was Toyota Corolla previous model (AE110) not equipped with an EDR. A stopping car (A-9) used for the full-lap frontal impact was Mazda Demio (Mazda2, DE3FS) equipped with an EDR and front airbags. Totally twenty-two cars were used for the rash tests, and twenty-on cars were equipped EDRs. After the crash tests, the ACMs were removed for downloading the EDR data.

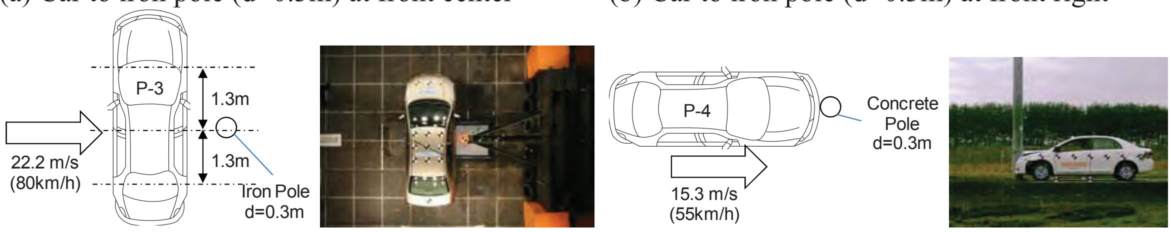


(a) Car to barrier, 40% offset (b) Car to concrete block, full-lap

Figure 2. Frontal barrier/block crash tests

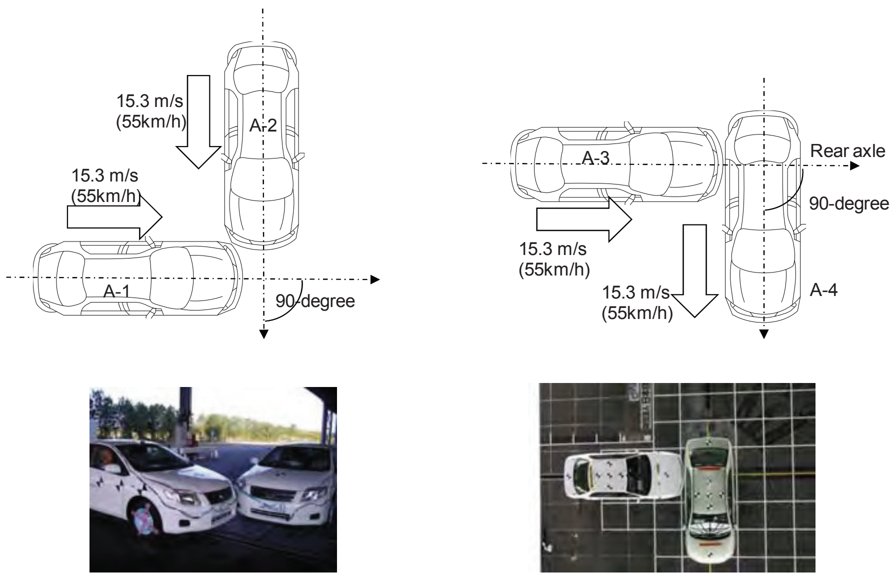


(a) Car to iron pole (d=0.3m) at front center (b) Car to iron pole (d=0.3m) at front right



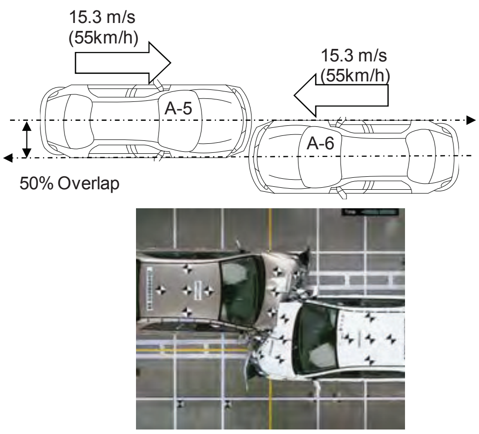
(c) Car to iron pole (d=0.3m) at side right (d) Car to concrete pole (d=0.3m) at front center

Figure 3. Car to pole crash tests

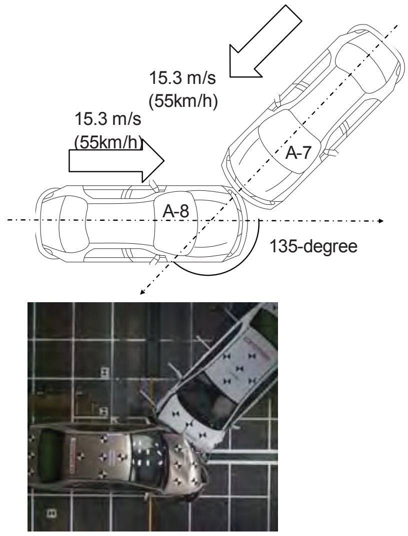


(a) 90-degree side impact, front-left and front-right (b) 90-degree side impact, front and side-right

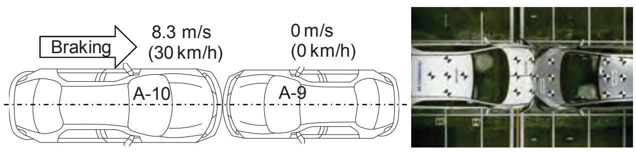
Figure 3. Car to car crash tests



(c) 50% offset (right) frontal impact,



(d) 135-degree impact, front-center and front-left



(e) full-lap frontal impact

Figure 3. Car to car crash tests (Cont.)

