The Force Measurement of Primary Parts in Vehicle Side/Smalloverlap Crash
- by Strain Gauge Calibration -

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ABSTRACT

In this research, the new calibration component test methodology and converted forces from strain gauge will be proposed about measuring real time force of side structure like B-pillar, roof rail, door beams and side sill of IIHS side crash and lower arm, A-pillar force of IIHS smalloverlap.

Key Word : Strain Gauge, Crash, side crash, smalloverlap, Force Calculation, Structure

1. Introduction

Strain gauges are commonly used in Aerospace and vehicle durability tests but not for the vehicle dynamic crash so often. Recently some vehicle crash institutes are applying the strain gauge to predict the vehicle deforming time in case of accelerometer measuring failure or dummy ribs displacement but not for the force measurement. [1)~3)]

To know the force distribution of structure in vehicle crash test is very important because all the strength design of each part can be changed by it. In the CAE, we can easily measure the value it but it's not easy in the real car crash test because the most of side structure and smalloverlap steel parts like lower arm and A-pillar are in plastic deformation. But even if they are in plastic deformation if the strain curve keep continuity and reasonable value we assume the converted force is closed to the real force. This would be profitable because we cannot insert the load cell device worrying about its breakage.

So in this research we will find how to attach strain gauges efficiently to know side structure force of IIHS side crash and lower arm/A-pillar of smalloverlap in real-time. IIHS side To calibrate the component we also developed some component tests which can be tested easily. The side structure deforming modes are simplified to make this calibration component tests.

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2. Main Subject

2.1 Side Structure Force Measurement

2.1.1 Simplifying deforming mode

The side crash deforming mode is not simple as front side member's initial simple compressing. But fortunately recent Hyundai-Kia vehicle are using hot stamping material in B-pillar so the most deformation of the structure is concentrated on the B-pillar, struck side doors, roof rail and side sill if there is no tearing and cut parts.

The used YD vehicle is the US model, it has Good grade in structural rating with over 160mm distance from B-pillar to seat centerline. There is almost no big deformation in Y direction on the floor and A&C –pillar. So we already made trolley test method for the only evaluation of side structure. [6)]

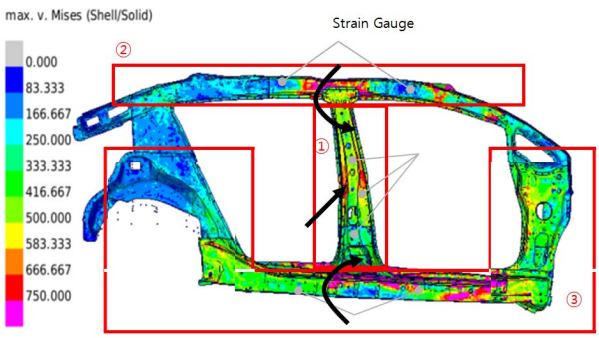

Fig.1 YD IIHS side trolley CAE model

When we review the strain distribution in YD IIHS side trolley CAE model in Fig.1 we can define the deforming modes as 3 types except doors. Firstly, the B-pillar is on the bending. Considering the modes we

attached rosette strain gauges at 3 positions of plane surface and no big deformation after crash. Secondly the roof rail is on the distorting mainly on the B-pillar connected position. Considering the modes we attached rosette strain gauges at 2 positions. Thirdly the side sill is also on the distorting mainly on the B-pillar connected position. Considering the modes we attached rosette strain gauges at 2 positions.

In case of doors, the major strength parts are door beams and they are in the simple bending mode with both ends restricted. So we can make component test for the calibration easily

2.1.2 Von Mises equation rosette calculation

The reason why we attached rosette strain gauge is we don't know the principle force, direction and equivalent stress. If we calculate the rosette by Von Mises equation we can get 2 principle stress value, 2 principle direction and 1 equivalent stress.

- Main stress formula:

$$\sigma_{1,2} = \frac{E}{1-\mu} \bullet \frac{\varepsilon_a + \varepsilon_c}{2} \pm \frac{E}{\sqrt{2}(1+\mu)} \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_c - \varepsilon_b)^2}$$

- Mohr circle:

$$\tan \Psi = \frac{2\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c} = \frac{N}{D}$$

- Direction:
  - If N>0 and D>0 then the direction is $\varphi = \frac{1}{2}(0° + \psi)$
  - If N>0 and D<0 then the direction is $\varphi = \frac{1}{2}(180° - \psi)$
  - If N<0 and D<0 then the direction is $\varphi = \frac{1}{2}(180° + \psi)$
  - If N<0 and D>0 then the direction is $\varphi = \frac{1}{2}(360° - \psi)$

Fig.2 Von Mises equation

The equivalent stress is a fictive, single directional stress amount that equals the deformation caused by the real, multi directional stress configuration. So it can be used for real force and torque calculation.

