Ministry of Land, Infrastructure and Transport

Korea Transportation Safety Authority
Korea Automobile Testing & Research Institute

Research Review about Fuel Integrity Safety Assessment from Rollover Test of Hydrogen Bus in Korea

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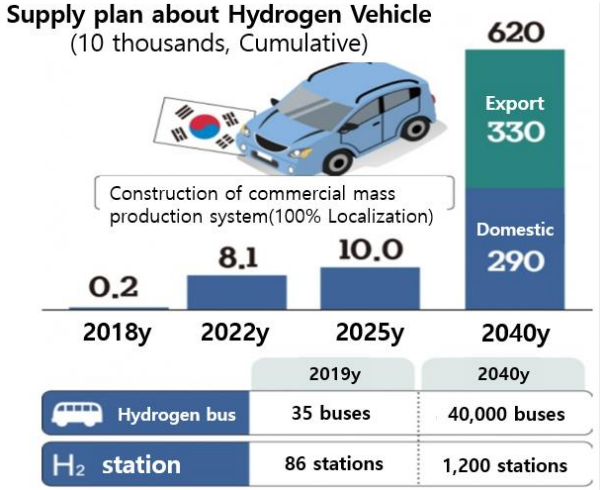
1. Research Overview

- Korea government had to need relieve the public safety concerns about the risk of hydrogen fuel system according the plan to enlarge the supplement of hydrogen bus(N3). Accordingly Korea government developed the vehicle safety regulation(2018yr) about fuel safety integrity for hydrogen bus.

- Need to minimize the potential risk factors(ex. fuel leakage, breakage of fuel tank) considering the relatively high risk of overturn such as hydrogen buses.



<The supply plan about Hydrogen Bus in Korea>

<The overturn risk of Bus(N3)>

2. Korea Motor Vehicle Safety Standard(Regulation)

- **Current Regulation in KMVSS 91(Fuel Safety Integrity of Hydrogen/CNG bus)**
  - Established Date : July. 11, 2018, Enforcement date : July. 1, 2019
  - Main contents : This regulation doesn't meet in case the the fuel system(ex : fuel tank and valves) happen the direct contact with the vehicle structure/ground during rollover test.
  - Test methods : Actual vehicle Rollover (same as UN R 66) test and Computer Simulation
- **Development Research of Detailed test protocols(2020yr)**
  - Accomplished the evaluation study for making detailed test protocols about both the rollover test and the computer simulation in accordance with the establishment of vehicle safety regulation(KMVSS 91) for evaluation of fuel system safety at the time of rollover of hydrogen/CNG gas buses.

수소가스를 연료로 사용하는 자동차의 연료장치 충돌시험기준

(제91조제5항 관련)

시 험 조 건	기 준
1. 시속 40.3킬로미터의 속도로 자동차를 고정벽에 정면 충돌시킬 때	가. 자동차의 정지 순간부터 60분동안 누출된 가스량은 평균 118 NL/분(min) 이하 일 것 나. 승객기주 공간 및 수화물 공간의 공기 중 수소농도는 3±1.0% 이하일 것. 다만, 충돌 후 5초 이내에 저장소의 자단벨브가 잠기고 저장소로부터 누출이 없는 경우는 제외한다. 다. 수소가스내압용기는 자동차의 부착지점으로부터 1곳 이상 부착되어 있을 것
2. 시속 40.3킬로미터의 속도로 이동벽을 자동차의 뒷면에 충돌시킬 때	
3. 시속 50킬로미터의 속도로 이동벽을 자동차의 옆면에 충돌시킬 때	

주) NL(Normal Liter) : 표준상태(0℃, 1기압)에서 측정한 부피

<Korea Motor Vehicle Safety Standards(KMVSS 91) about Hydrogen/CNG Bus>

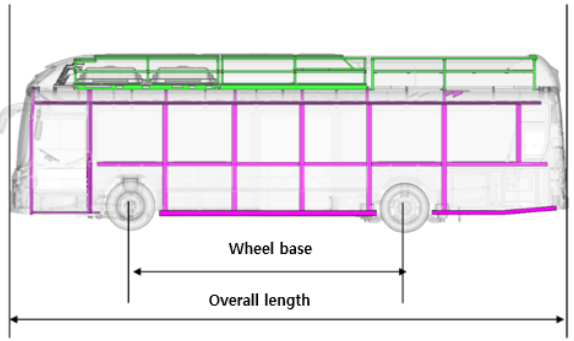
3. Test configuration (Preparation)