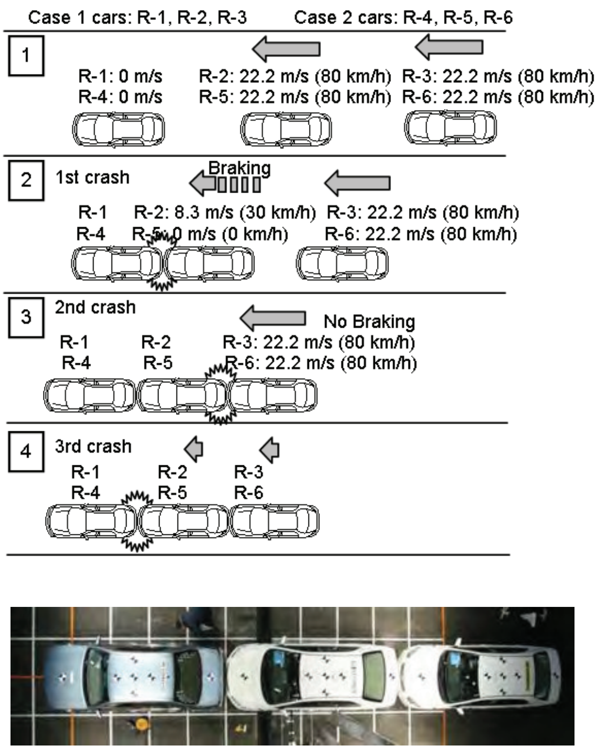


Figure 4. Multiple rear-end collision crash tests

RESULT OF RECORDING DATA

Pre-Crash Data (Impact Velocities)

Table 1 shows the comparison results of the impact velocities (i.e. velocities at the collision detected momentum) recorded by the EDRs with those from the optical speed sensors. In some cases video image analysis data were used because of difficult conditions for placement of the optical speed sensors.

As shown in Table 1, the absolute differences between the EDR impact velocities (V_{EDR}) and that obtained from the optical speed sensors (V_{OP}) were less than 2m/s in almost all the tested cars except for A-10 and R-2. The difference in A-10 was 2.2m/s. The difference in R-2 was 2.6m/s for the first data and 1.1m/s for the second data. In the case of A-10 and R-2, braking before the impact could significantly affect the pre-crash velocity recorded by the EDR. It should be noted that the pre-crash velocities recorded by the EDR were highly accurate and reliable when cars proceeded without braking prior to the collision. The accuracy and reliability of the EDR pre-crash velocity might be affected by the level of braking.

Table 1. Comparison results of pre-crash impact velocities in accident reconstruction tests.

Test Type	No.	Model	Impact-direction	Brake	V_{OP}	V_{EDR}	Difference	
					m/s	m/s	m/s	%
Frontal	1	O-1 (offset rigid barrier)	front-right	off	17.9	17.8	-0.1	-0.6
	2	F-1 (concrete block)	front	off	8.9 *1	8.9	0.0	0.2
Pole	1	P-1 (iron, d=0.3m)	front-center	off	22.4	22.8	0.4	1.8
	2	P-2 (iron, d=0.3m)	front-right	off	22.2	22.2	0.0	0.0
	3	P-3 (iron, d=0.3m)	side-right	off	22.3	- *2	- *2	- *2
	4	P-4 (concrete, d=0.3m)	front-center	off	15.3	15.6	0.3	1.6
Car to car Impact	1	A-1	front-left	off	15.4	15.6	0.2	1.3
		A-2	front-right	off	15.4	15.6	0.2	1.3
	2	A-3	front	off	15.4	- *3	- *3	- *3
		A-4	side-right	off	15.4	15.6	0.2	1.3
	3	A-5	front-right	off	15.3	15.6	0.3	1.4
		A-6	front-right	off	15.3	15.6	0.3	1.4
	4	A-7	front-center	off	15.3	15.6	0.3	1.6
		A-8	front-left	off	7.6	7.8	0.2	2.2
	5	A-9	front	off	0.0	0.0	- *4	- *4
		A-10	front	on	10.0	12.2	2.2	22.4
Multiple rear-end	1	R-1 (1st data)	rear	on	0.0 *1	0.0	- *4	- *4
		R-1 (2nd data)	rear	on	0.0 *1	0.0	- *4	- *4
		R-2 (1st data)	front	on	8.5	11.1	2.6	30.6
		R-2 (2nd data)	rear	on	0.6 *1	1.7	1.1	- *5
		R-3	front	off	21.5	21.7	0.2	0.9
	2	R-4 (1st data)	rear	on	0.0 *1	0.0	- *4	- *4
		R-4 (2nd data)	rear	on	0.0 *1	0.0	- *4	- *4
		R-5 (1st data)	front	on	4.1 *1	4.4	0.3	7.3
		R-5 (2nd data)	rear	on	0.0 *1	0.0	- *4	- *4
		R-6	front	off	22.0	22.2	0.2	0.9
Average					-	-	0.5	4.2
Number of analyzed data					-	-	18	19
Root mean square					-	-	0.8	9.2

*Difference in shaded cell is over 2 m/s.
*1: Data from video image analysis.
*2: No speed data because of side slip condition in pre-crash period.
*3: Vehicle without EDR.
*4: Excluded data because of stop condition in pre-crash period.
*5: Excluded data because of too small pre-crash impact velocity.