For a two dimensional strain configuration, the equivalent strain us given by:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2}$$

Using the main stress configuration, the shear will be null and the equivalent stress. [4)~5)]

$$\sigma_v = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \cdot \sigma_2}$$

2.1.3 B-pillar calibration test and calculation

To calibrate the B-pillar with static we chose the side strength test machine. The pusher, if it is too narrow it can cause too partial bending, we selected 254mm round shape pole. The pushing position on the B-pillar we marked is the first plastic bending occurred place z=548mm in car coordinates from CAE model. By experience we selected maximum force 5.2ton and stroke 400mm with 1.66mm/s speed.

Fig.3 YD B-pillar component test

As a result, we got the F-D curve and strain gauges' value of 10Hz filtering by time. From 5 times test with 1,2,3,4 and 5 ton we can get the trend equation from Fig6. These values are equivalent stress from rosette macro calculation.

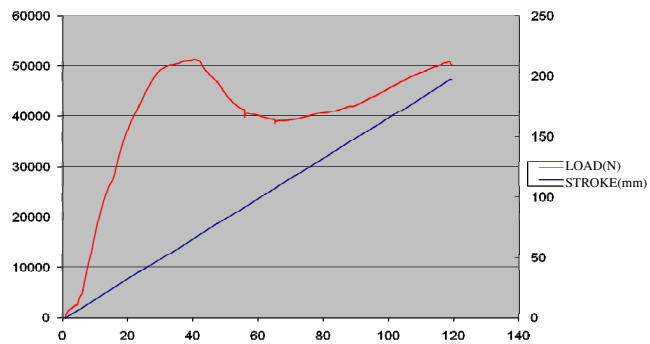

Fig.4 YD B-pillar component test F-D (5ton)

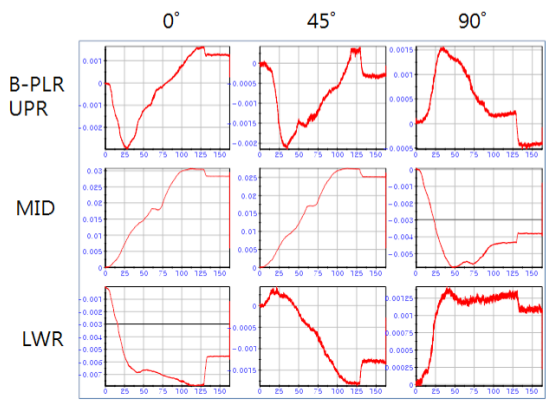

Fig.5 YD B-pillar component test SG graphs (5ton)

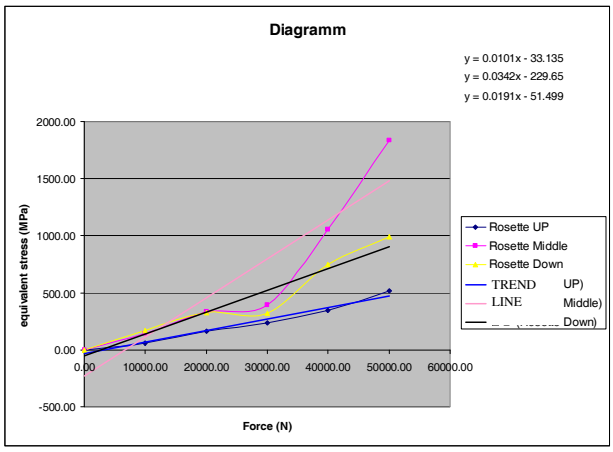

Fig.6 YD B-pillar component test trend line

2.1.4 Roof Rail calibration test and calculation

To calibrate the roof rail with static we chose the pulling test machine. We cut the B-pillar on the level of Z=548mm because it is the bending start point in the side crash and adequate to calculation the torque. The pusher, we used the steel chain, Also we welded B-pillar reinforcing stand because the B-pillar could be deformed without it before roof rail distorting. By experience we selected maximum torque 1kN with 1.66mm/s speed.