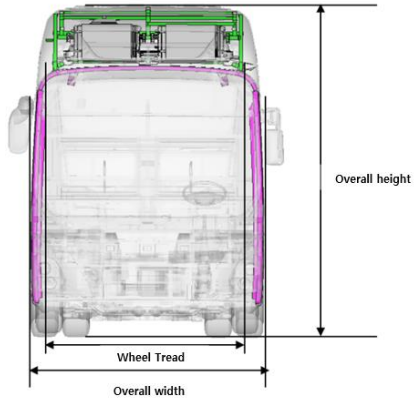
Specification of Test models

Specification of Actual Test vehicle

Specification	
Maker	Hyundai
Overall length	10,995mm
Overall width	2,490mm
Overall height	3,420mm
Wheel base	5,400mm
FC stack power	180KW
Motor power	300KW
Tank capacity	845L(33.1kg)
Tank pressure	700bar
Battery capacity	78.4KWh(39.2X2)

Specification of Simulation Model

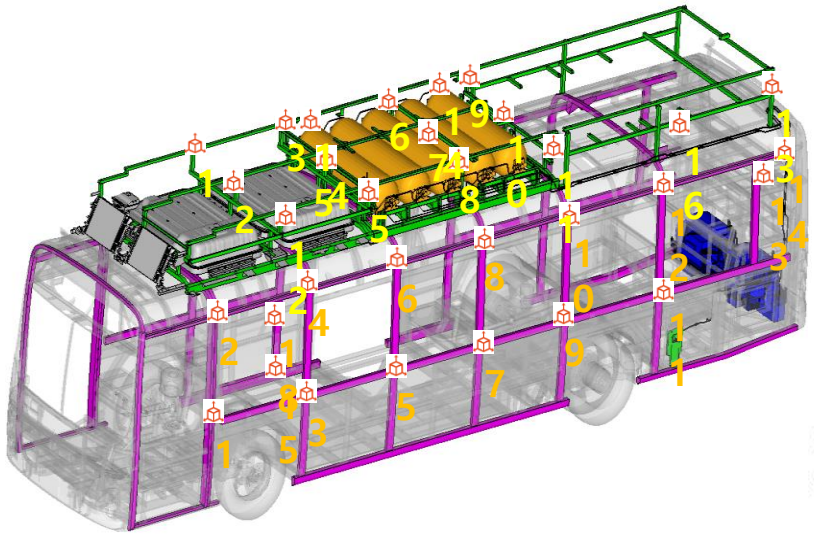




Specification	
Solver	LS-Dyna
Number of nodes	4,482,317
Number of elements	4,952,528
Average size of elements	15 mm
Vehicle weight	13.554 ton
Run time	32 hr 21 min (Xeon 40 cores)

3. Test configuration (Preparation)

Composition of measuring instrumentation for fuel integrity safety in Roll-over test

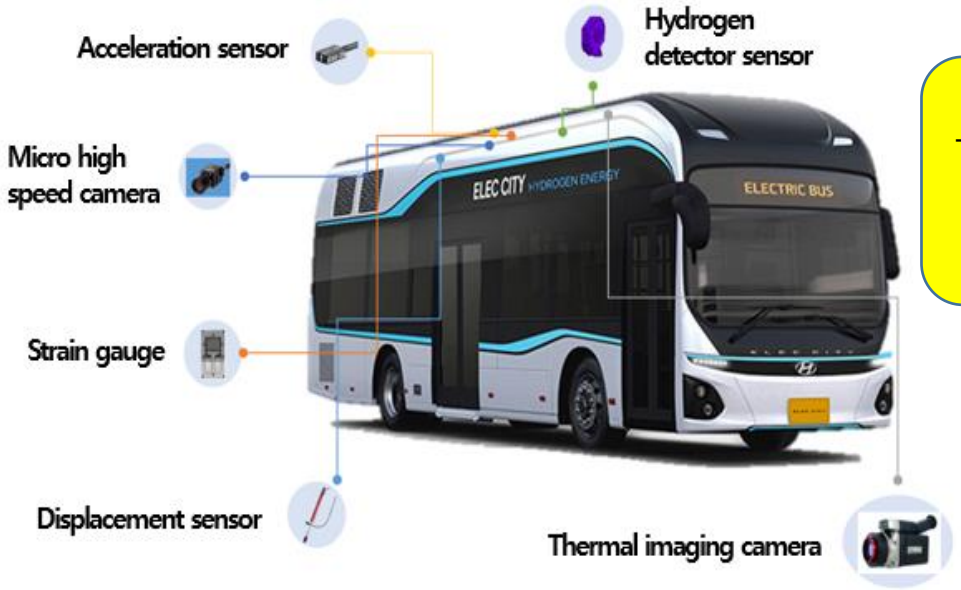


Installation of acceleration/angular sensors

- Installation of acceleration sensors(77 points) in main structure (Cantrail, b-pillar) and fuel tanks for measurement of impact severity.
- Installation of angular velocity at COG points(3 axial sensor)

