

## **‘FRONT CENTER POLE’ AND ‘REAR CAR TO CAR’ CRASH TEST IN DEVELOPMENT OF CLARITY FUEL CELL VEHICLE**

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### **ABSTRACT**

A high level of crash safety performance is important to expand Fuel Cell Vehicle’s market acceptance. In addition to achieving equivalent crash safety performance to conventional gasoline and hybrid vehicles, it's also important task for manufacturer to consider and test FCVs specific issues. This will help users understand the crash safety performance of FCVs and hydrogen is similar to conventional gasoline and hybrid vehicles. In this paper, we report on two crash tests, the ‘Front Center Pole’ and ‘Rear Car to Car’ crash. Both of these crash tests were conducted during the development of the Clarity FCV in addition to regulation and third party evaluation crash tests. The ‘Front Center Pole’ crash is frontal crash that concentrates the impact in a way that locally deforms the front region of the vehicle, testing the protection of the fuel cell stack in severe frontal crashes. The ‘Rear Car to Car’ crash is rear-ending crash test where an actual bullet vehicle collides into the Clarity FCV using the FMVSS 301 test conditions for the purpose of testing the safety performance of the high-pressure hydrogen tank.

The ‘Front Center Pole’ crash is a frontal crash where the Clarity FCV impacts at 26kph a stationary pole at the vehicles front center axis. The ‘Rear Car to Car’ crash is rear end crash test using a mass production vehicle, in this case a Honda Legend Hybrid, as a bullet vehicle travelling at 80kph that strikes the rear of the Clarity FCV with a 70% overlap.

‘Front Center Pole’ crash test, we have confirmed there is no serious damage to the fuel cell stack and no hydrogen leakage. ‘Rear Car to Car’ crash, we have confirmed there is no serious damage to the high-pressure hydrogen tank and no hydrogen leakage.

## INTRODUCTION

Honda recognizes that the products we sell throughout the world contribute to global climate change through CO<sub>2</sub> emissions. As such, we have a responsibility to help solve the global environmental problems that constitute a pressing issue for society. As a possible solution, the design of zero emission vehicles, vehicles that do not discharge CO<sub>2</sub>, are attracting much attention. FCVs are one type of zero emission vehicles that generate electricity by a chemical reaction between stored hydrogen and atmospheric oxygen. These FCVs discharge no CO<sub>2</sub>, the only exhaust is water vapor. As such, FCV could eliminate the CO<sub>2</sub> released due to transportation.

Honda started to sell the Honda Clarity, a fuel cell vehicle in March of 2016. The key feature of Clarity FCV was designing a fuel cell power train placed in the traditional vehicle engine compartment. (Photograph 1) Other conventional FCV have placed the vehicle fuel cell under the vehicle floor. This layout allows for both an increased interior volume and allows placing an additional hydrogen storage tank under the vehicle's floor. With this additional storage provided by this additional hydrogen tank, the Clarity FCV achieves a class-leading five passenger seating and a 750km range. In addition to not emitting CO<sub>2</sub>, with this design the Clarity FCV achieves the same usability as conventional gasoline fueled cars and hybrid cars.



*Photograph1. Clarity FCV layout*

Crash safety performance has always been of critically important to Honda, and this focus on safety applies to our FCVs as well. In addition to achieving equal crash safety performance to conventional gasoline and hybrid vehicles, it is important for manufacturers to consider FCVs specific issues and educate customers about the crash safety performance of FCVs and the hydrogen storage systems they use.

Crash safety performance of mass-produced cars is evaluated by regulation crash tests of each country and crash tests by third party organizations. Crash testing has improved crash safety performance and steadily reduced the number of victims of traffic accidents. However, today innovation is rapidly changing vehicle technology. It is important that manufactures consider these innovations and new technologies when designing vehicles to protect their occupants during well-established crashes tests, and real world crashes.