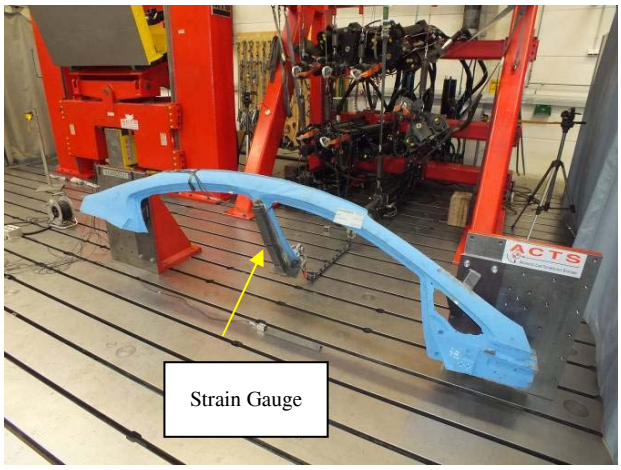

Fig.7 YD roof rail component test

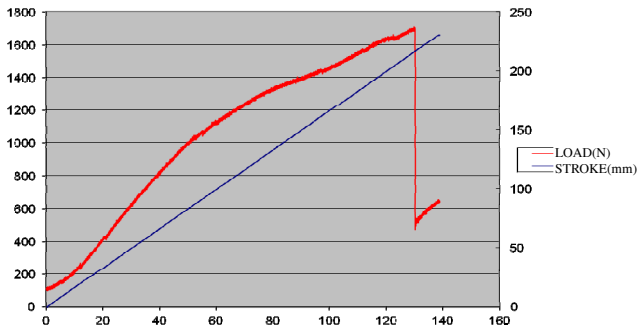

Fig.8 YD roof rail component test F-D

As a result, we got the F-D curve and strain gauges' value of 10Hz filtering by time. From 5 times test with 0.2, 0.4, 0.6, 0.8 and 1kNm torque we can get the trend equation from Fig10. These values are equivalent stress from rosette macro calculation.

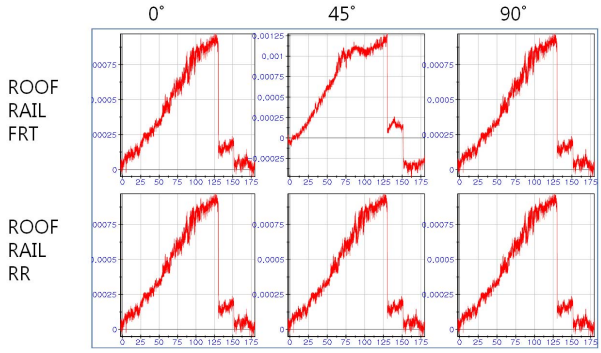

Fig.9 YD roof rail component test SG graphs

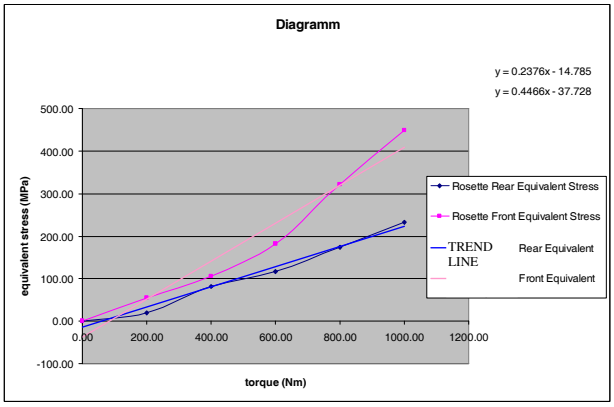

Fig.10 YD roof rail component test trend line

2.1.5 Side Sill calibration test and calculation

To calibrate the side sill with static we chose the pulling test machine again. We cut the B-pillar on the level of Z=548mm because it is the bending start point in the side crash and adequate to calculation the torque. The pusher, we used the steel chain, Also we welded B-pillar reinforcing stand because the B-pillar could be deformed without it before side sill distorting. By experience we selected maximum torque 10kN with 1.66mm/s speed.