Post-Crash Data (Maximum Delta-V)

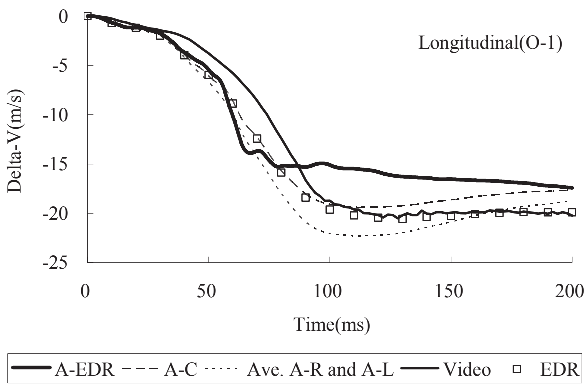
Table 2 compares the results obtained for the post-crash longitudinal maximum delta-V. When excluding the offset rigid barrier impact (O-1, Figure 5-a) and pole impacts (P-1, Figure 5-b), the differences between the EDR maximum delta-Vs and the reference values (Max delta- $V_{A\text{-}EDR}$) were less than 2m/s. The differences were greater than 10% in six of twenty-five test data. Maximum absolute difference was 30.0% in P-1. The root mean square of differences in the all maximum delta-Vs was approximately 2m/s or 11%.

The conditions of overlap and crash speed were same in both of P-1(Figure 5-b) and P-2(Figure 5-c). However there was large difference in accuracy of EDR data. In case of P-1, the pole impacted against front-center of the test car. In case of P-2, the pole impacted against front-right of the test car (0.46m form center). Front airbag sensors were located in the front side members of the tested cars and the side member of P-2 directly crashed against the pole. Accordingly, the airbag sensors of P-2 could detect the crash event much earlier as compared to those of P-1. Figure 5 shows delta-Vs versus time history data recorded in EDRs of O-1, P-1 and P-2. The results indicate that the accuracy and reliability of the maximum longitudinal delta-V obtained by the EDR decreased under more complex crash conditions as compared to the standardized crash tests or the JNCAP test [4-6].

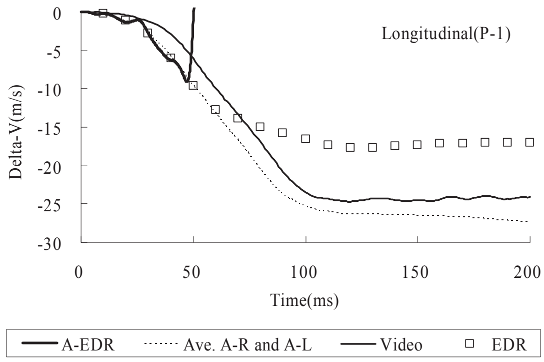
Table 2. Comparison results of post-crash maximum delta-V accident reconstruction tests.

Test Type	No.	Model	Impact-direction	Max $\Delta V_{A\text{-}EDR}$	Max ΔV_{EDR}	Difference	
				m/s	m/s	m/s	%
Frontal	1	O-1 (offset rigid barrier)	front-right	17.4	20.2	2.8	16.1
	2	F-1 (concrete block)	front	7.3	7.0	-0.3	-4.1
Pole	1	P-1 (iron, d=0.3m)	front-center	25.0 *1	17.5	-7.5	-30.0
	2	P-2 (iron, d=0.3m)	front-right	22.5	20.9	-1.6	-7.1
	3	P-3 (iron, d=0.3m)	side-right	8.0	7.9	-0.1	-1.3
	4	P-4 (concrete, d=0.3m)	front-center	12.6	11.7	-0.9	-7.1
Car to car impact	1	A-1	front-left	8.3	8.0	-0.3	-3.6
		A-2	front-right	8.8	7.9	-0.9	-10.2
	2	A-3	front	4.5	- *2	- *2	- *2
		A-4	side-right	3.8	3.5	-0.3	-7.9
	3	A-5	front-right	16.2	15.9	-0.3	-1.9
		A-6	front-right	15.9	15.6	-0.3	-1.9
	4	A-7	front-center	12.4	11.0	-1.4	-11.3
		A-8	front-left	9.7	8.8	-0.9	-9.3
	5	A-9	front	5.7	5.3	-0.4	-7.0
		A-10	front	5.0	5.3	0.3	6.0
Multiple rear-end	1	R-1 (1st data)	rear	3.8	4.2	0.4	10.5
		R-1 (2nd data)	rear	6.6	6.9	0.3	4.5
		R-2 (1st data)	front	5.7	6.1	0.4	7.0
		R-2 (2nd data)	rear	7.5	6.9	-0.6	-8.0
		R-3	front	17.7	16.8	-0.9	-5.1
	2	R-4 (1st data)	rear	1.9	1.9	0.0	0.0
		R-4 (2nd data)	rear	6.3	6.7	0.4	6.3
		R-5 (1st data)	front	4.2	3.2	-1.0	-23.8
		R-5 (2nd data)	rear	8.3	9.1	0.8	9.6
		R-6	front	16.8	16.0	-0.8	-4.8
Average				-	-	-0.5	-3.4
Number of analyzed data				-	-	25	25
Root mean square				-	-	1.7	10.5

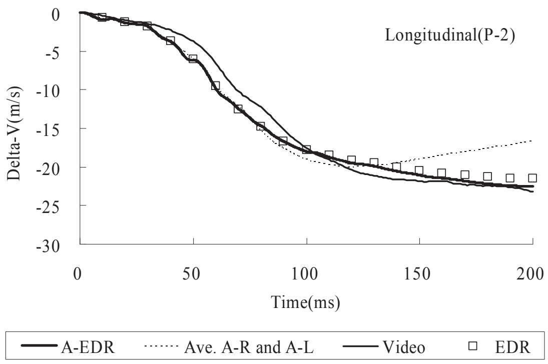
*Difference in shaded cell is over 2 m/s or over 10% (absolute).
*1: data from $\Delta V_{A\text{-}C}$.
*2: Vehicle without EDR.