Crash safety performance consists primarily of passenger safety performance, high-voltage electrical safety performance, and fuel safety performance. FCVs are different from conventional gasoline and hybrid vehicles as they use compressed hydrogen for fuel. For this reason, to establish crash safety performance of

FCVs, it's important to establish fuel safety performance at the crash, i.e., hydrogen safety performance. The main hydrogen fuel parts of Clarity FCV are the fuel cell stack in the front of the vehicle and the high-pressure hydrogen tank set at the vehicle's rear. In this paper, we reported two crash verification tests that are among the many considerations and tests for establishing the Clarity FCV crash safety performance. One is the verification of 'Front Center Pole' crash to evaluate fuel safety performance of fuel cell stack in a frontal crash. Another is verification of the 'Rear Car to Car' crash to evaluate fuel safety performance of the high-pressure hydrogen tank in rear-end crashes.

## VERIFICATION OF 'FRONT CENTER POLE' CRASH

In this section, we will review the safety performance of the Clarity FCV in the 'Front Center Pole' crash. First, we will explain the fuel safety systems of the fuel cell stack. Second, we will provide an overview of the 'Front Center Pole' crash. Lastly, we will report the results of the 'Front Center Pole' crash testing that we conducted in the development of the Clarity FCV.

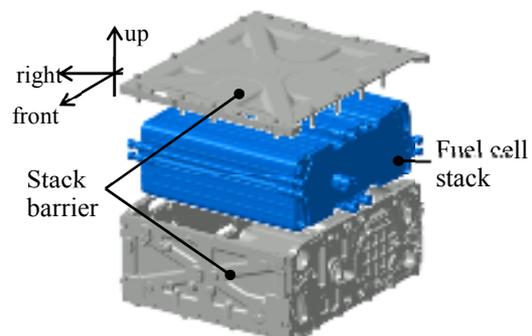
### Fuel Safety Systems of the Fuel Cell Stack in Frontal Crashes

Protecting the fuel cell stack in frontal crashes depends on two complementary strategies, the hydrogen fuel shutoff system and the structural protection of the fuel cell stack. We will explore the details of these systems in next section.

**Fuel shutoff system** The hydrogen fuel shutoff system controls the main supply valve of the high-pressure hydrogen tank. This system suspends the supply of fuel when a crash is detected. In CLARITY FUEL CELL, the main valve of high-pressure hydrogen tank is closed when serious crash is detected that could result in hydrogen leakage from the fuel cell stack. By closing the main supply valve, the Clarity FCV fuel shutoff system prevents the escape of hydrogen from the high-pressure hydrogen tank through damaged fuel cell stack.

**Structural protection** Structural protection is physical protection of fuel cell stack by the vehicle's body structure and fuel cell stack protective housing.

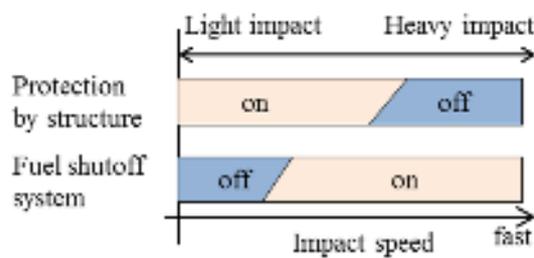
During a crash, the vehicle's body structure will efficiently absorb impact energy while minimizing intrusion. This will minimize the risk of damage to the fuel cell stack resulting from intrusion of the body structure into the vehicle space occupied by the fuel cell. Moreover, we enclose the fuel cell stack in a strong housing, called the stack barrier (Photograph 2), additionally protecting it from intrusion of surrounding structure during the crash.



*Photograph2. Fuel cell stack and stack barrier*

### Strategy of the Fuel Safety Systems of Fuel Cell Stack

Clarity FCV establishes a robust level of fuel safety performance by combination of the fuel shutoff system and the structural protections described. During low-speed crashes, fuel safety performance primarily is provided by structural protection. During high-speed crashes, fuel safety performance is provided by both the structural protections and the fuel shutoff system. (Figure 1)



**Figure1. Strategy of the fuel safe systems of the fuel cell stack**

In development of Clarity FCV, we designed for fuel safety performance by considering various crash configurations in addition to regulation crash tests and crash tests by third party organizations.

In this next section, we will discuss the ‘Front Center Pole’ crash, which is one of the additional crash verifications of Clarity FCV fuel safety performance.