Fig.11 YD side sill component test

As a result, we got the F-D curve and strain gauges' value by time. From 5 times test with 2, 4, 6, 8 and 10kNm torque we can get the trend equation from Fig14. These values are equivalent stress from rosette macro calculation.

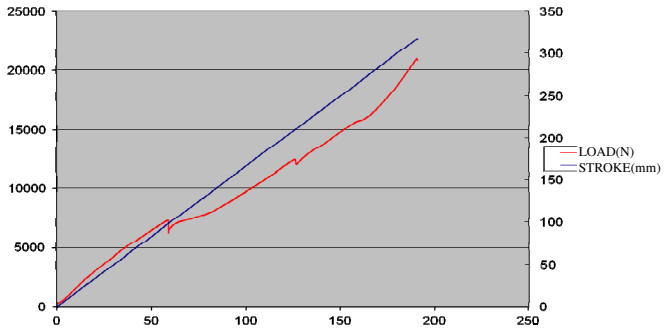

Fig.12 YD side sill component test F-D

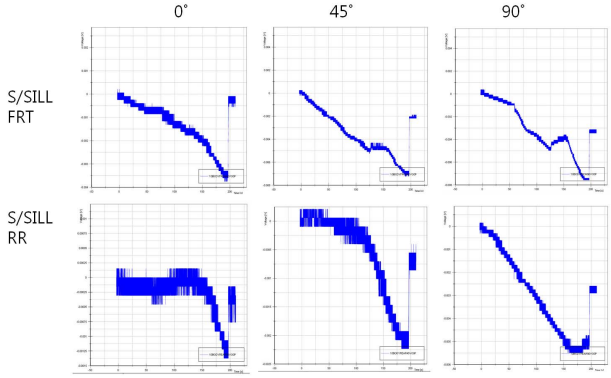

Fig.13 YD side sill component test SG graphs

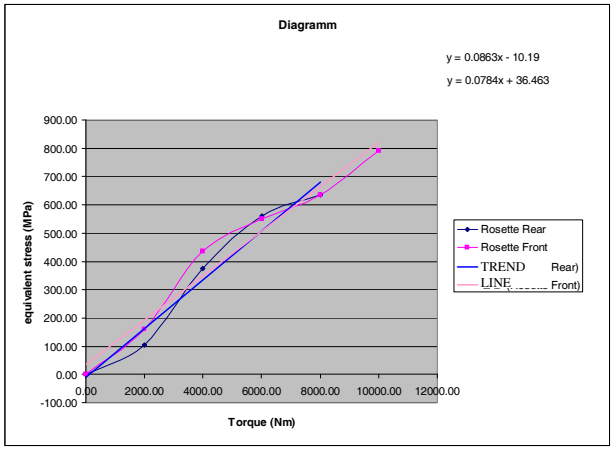

Fig.14 YD side sill component test trend line

2.1.6 Side door beams calibration test and calculation

To calibrate the door beams we chose the pulling test machine again. We mounted the 3 types of door beams (front, rear upper and lower) on the jig and pulled by 60mm width belt to prevent from point-concentrated load until plastic bending with 1.66mm/s speed.

Fig.14 YD door beam component test

The breakage force of door was 2.9 ton at front door beam and 3.3 ton at rear door upper beam. For the rear door lower beam the breakage force was not measured because we limited the maximum force as 4 ton.

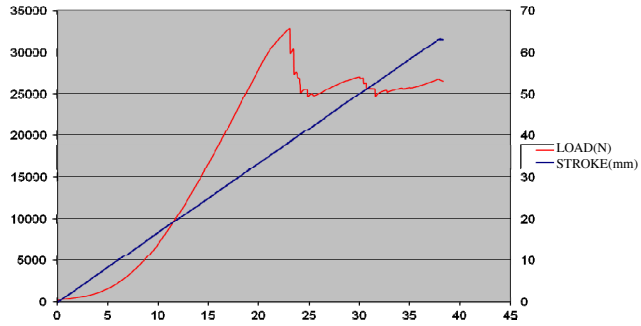

Fig.15 YD rear door upper beam component test F-D

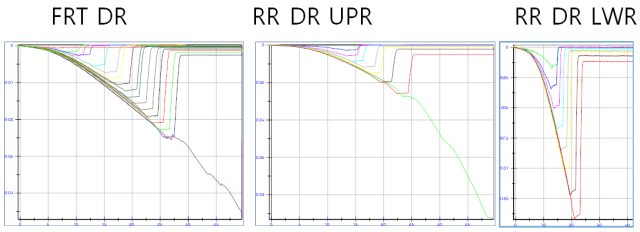

Fig.16 YD door beam component test SG graphs

As a result, we got the F-D curve and strain gauges' value by time. From 6~16 times test with different forces we can get the very linear trend equation from Fig16. These values are simple voltage because we think beam deformation is simple bending mode.