(a) Frontal barrier (40% offset) crash test (O-1)



(b) Car to iron pole crash test, at front-center (P-1)



(c) Car to iron pole crash test, at front-right (P-2)

Figure 5. Longitudinal delta-V time history curves in accident reconstructing crash tests.

CASE STUDY OF CRASH TEST RECONSTRUCTION

Case studies of crash test reconstructions using EDRs data were conducted. Examples were multiple rear-end collision crash tests shown in Figure 4.

Reconstruction of Multiple Rear-End Collision Crash Test, Case 1

Table 3 shows pre-crash speeds and post-crash delta-Vs recorded in EDRs of R-1, R-2 and R-3 in case 1 of multiple rear-end collision crash test. EDRs of R-1 and R-2 recorded two events and EDR of R-3 recorded one event, and each EDR recorded pre-crash speed data and post-crash delta-V data. For pre-crash data, continuous recording every one second and recording at event (i.e. impact) detected moment are combined, so that last time interval of pre-crash speed data may not be same among all records. Moreover if one EDR recorded two events, a time interval of two events was recorded.

For R-1, last time interval of the first event was 900msec, and it of the second event was 700msec. The time interval of the first event and the second event was 840msec. For R-2, last time interval of the first event was 600msec, and it of the second event was 400msec. The time interval of the first event and the second event was 816msec. For R-3, last time interval was 200msec.

Figure 6 shows integrated collision reconstruction result of all events using EDRs data of three vehicles under common reference time. Time 0msec was selected as the first event detection moment, assuming that both of EDRs of R-1 and R-2 detected the moment at the same time. Event detection times of different vehicles might be shifted in a few tens of millisecond at one same collision in a strict sense. However accurate assessment was difficult so that we assumed that different vehicle detected event same time at same collision. Moreover post-crash delta-V data was merged (post-crash recording time was 150msec for R-1 and 200msec for R-2 and R-3). This common reference time was indicated as total time in table 3. Vehicle velocities in post-crash period were calculated as differences between pre-crash speeds at event detected moment and delta-Vs.

Table 3. Pre-crash speed and post-crash longitudinal delta-V data recorded in EDRs of R-1, R-2 and R-3 in multiple rear-end collision crash test (Case 1).

(1) R-1 (1st data), Non-deployment.

Pre-crash							Post-crash			
Recording Time (ms)	-4900	-3900	-2900	-1900	-900	0	Recording Time (ms)	0	150	-
Total Time (ms)	-4900	-3900	-2900	-1900	-900	0	Total Time (ms)	0	150	-
Brake	on	on	on	on	on	on	Record ⊿V (km/h)	0	+14.8	-
Record Speed (km/h)	0	0	0	0	0	0	Total Velocity (km/h)	0	14.8	-

(2) R-2 (1st data), Non-deployment, Matching by Event detected time (t=0) to R-1 (1st data).

Pre-crash							Post-crash			
Time (ms)	-4600	-3600	-2600	-1600	-600	0	Recording Time (ms)	0	150	200
Total Time (ms)	-4600	-3600	-2600	-1600	-600	0	Total Time (ms)	0	150	200
Brake	off	off	off	off	on	on	Record ⊿V (km/h)	0	-23.4	-23.3
Record Speed (km/h)	78	80	80	80	58	40	Total Velocity (km/h)	40	16.6	16.7

(3) R-1 (2nd data), Non-deployment, Matching by Interval time (840msec) between R-1 (1st data) and (2nd data).

Pre-crash							Post-crash			
Time (ms)	-4700	-3700	-2700	-1700	-700	0	Recording Time (ms)	0	150	-
Total Time (ms)	-3860	-2860	-1860	-860	140	840	Total Time (ms)	0	990	-
Brake	on	on	on	on	on	on	Record ⊿V (km/h)	0	25.0	-
Record Speed (km/h)	0	0	0	0	0	0	Total Velocity (km/h)	0	25.0	-

(4) R-2 (2nd data), Deployment, Matching by Interval time (816msec) between R-2 (1st data) and (2nd data).

Pre-crash							Post-crash			
Time (ms)	-4400	-3400	-2400	-1400	-400	0	Recording Time (ms)	0	170	200
Total Time (ms)	-3584	-2584	-1584	-584	416	816	Total Time (ms)	0	986	1016
Brake	off	off	off	on	on	on	Record ⊿V (km/h)	0	+22.5	+23.3
Record Speed (km/h)	80	80	80	58	12	6	Total Velocity (km/h)	6	28.5	29.3

(5) R-3 (1st data), Deployment, Matching by Event detected time (t=0) to R-2 (2nd data).