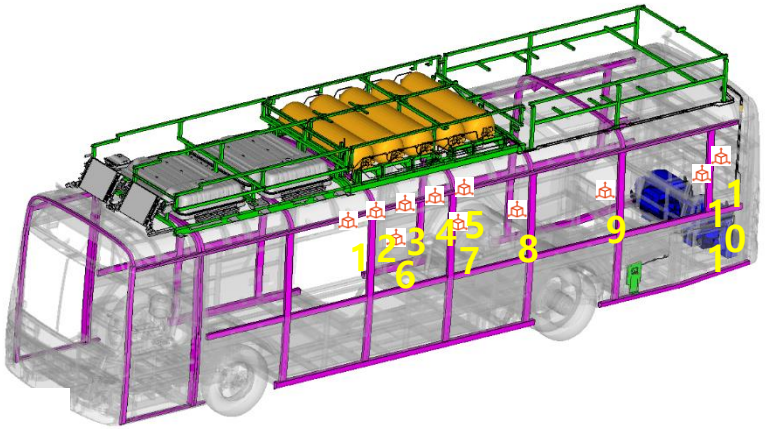
Installation of hydrogen gas sensor

- Installation of gas detect sensors(15 points) in both main fuel systems(fuel tanks and fuel-cell stacks) and passenger compartments for measuring hydrogen gas leakage.



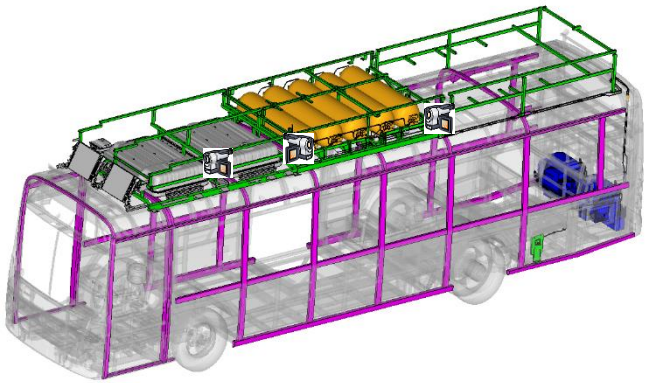
Installation of Micro high speed camera

- Installation of on-board camera for measuring both direct contact and breakage of fuel systems and REESS.