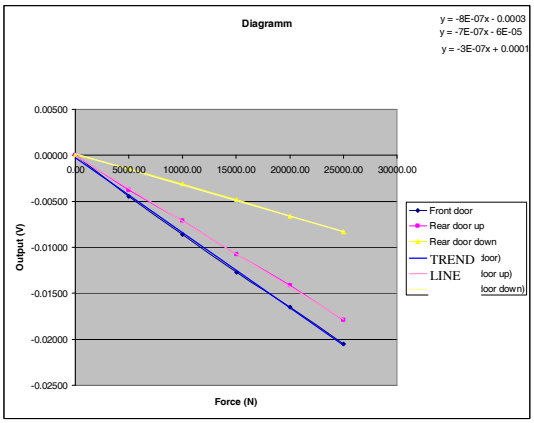

Fig.16 YD door beam component test trend line

2.1.7 Force calculation in YD IIHS side trolley test

By each trend line we did get the forces of the primary parts like table.1. We were successful for 8 points in 10 measuring place.

DOOR BEAM	ROOF RAIL	B-PLR	S/SILL
7.3t (FRT)	1.2kNm (FRT)	20t (UPR)	Error (FRT)
3.4t (RR UPR)	Error (RR)	26t (MID)	7.1kNM (RR)
21t (RR LWR)	-	5t (LWR)	-

Table.1 MaxForce and Torque results

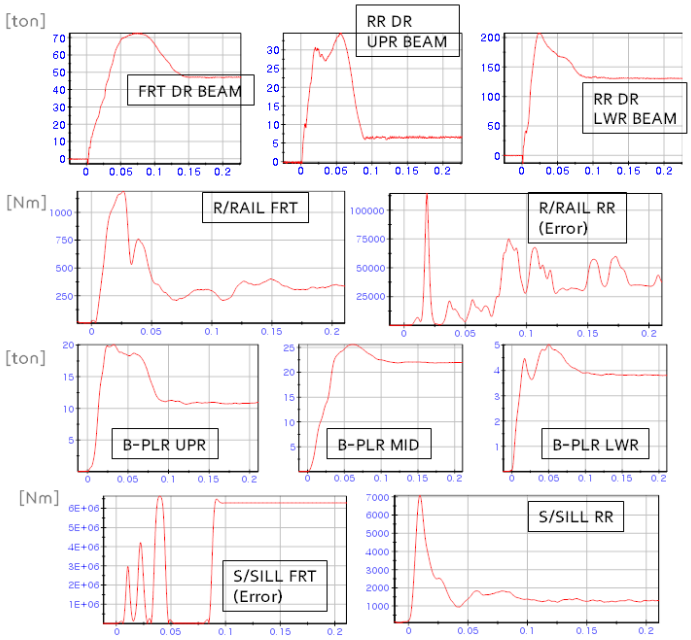

Fig.17 YD side trolley Converted to force graph

2.2 Smalloverlap Structure Force Measurement

2.2.1 A-pillar calibration test and calculation

We assumed the A-pillar deformation and attached 2 strain gauges on the edge place where there is no plastic deformation. We pushed at side door strength test bench with 0.33m/s speed until 400mm deformation. Because the vehicle test was MD, we carried out the component test also with MD A-pillar.

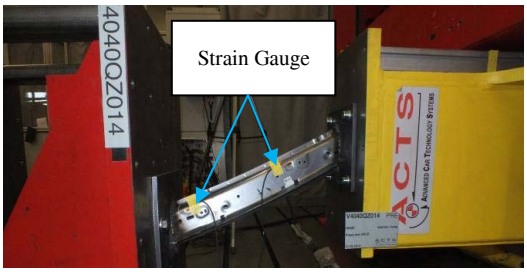

Fig.18 MD A-pillar component calibration test

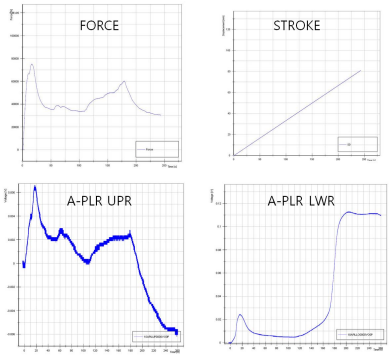

Fig.20 MD A-pillar component test SG graphs

As a result, we got the F-D curve and strain gauges' value by time. From 5 times test with 2, 4, 5, 6 and 7 ton force we can get the trend equation from Fig21. These values are equivalent stress from rosette macro calculation.