Pre-crash							Post-crash			
Time (ms)	-4200	-3200	-2200	-1200	-200	0	Recording Time (ms)	0	170	200
Total Time (ms)	-3384	-2384	-1384	-384	616	816	Total Time (ms)	0	986	1016
Brake	off	off	off	off	off	off	Record ⊿V (km/h)	0	-59.6	-61.9
Record Speed (km/h)	80	80	80	78	78	78	Total Velocity (km/h)	78	18.4	16.1

0ms 150ms 816ms 840ms 990ms

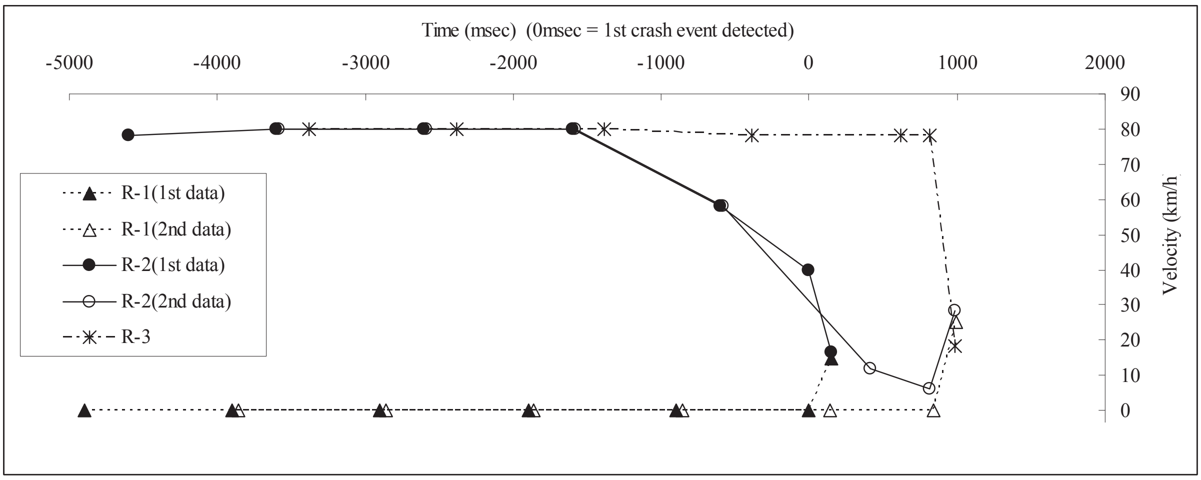


Figure 6. Velocity of R-1, R-2 and R-3 reconstructed from EDR recording data in multiple rear-end collision crash test (Case 1).

Reconstruction result in Figure 6 well means situations of case 1 of multiple rear-end collision crash test. In an accident analysis of multiple rear-end collision, orderly sequence of collisions is one of the important issues. In this reconstruction these sequence become evident that the first collision was by R-2 into R-1, and the second collision was by R-3 into R-2 and R-1. The crash condition can be described as follows:

- About 1.4sec before time 0 (i.e. the first event detected by EDRs of R-1 and R-2), R-2 had started deceleration.
- At 0sec, R-2 collided into R-1 in 40km/h (However, result of the optical speed sensor showed 31km/h as the impact velocity of R-2).
- After the first rear-end collision, R-1 accelerated and R-2 decelerated. Common velocities of the vehicles become about 15 – 17km/h in 150 – 200msec.
- About 0.8 – 0.9sec after the first collision, the second collision event was detected. R-3 collided into R-2 in 78km/h without prior braking. At the second event, R-1 and R-2 had been stopping or moved in very low velocity.
- R-1, R-2 and R-3 became about 16 – 29km/h at 150 – 200msec after the second collision.

A few points included issues such as difference of impact velocity of R-2 at the first event between the optical speed sensor data and EDRs data, disagreement of the impact velocities at the second event between R-1 and R-2, variation of velocities after the second collision among three vehicles. However if all vehicles were equipped EDR in multiple rear-end collision, overview of accident situation and velocities of vehicles must be reconstructed accurately like this case study.
In this crash test, R-1 and R-2 marked 4.9m of tire skid mark. If coefficient of longitudinal friction between tires and road were about 0.7, length of the tire mark was not contradiction to above results of post-crash velocities.

Reconstruction of Multiple Rear-End Collision Crash Test, Case 2

Table 4 shows pre-crash speeds and post-crash delta-Vs recorded by EDRs of R-4, R-5 and R-6 in case 2 of multiple rear-end collision crash test. EDRs of R-4 and R-5 recorded two events and EDR of R-6 recorded one event.

For R-4, last time interval of the first event was 500msec, and it of the second event was 1000msec. The time interval of the first event and the second event was 1480msec. For R-5, last time interval of the first event was 800msec, and it of the second event was 300msec. The time interval of the first event and the second event was 1436msec. For R-6, last time interval was 300msec.

Figure 7 shows integrated collision reconstruction result of all events using EDRs data of three vehicles under common reference time. Time 0msec was selected as the first event detection moment, assuming that both of EDRs of R-4 and R-5 detected the moment at the same time. Moreover post-crash delta-V data was merged (post-crash recording time was 150msec for R-4 and 200msec for R-5 and R-6). This common reference time was indicated as total time in table 4. All other assumption and reconstruction method was same as case 1.

Reconstruction result in Figure 7 well means situations of case 2 of multiple rear-end collision crash test. In this reconstruction orderly sequence of collision become evident that the first collision was by R-5 into R-4, and the second collision was by R-6 into R-5 and R-4. The crash condition can be described as follows:

- About 1.8sec before time 0 (i.e. the first event detected by EDRs of R-4 and R-5), R-5 had started deceleration.
- At 0sec, R-5 collided into R-4 in 16km/h.
- After the first rear-end collision, R-4 accelerated and R-5 decelerated. Common velocities of the vehicles become about 3 – 6km/h in 150 – 200msec.
- About 1.4 – 1.5sec after the first collision, the second collision event was detected. R-6 collided into R-5 in 80km/h without prior braking. At the second event, R-4 and R-5 had been stopping.
- R-4, R-5 and R-6 became about 20 – 25km/h at 150 – 200msec after the second collision.