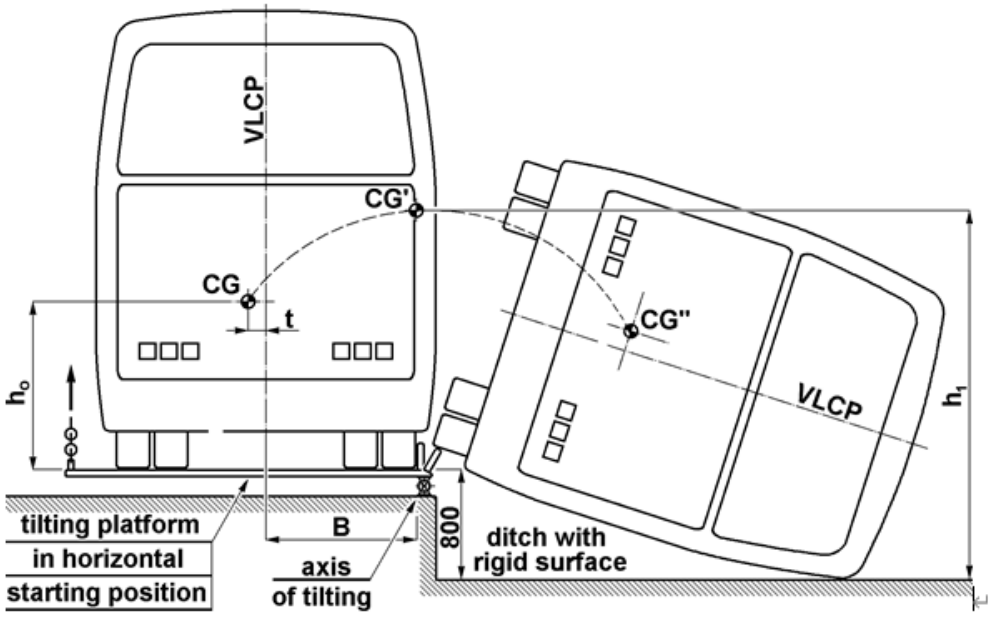
Installation of touch/force sensors

- Installation of strain gauge(11 points) for measuring impact force in fuel systems systems(fuel tanks and fuel valves) during rollover test.



3. Test configuration (Preparation)

Rollover test



<UN R 66 Rollover Test>

Primary Test Condition

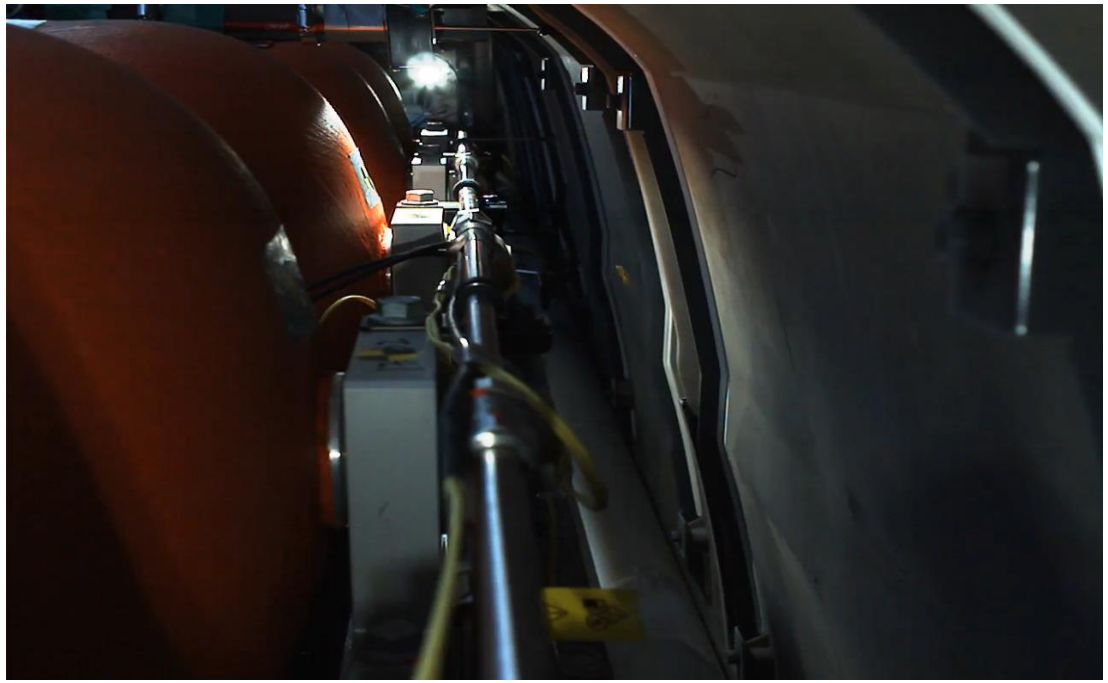
- Each Hydrogen fuel tank is filled to 95 percent of service pressure with Hydrogen (H_2).
- Test vehicle states ignition on during Roll-over test.
  - All fuel valves are to be in open position.
  - All electric system are also to be in operation position.
- Rollover test conducts that the angular velocity of tilt platform shall not exceed five degree/sec.

4. Test Results

High Speed Image of Rollover test

4. Test Results

Fuel system (Fuel Tanks and Shut-off valves)



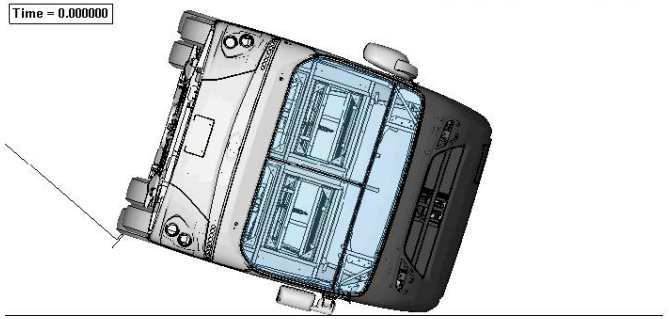
REESS (Rechargeable Energy Storage system)