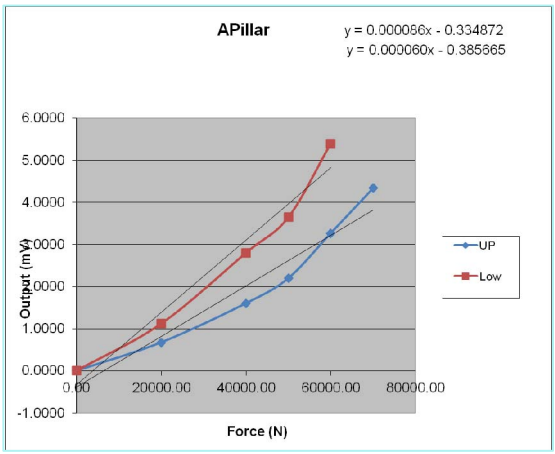

Fig.21 MD A-pillar component test trend line

2.2.2 Side sill calibration test and calculation

We assumed the side sill deformation and attached 2 strain gauges on the edge place where there is no plastic deformation. We pushed at side door strength test bench with 0.33m/s speed. But unfortunately, in the MD vehicle test, we didn't get meaningful voltage data. But this type of test method for side sill can be used in the next research.

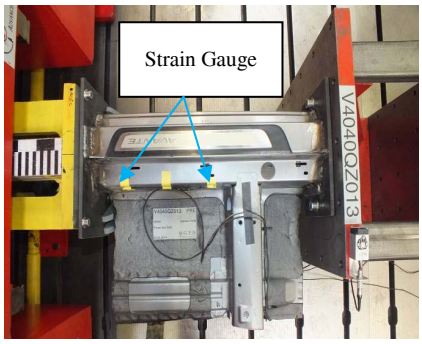

Fig.22 MD side sill component calibration test

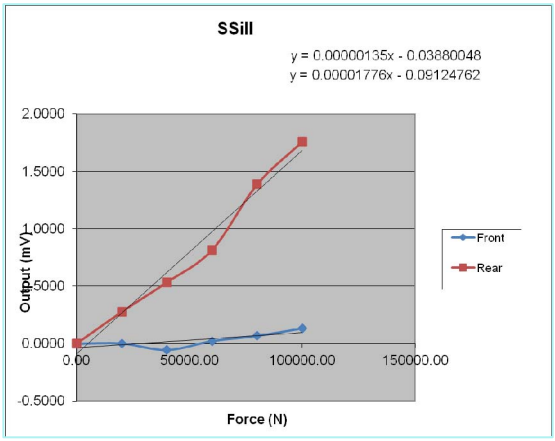

Fig.23 MD side sill component test trend line

2.2.3 Lower arm calibration test and calculation

We also tried to calculated YD smalloverlap lower arm A & B point removal force. We pulled G point at the chain pulling device with 3.33mm/s in 3 ways, firstly

only A point fixation and pulling in Y direction, secondly only B point fixation and pulling in Y direction and lastly A & B point fixation and pulling in X direction. We substitute YD smalloverlap trolley test which its structure deformation and movement was very close to the real crash.