Table 4. Pre-crash speed and post-crash longitudinal delta-V data recorded in EDRs of R-1, R-2 and R-3 in multiple rear-end collision crash test (Case 2).

(1) R-4 (1st data), Non-deployment.

Pre-crash							Post-crash			
Recording Time (ms)	-4500	-3500	-2500	-1500	-500	0	Recording Time (ms)	0	150	-
Total Time (ms)	-4500	-3500	-2500	-1500	-500	0	Total Time (ms)	0	150	-
Brake	on	on	on	on	on	on	Record ⊿V (km/h)	0	6.3	-
Record Speed (km/h)	0	0	0	0	0	0	Total Velocity (km/h)	0	6.3	-

(2) R-5 (1st data), Non-deployment, Matching by Event detected time (t=0) to R-4 (1st data).

Pre-crash							Post-crash			
Time (ms)	-4800	-3800	-2800	-1800	-800	0	Recording Time (ms)	0	150	200
Total Time (ms)	-4800	-3800	-2800	-1800	-800	0	Total Time (ms)	0	150	200
Brake	off	off	off	on	on	on	Record ⊿V (km/h)	0	-12.7	-12.7
Record Speed (km/h)	70	78	80	80	46	16	Total Velocity (km/h)	16	3.3	3.3

(3) R-4 (2nd data), Non-deployment, Matching by Interval time (1480msec) between R-4 (1st data) and (2nd data).

Pre-crash							Post-crash			
Time (ms)		-4000	-3000	-2000	-1000	0	Recording Time (ms)	0	150	-
Total Time (ms)		-2520	-1520	-520	480	1480	Total Time (ms)	1480	1630	-
Brake		on	on	on	on	on	Record ⊿V (km/h)	0	24.3	-
Record Speed (km/h)		0	0	0	0	0	Total Velocity (km/h)	0	24.3	-

(4) R-5 (2nd data), Deployment, Matching by Interval time (1436msec) between R-5 (1st data) and (2nd data).

Pre-crash							Post-crash			
Time (ms)	-4300	-3300	-2300	-1300	-300	0	Recording Time (ms)	0	150	200
Total Time (ms)	-2864	-1864	-864	136	1136	1436	Total Time (ms)	1436	1586	1636
Brake	off	on	on	on	on	on	Record ⊿V (km/h)	0	26.2	21.4
Record Speed (km/h)	80	80	46	16	0	0	Total Velocity (km/h)	0	26.2	21.4

(5) R-6 (1st data), Deployment, Matching by Event detected time (t=0) to R-5 (2nd data).

Pre-crash							Post-crash			
Time (ms)	-4300	-3300	-2300	-1300	-300	0	Recording Time (ms)	0	170	200
Total Time (ms)	-2864	-1864	-864	136	1136	1436	Total Time (ms)	1436	1586	1636
Brake	off	off	off	off	off	off	Record ⊿V (km/h)	0	-53.8	-59.4
Record Speed (km/h)	80	82	82	80	80	80	Total Velocity (km/h)	80	26.2	20.6

0ms 150ms 1436ms 1480ms 1586ms

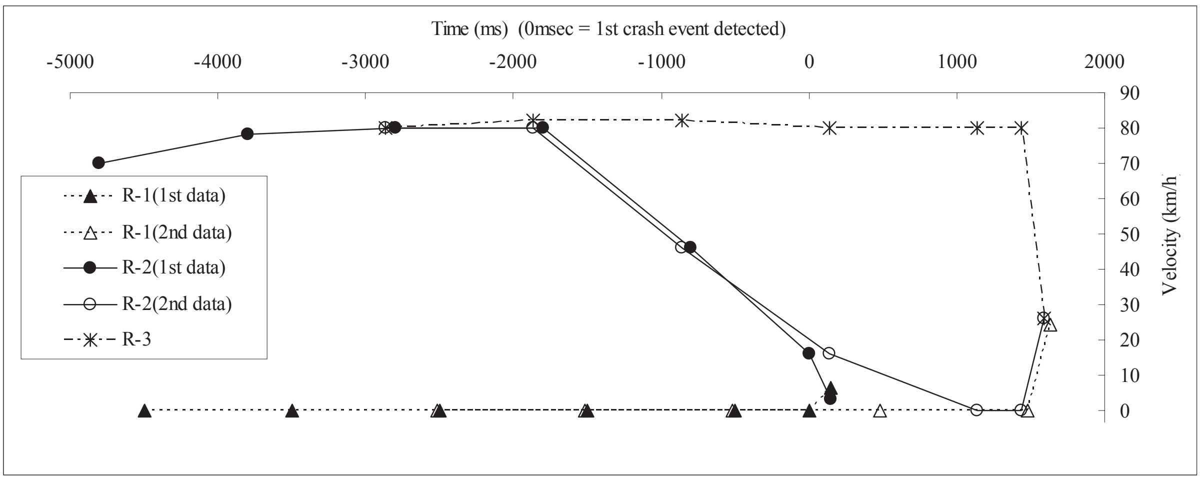


Figure 7. Velocity of R-4, R-5 and R-6 reconstructed from EDR recording data in multiple rear-end collision crash test (Case 2).

Velocities after the second collision among three vehicles were not well agree, however reconstruction of case 2 using EDRs data also shown good accuracy of overview of accident situation and velocities of vehicles.
In this crash test, R-4 and R-5 marked about 3.5m of tire skid mark. If coefficient of longitudinal friction between tires and road were about 0.7, length of the tire mark was not contradiction to above results of post-crash velocities.