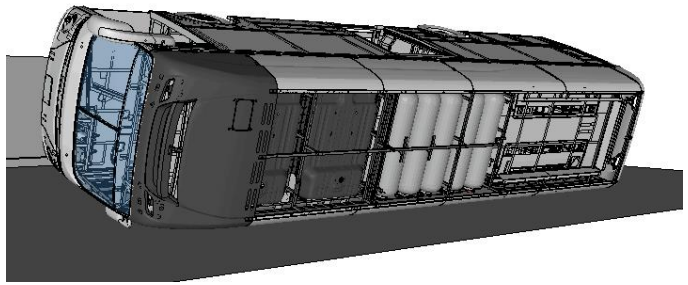
- Direct contacts were observed between fuel system(fuel lines and valves) and vehicle side wall during rollover test.
  - High accelerations of 60 ~ 80g were measured in terms of impact severity of fuel tanks. But no leak of hydrogen gas.
- Direct contacts were observed between REESS and vehicle side wall during rollover test, too.
  - Failure of isolation resistance between high voltage bus and electrical chassis.

※ 65~90 Ω/V were measured from the test (Regulation : equal or over 500 Ω/V(A/C))

4. Test Results

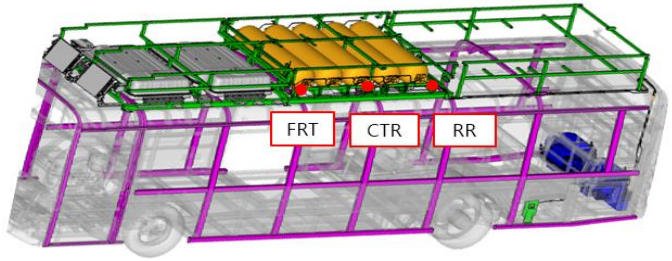
Comparison between actual test and computer simulation(1)

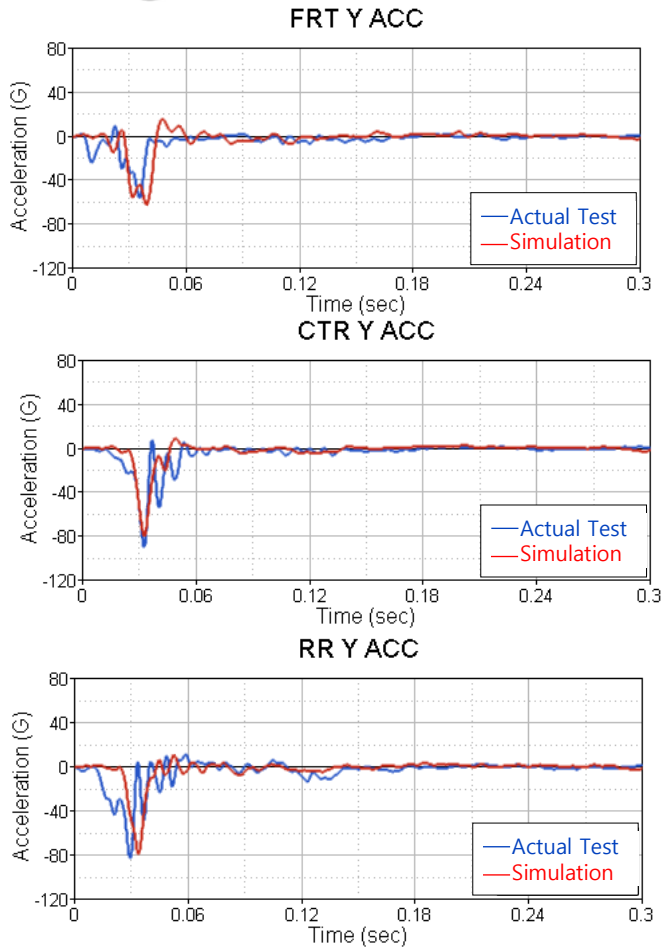




<Comparison of FECV bus rollover crash between test and simulation>

- Confirm the good correlation(equivalent level) about measurement data of both fuel tanks and main body regions between actual test and computer simulation.
- Accelerations of roof structure(Fuel tanks) : peaks, shapes and event times are similar between test and simulation data.