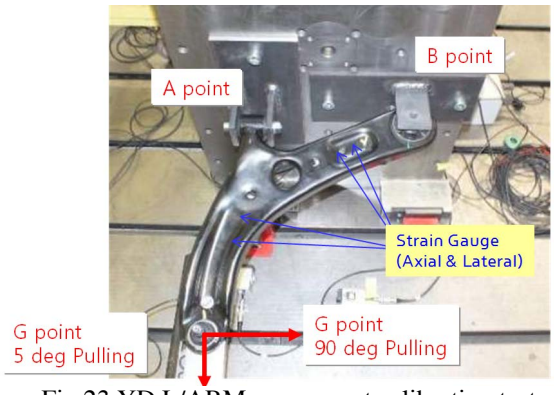

Fig.23 YD L/ARM component calibration test

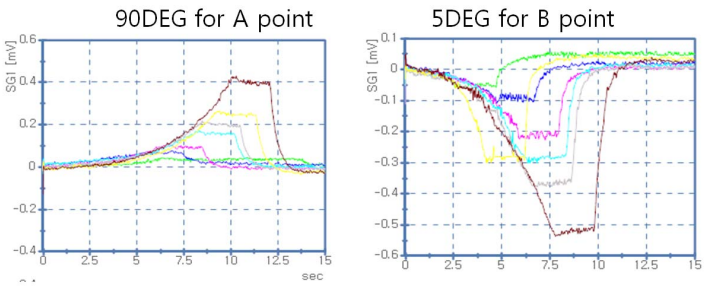

Fig.24 YD L/ARM component calibration test SG graphs

As a result, we got the F-D curve and strain gauges' value by time. From 8~9 times test with different forces we can get the linear trend equation from Fig25. These values are simple voltage because we think lower arm main load path is in axial direction.

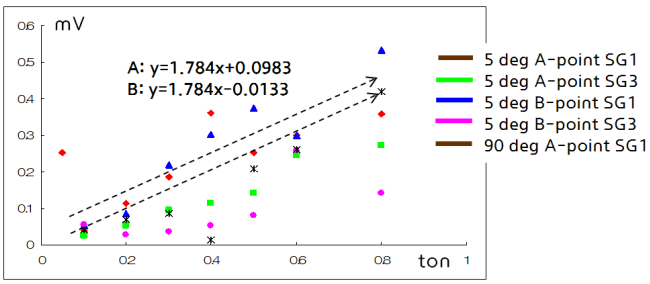

Fig.25 YD L/ARM component test trend line

2.2.4 Force calculation in YD smalloverlap trolley test

By each trend line we did get the forces of the primary parts of side and small overlap vehicle tests like table.2. We were successful for 6 points in 8 measuring place. In case of YD lower arm we selected the meaningful force measuring time with A point disconnection and the B point before being crushed from high speed video.

MD A-PLR	YD L/ARM
12t (UPR)	13t@40ms (A point)
11t (LWR)	16.5t@44ms (B point)

Table.2 Max Force results

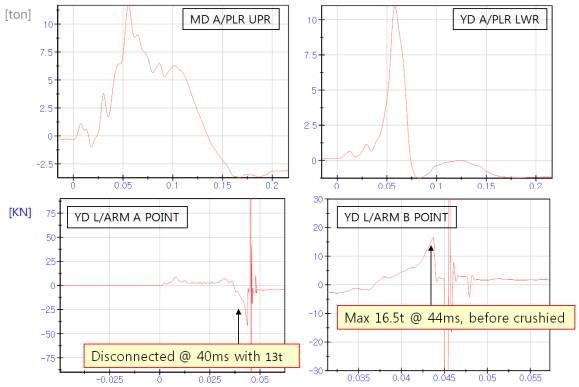

Fig.26 MD/YD smalloverlap converted to force graph

3. Conclusion

As we discussed at the introduction, knowing the force of each part is very important. If we know it, we can optimize the parts' weight and design for the good performance. To this time, those works were in the area of CAE but with this research we can also try more from test data. We expect test numbers side and smalloveralp could be reduced half. For one vehicle development the developing cost saving would be over $150,000. We are planning this methodology adaptation from PD project. We did know below facts in this research.

1) Even complicate deforming mode like side crash if we simplify the modes and use rosette strain gauge calibration, we can know its abbreviate real time force.

2) From the each part calibration test of the vehicle we can check its unique F-D curve. This could be used for the quality comparison.

3) For the YD IIHS side, the maximum force and torque of B-pillar 26t, door beam 21t, roof rail 1.2kNm and side sill 7.1kNm

4) For the MD smalloverlap, the maximum force of A-pillar 12t. For the YD smalloverlap, the maximum force of Lower arm A point was 13t and B point 16.5t.

If we stack these measurement and analyze we could improve the prediction for the crash performance.

■ Patent: Be submitted Diadem macro Rosette strain calculation

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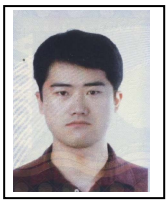
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