Reconstruction of Multiple Rear-End Collision Crash Test using Single EDR data

At present time, equipment of an EDR is not obligation so that there are many vehicles without an EDR in real traffic. EDR data is not expected for all vehicles in real accident analyses so that reconstructions from limited EDR data must be discussed. Therefore reconstructions of multiple rear-end collision crash tests using only one vehicle's EDR were attempted. EDRs data were used in general accident analysis methods. Especially velocities were calculated according to method of conservation of vehicle momentum and method of conservation of energy. Following measurement results of vehicle total mass and energy absorption for deformation were also used.

- Vehicle total mass (kg), R-1: 1,678kg, R-2 and R-3: 1,235kg.
- Energy absorption for deformation, rear of R-1: 37,073J, front of R-2: 19,953J, rear of R-2: 136,612J, front of R-3: 50,196J.

Reconstruction Using R-1 EDR Data Only

Table 5 shows results of reconstructions of case 1 of multiple rear-end collision crash test using only R-1's EDR data. Impact velocity of R-2 at the first collision and impact velocity of R-3 at the second collision were calculated according to method of conservation of vehicle momentum and method of conservation of energy.

Table 5. Accident reconstructions of multiple rear-end collision crash test (Case 1) using speed and longitudinal delta-V recorded in R-1's EDR.

Vehicles		R-1	R-2	R-3
Mass (kg)		1,678	1,235	1,235
Velocity at 1st event (km/h)		0.0	unknown	-
Velocity after 1st event (km/h)		14.8	14.8	-
Velocity at 2nd event (km/h)		0.0	0.0	unknown
Velocity after 2nd event (km/h)		25.0	25.0	25.0
Deformable energy for front body (J)		0	19,953	50,196
Deformable energy for rear body (J)		37,073	136,612	0
Time between 1st event and 2nd event (msec)		840		
Reference data of velocity at 1st event by optical speed sensors (km/h)		0.0	31.0	-
Reference data of velocity at 2nd event by optical speed sensors (km/h)		0.0	2.2	77.4
Result of reconstruction	Velocity at 1st event by conservation of momentum (km/h)	-	34.9	-
	Velocity at 1st event by conservation of energy (km/h)	-	22.7 - 41.4	-
	Velocity at 2nd event by conservation of momentum (km/h)	-	-	84.0
	Velocity at 2nd event by conservation of energy (km/h)	-	-	77.6- 85.0

Two collision events and time interval between the two events were recorded in R-1's EDR so it was estimated that the first collision was by R-2 to R-1 and the second collision was by R-3 to R-2 (and combined R-1). Reconstructions were according to following assumption:

- Post-crash velocities of R-2 and/or R-3 were equal to post-crash velocity of R-1.
- After collisions, multi vehicles were combined.
- Deformations of rear of R-1 and front of R-2 involved in both of the first and the second collisions, so that allocation of deformation was impossible. Therefore two boundary conditions were used. One condition was that all deformations of rear of R-1 and front of R-2 were conducted by the first collision, and another condition was that all deformations were conducted by the second collision,

The velocity of R-2 at impact of the first collision was calculated as 34.9km/h (conservation of momentum), or 22.7 – 41.4km/h (conservation of energy). The difference between the former value and 31.0km/h measured result of the optical speed sensor is only 4km/h. Also median of latter bound (32km/h) is very similar to result of the optical speed sensor. These estimations showed good accuracy.
The velocity of R-3 at impact of the second collision was calculated as 84.0km/h (conservation of momentum), or 77.6 – 85.0km/h (conservation of energy). The results showed over estimation comparing to 77.4km/h from the optical speed sensor. However differences were under 10%.

Reconstruction Using R-2 EDR Data Only

Table 6 showed results of reconstructions of case 1 of multiple rear-end collision crash test using only R-2's EDR data. Impact velocity of R-1 at the first collision and impact velocity of R-3 at the second collision were calculated according to method of conservation of vehicle momentum and method of conservation of energy.
First recording event was with post-crash deceleration delta-V of R-2, and second recording event was with post-crash acceleration delta-V so it must be estimated that first collision was by R-2 to R-1 and second collision was by R-3 to R-2 (and combined R-1). Reconstruction is according to above assumptions. Also it must be aware that the results were based on pre-crash impact speed of R-2 (40.0km/h) and it was large differ from the optical speed sensor data (31.0km/h).

Table 6. Accident reconstructions of multiple rear-end collision crash test (Case 1) using speed and longitudinal delta-V recorded in R-2's EDR.

Vehicles		R-1	R-2	R-3
Mass (kg)		1,678	1,235	1,235
Velocity at 1^{st} event (km/h)		unknown	40	-
Velocity after 1^{st} event (km/h)		16.7	16.7	-
Velocity at 2^{nd} event (km/h)		6.0	6.0	unknown
Velocity after 2^{nd} event (km/h)		29.3	29.3	29.3
Deformable energy for front body (J)		0	19,953	50,196
Deformable energy for rear body (J)		37,073	136,612	0
Time between 1^{st} event and 2^{nd} event (msec)		816		
Reference data of velocity at 1^{st} event by optical speed sensors (km/h)		0.0	31.0	-
Reference data of velocity at 2^{nd} event by optical speed sensors (km/h)		0.0	2.2	77.4
Result of reconstruction	Velocity at 1^{st} event by conservation of momentum (km/h)	-0.4	-	-
	Velocity at 1^{st} event by conservation of energy (km/h)	00. – 13.7	-	-
	Velocity at 2^{nd} event by conservation of momentum (km/h)	-	-	84.3
	Velocity at 2^{nd} event by conservation of energy (km/h)	-	-	82.0 – 83.5

The velocity of R-1 at impact of the first collision was calculated as -0.4km/h (conservation of momentum), or 0.0 – 13.7km/h (conservation of energy). Before the first collision, R-1 had been stopping so that the result from calculation of conservation of momentum was in good agreement with the crash test conditions. The result from calculation of conservation of energy included bond with large difference.
The velocity of R-3 at impact of the second collision was calculated as 84.3km/h (conservation of momentum), or 82.0 – 83.5km/h (conservation of energy). The results showed over estimation comparing to 77.4km/h from the optical speed sensor. However differences were under 10%.