#### Overview of ‘Front Center Pole’ Crash

‘Front Center Pole’ crash is a crash configuration where the car impacts a narrow object such as a streetlight, utility poles, or trees at the center of the vehicle. Since the crash surface is narrow, there is tendency for large intrusions into the central part of the vehicle. (Photograph 3)



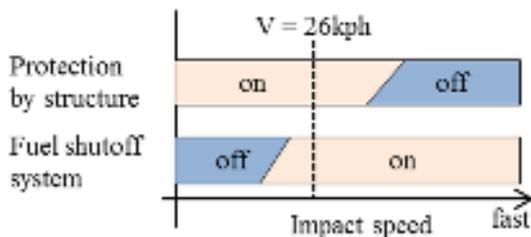
**Photograph3. Vehicle collided to a tree[1]**

Since the Clarity FCV fuel cell stack is located near the vehicle’s front center position, intrusion into the fuel cell stack area during the ‘Front Center Pole’ crash can be large. This large intrusion of the pole into the area of the fuel cell stack can make this crash particularly severe for the Clarity FCV compared to traditional vehicles. Because of the potential risk to the Clarity FCV vehicle, a ‘Front Center Pole’ test was used to evaluate the performance of the Clarity FCV.

#### ‘FR Center Pole’ Crash Test

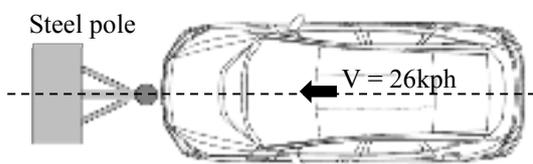
In this next section we will describe the ‘Front Center Pole’ test condition and review the performance of the Clarity FCV in the ‘Front Center Pole’ crash test that was conducted as part of the Clarity FCV development.

**Crash test condition** During the crash test, we place an AM50% Anthropomorphic Test Device (ATD) in both the driver and front passenger position and 40kg of additional weight in the vehicle to represent vehicle cargo. Vehicle impact velocity is 26kph, which is above threshold that will activate the fuel shutoff system to confirm strategy of the fuel safety systems of fuel cell stack. (Figure 2)



**Figure2. ‘Front Center Pole’ crash test velocity**

The pole impact fixture used is a 254 mm diameter steel pole typically used for side impact crash testing. (Figure 3)



**Figure3. Configuration of ‘Front Center Pole’ crash test**

**Crash test result** After the impact, we confirmed no hydrogen leakage from either the fuel cell stack or any other vehicle location. Moreover, we also confirmed that fuel shutoff system had also functioned normally.



**Photograph4. Clarity FCV ‘Front Center Pole’ crash test**



**Photograp5. Left : Clarity FCV after ‘Front Center Pole’ test and Right : Fuel cell stack after ‘Front Center Pole’ test**

From this test result, we confirmed that structural protection could be achieved at speed range which operates fuel shutoff system.

That is, during low-speed that does not activate the fuel shutoff system, fuel safety performance is established by structural protections. And during high-speed, additional fuel safety performance was provided by the fuel shutoff system. We confirmed that fuel safety performance was established in ‘Front Center Pole’ crash which is severe condition for fuel safety performance of fuel cell stack.

### **VERIFICATION OF ‘REAR CAR TO CAR’ CRASH**

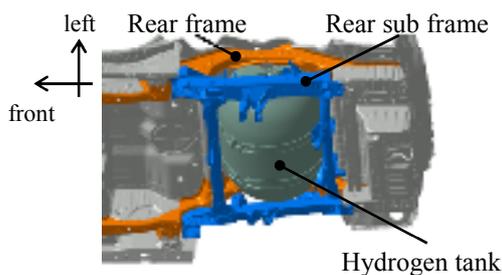
Next, we will explore fuel safety performance of the ‘Rear Car to Car’ crash test used to establish the safety performance of high-pressure hydrogen tank located at the rear of the Clarity FCV.

First, we will explain the fuel safety systems of the high-pressure hydrogen tank at the rear end crash. Second, we will provide an overview of ‘Rear Car to Car’ crash test. Lastly, we review the results of the ‘Rear Car to Car crash test we conducted during the development of the Clarity FCV.