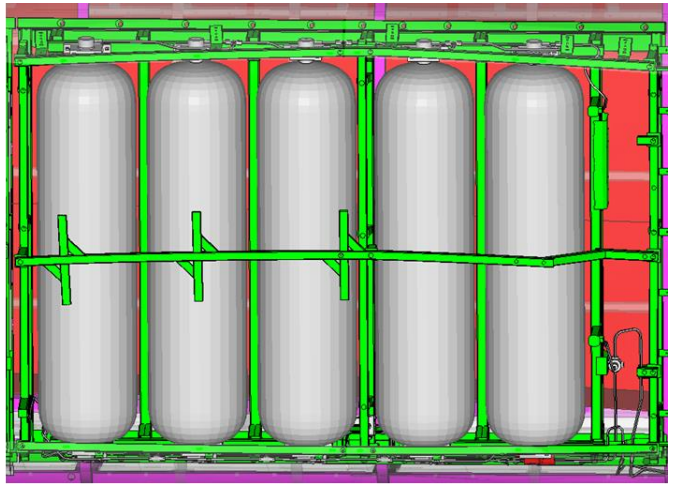


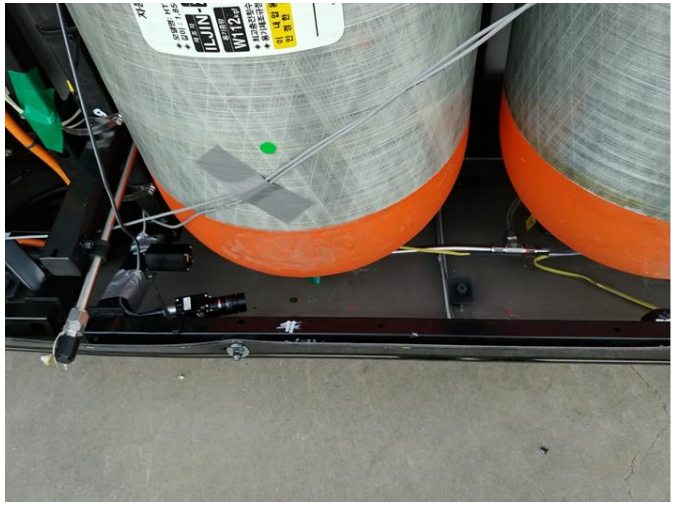


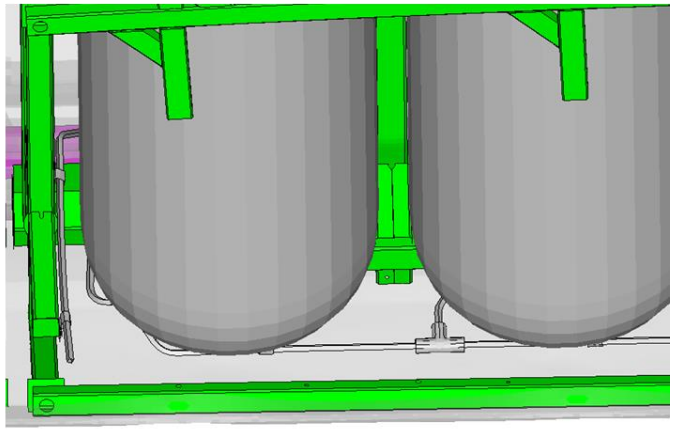
< Acceleration on frame structure of hydrogen fuel tank>

4. Test Results

Comparison between actual test and Computer simulation (2)







<Comparison of FECV bus rollover crash between test and simulation>

- Confirm the good correlation(equivalent level) about deformed shape of fuel system and structure.
  1) Direct contacts are observed between fuel system and vehicle side wall in both test and simulation.
  2) Deformed shapes of vehicle structures are similar.

5. Conclusion

- **Confirm the regulation necessity about fuel safety** in terms of rollover crash.
  - Happen high impact severity(Acceleration) because of direct contact between fuel systems and vehicle side wall/ground. But, no happen the breakage of fuel tank/valves and fuel gas leakage.

  ⇒ Consideration to include fuel leakage as well as direct contact.
- **Need to develop regulation about electrical safety of REESS** in terms actual vehicle crash of bus or coach.
  - Confirm not to meet isolation resistance regulation following to UN R 100.
- **Confirm validity between actual rollover test and computer simulaton**
  - KMVSS permit both of these two methods about fuel safety regulation.

Thank you for your attention !