Reconstruction Using R-3 EDR Data Only

EDR of R-3 recorded only one event so that total number of collision and sequence of collision could not be estimated. Only one collision event between R-3 and forward vehicles was analyzed using R-3's EDR data with same methods and same assumptions of above. However the both results according to conservation of momentum and conservation of energy showed negative pre-crash velocities of combined R-1 and R-2. The results did not seem to be available solutions. The reconstruction by only R-3's EDR data was not enough for accurate analysis.

DISCUSSIONS

As shown in reference [4], an EDR data is very accurate and reliable under basic and stable crash conditions like J-NCAP crash tests. However, accuracy and reliability of an EDR data may be reduced by some crash conditions as shown in this paper.

For pre-crash speed, the most influential factor is braking prior to collisions. As shown in table 1, differences between EDR data and reference data were over 20% in two cases with pre-crash braking. However the first crash data of R-5 in case 2 of multiple rear-end collision crash test had less error even though the vehicle had be braking prior to the collision. Therefore, it was difficult to identify the extent of effect of braking prior to collisions from these three data.
Pre-crash speeds of EDR are converted from tire rotation velocity same as speed indicator. General braking causes disagreement between ground velocities and tire tangential velocities so that braking might be one of factors of differences between EDR data and reference data. However pre-crash speeds of EDR are recorded as higher than reference velocities in the cases of large differences. Tire tangential velocities normally don't exceed ground velocities during braking so that these tire conditions are not main factor for the differences.
Figure 6 in the reconstruction case study shows overlap of pre-crash speeds data for two different events by same EDR in R-2. At time 0 in the figure, pre-crash speed of the first event was higher than pre-crash data of the second event estimated from 58km/h at -584msec and 12km/h at 416msec. It suggested that the factors of differences may be data holding time and/or recording delay. However to determine the factors and its influence characteristic, more crash tests with braking prior to collisions must be conducted.

For post-crash delta-V, if the collisions caused large deformation at narrow area, differences between post-crash delta-V of EDRs and reference data were large (see results of O-1 and P-1 in table 2).
However this characteristic was not constant trend. P-2 had similar crash conditions to P-1, and a different condition was only the contact position. However, the result of P-2 showed less difference. It suggested that the factor of differences may be relation between the location of ACM and deformation area. More crash test must be conducted for discuss of this factor.

Reconstruction case studies were conducted to confirm possibility of accident reconstruction by EDR data using multiple rear-end collision crash tests. The results showed that accurate and reliable reconstructions were possible using integrated multi EDR data. Recording data of individual vehicle's EDR may have various values for same momentum, however average or some other statistical values seem to lead less error.
Moreover, reconstructions from only one EDR data were attempted. If the EDR recorded long term data, i.e. two event data with suitable interval such as R-1 or R-2 data, the acceptable reconstruction was possible. However, if EDR recorded short term data, i.e. only one event data such as R-3, the result of reconstruction was not acceptable. In this report, only rear-end collision crash tests were reconstructed. A rear-end collision generally includes only longitudinal motions. Therefore more complex reconstructions (i.e. two-dimensional phenomenon by multi vehicle) are necessary for practical discussions.

CONCLUSIONS

The pre-crash velocity and the maximum delta-V data recorded in EDRs were compared with those of the data obtained from accident reconstruction crash tests data in order to evaluate the performance and accuracy of EDRs. For the purpose, thirteen accident reconstruction crash tests including six single vehicle crash tests (with barrier, block and poles), five car to car crash tests (head-on collisions and side impacts) and two multiple rear-end collision tests were conducted. Twenty-one of all test cars were equipped EDRs, and twenty-five crash event were recorded by EDRs. Conclusions are summarized as follows:

- Pre-crash velocities of EDRs were very accurate and reliable. An average difference between the EDR recording values and reference speeds was 4.2% and a root mean square of the differences was 9.2%. Only two cases resulted large differences for the pre-crash velocity. Both of them were cases with braking prior to the collision. However, another test with braking resulted less difference. The braking condition may influence accuracy of pre-crash velocities.

- Maximum delta-Vs obtained from the EDRs showed uncertainty of measurement in several cases in comparisons with the reliable delta-V data. The differences in maximum delta-V were more than 10% in five of twenty-five events data and more than 20% in two of twenty-five events data. An average of the all differences was about 4% and root mean square of the differences was about 11%. Especially large deformation at narrow area may influence accuracy of post-crash delta-V.
- Multiple rear-end crash tests were reconstructed using EDRs data as case studies. Some EDRs recorded two events and a time gap between two events, so that these reconstruction case studies were very accurate and reliable.
- If though only one of three vehicles in multiple rear end crash was equipped EDR, overview and velocities of all cars may be reconstructed using these limited EDR data. In this case study, leading car's EDR data and middle car's EDR data were valuable. However if only following car was equipped EDR, the reconstruction was not accurate.

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