#### **Fuel Safety System in Rear End Crash**

Fuel safety system of high-pressure hydrogen tank in rear end crash consists of three overlapping protective systems: protection provided by the vehicle structure, the strength of the high-pressure hydrogen tank itself, and the hydrogen fuel shutoff system. The design of the Clarity FCV represents a completely new vehicle

design. As such, we designed the vehicle's rear frame to be straight and to provide more efficient energy absorption and less intrusion during a rear crash. We also surrounds the high-pressure hydrogen fuel tank with rear frame and strong sub frame, and makes less inputs to tank resulting from the rear crash. (Photograph 6)



**Photograph6. Structure surround high-pressure hydrogen tank**

Besides the protective strength of the vehicle structure and rear sub-frame, we designed a high-strength high-pressure hydrogen tank to resist forces from various real world crash situations. In addition, we designed the fuel shutoff system to function in rear crashes. When a serious crash occurs, the main valve of high-pressure hydrogen tank is automatically closed.

**Strategy of the Fuel Safety Systems of the High-pressure Hydrogen Tank**

Clarity FCV establishes fuel safety performance through the protection provided by the vehicle structure and the strength of the high-pressure hydrogen tank itself. This is the same strategy used in conventional gasoline-fueled vehicles and hybrid vehicles except for the increased higher strength of the tank carrying the hydrogen fuel to resist forces resulting from the rear crash. In

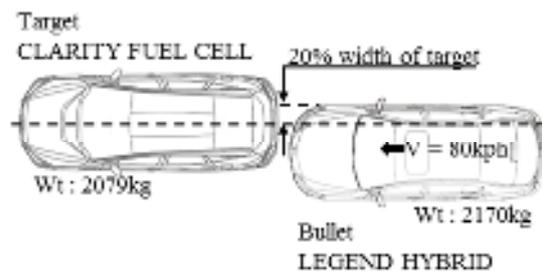
development of Clarity FCV, we designed for fuel safety performance during a ‘Rear Car to Car’ crash which actual vehicle collides into the rear of the Clarity FCV, in addition to regulation crash tests of each country and crash tests by third party organizations.

In the next section, we provide an overview of the ‘Rear Car to Car’ crash test procedure.

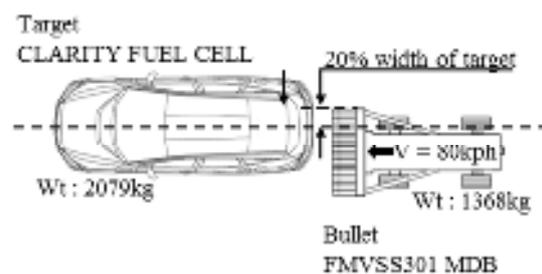
**Overview of ‘Rear Car to Car’ Crash**

Crash test conditions of the ‘Rear Car to Car’ crash – target vehicle weight, crash speed, and offset position are same as FMVSS 301R.

(Figure 4, Figure 5)



**Figure4. Configuration of ‘Rear Car to Car’ crash test**



**Figure5. Configuration of FMVSS301 crash test**

The characteristic of reaction force of crash surface was different between the Moving Deformable Barrier(MDB) used in FMVSS 301R and actual vehicles, so forces on the high-pressure

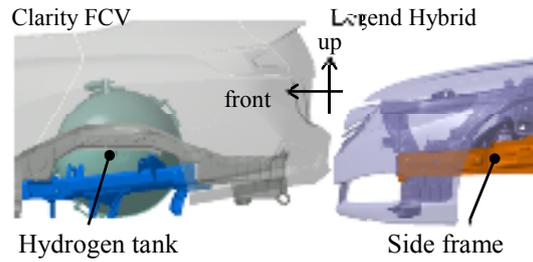
hydrogen tank of Clarity FCV would be different than those seen in real crashes.

Since crash surface of MDB is honeycomb made from aluminum, it tends to disperse the impact force of the crash. Whereas an actual vehicle has a non-uniform body structure, so impact forces changes with locations along the crash surface. Since there is the difference discussed above, in development of the Clarity FCV, we considered investigation of ‘Rear Car to Car’ crash in addition to FMVSS 301R,

**RR Car to Car’ Crash Test**

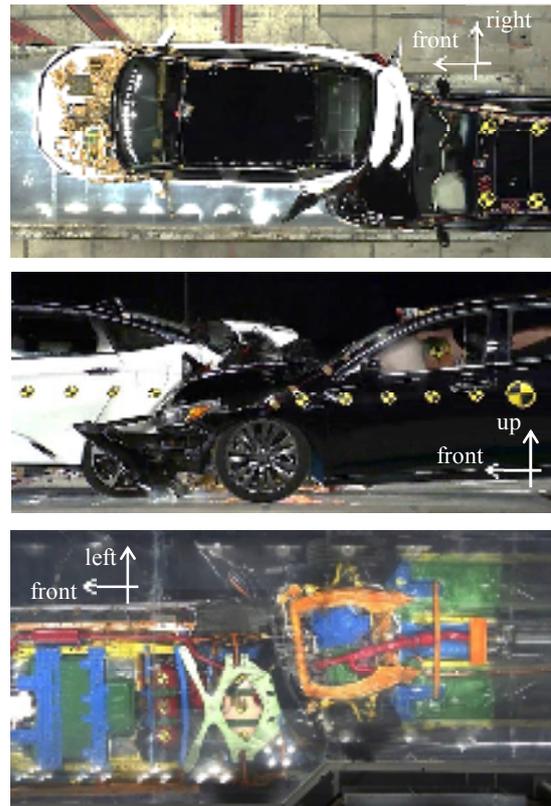
Now we will describe crash test condition and test result of ‘Rear Car to Car’ crash that we conducted in the development of the Clarity FCV.

**Crash test condition** In the ‘Rear Car to Car’ crash, the bullet vehicle was selected from perspective of maximizing the bullet vehicle side frame impact forces into the high-pressure hydrogen tank. Since inputs to high-pressure hydrogen tank would increase if side frame is long and firm, a heavy vehicle with such a characteristics were desired. Moreover, we chose a bullet vehicle from among sedans because their side frame height is close to center position of high-pressure hydrogen tank of Clarity FCV. Based on the criteria discussed, the Legend Hybrid was chosen as the bullet vehicle. The Legend Hybrid has all the structural characteristics desired and is the heaviest sedan that Honda produces. (Figure 7)

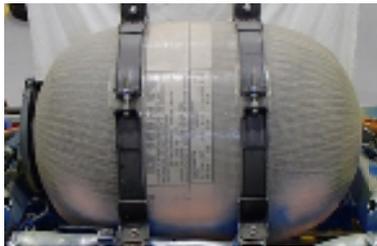


**Photograph7. Geometry of Clarity FCV hydrogen tank and Legend Hybrid side frame**

**Test result** From the ‘Rear Car to Car’ test we confirmed no serious damage on high-pressure hydrogen tank and no leakage from whole vehicle. Moreover, we confirmed that fuel shutoff system was also functionally normally.



**Photograph5. ‘Rear Car to Car’ crash test**



*Photograp6. High pressure-hydrogen tank after 'Rear Car to Car' crash test*

## REFERENCES

- [1] National Highway Traffic Safety Administration, 2005-2015, National Automotive Sampling System – Crashworthiness Data System (NASS-CDS)

## CONCLUSION

In this paper, we reported verification of 'Front Center Pole' crash and 'Rear Car to Car' crash which represent a part of the extensive verification Honda performed to establish the crash safety of the Clarity FCV. These two tests were selected to represent two real world crash types that could pose particular challenges to a fuel cell vehicle.

We verified the 'Front Center Pole' crash, because there is a tendency for large intrusions into the central part of the vehicle, and that characteristics is severe condition for Clarity FCV fuel stack

From the concept of the 'Front Center Pole' crash and the actual crash test result, we confirmed that the Clarity FCV achieved the safety performance goals established for a severe impact conditions to the region of the fuel cell stack.

We verified 'Rear Car to Car' crash, because impact forces to the high-pressure hydrogen tank are different between MDB and actual vehicle.

From the concept of the 'Rear Car to Car' crash and the actual crash test result, we confirmed Clarity FCV achieved the safety performance goals established for a severe impact conditions to the region of the high-pressure hydrogen tank.