

Crash Simulations of FMVSS No. 214 Safety Performance

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ABSTRACT

Objective: Federal Motor Vehicle Safety Standard (FMVSS) No. 214 requires doors in applicable vehicles to meet minimum force requirements when subjected to a static load in addition to the occupant protection requirements for the dynamic moving deformable barrier (MDB) and vehicle-to-pole (VTP) side impact tests. This paper explores how non-compliance of a single test condition affects the compliance and performance of the other two tests. Additionally, potential dynamic measurements that could be considered as a surrogate for the static test procedure, are discussed.

Methods: Validated FE models of a 2015 Toyota Camry sedan, and a 2020 Nissan Rogue SUV were used to understand the mutual effect of FMVSS-214 non-compliance. Modifications to the baseline model(s) were developed that demonstrated non-compliance to the static test. Simulations were then performed to evaluate how this affected vehicle and occupant responses in the dynamic tests. The effect of MDB and VTP non-compliance on the respective other two configurations were studied in the same manner. Measurements from the dynamic tests, such as deformation metrics, accelerometer, and load cell force data, were analyzed to determine if they can indicate performance in the static door crush test.

Results: Baseline simulation results showed FMVSS-214 compliance of the sedan vehicle for all three impact conditions. A first modified FE model was developed by reducing the door beam strength, resulting in non-compliance in the static test. Using this model, higher vehicle and occupant metrics were observed in the dynamic tests, while still clearly complying with FMVSS-214 requirements. A second and third modified FE model was developed by mainly reducing the strength of B-Pillar and sill components, resulting in non-compliance to the dynamic MDB and VTP conditions, respectively. Reduced door strength was observed using these models in the static test, while complying with FMVSS-214 static requirements. Limited correlation between measurements from the dynamic tests and door strength in the static test was observed.

Discussion and Limitations: The three FMVSS-214 configurations engaged different main load paths. Door beam strength was most relevant for the static test but did not significantly affect performance in the dynamic tests. B-Pillar and sill strength were most relevant for the MDB and VTP tests, respectively, but did not notably affect performance in the static test. The static door crush test impactor does neither overlap with the B-Pillar nor the sill. Similar results with respect to the static door crush test were observed using a validated FE model of a 2020 Nissan Rogue SUV. Since two specific vehicles representing the sedan and SUV categories were used, conclusions can not necessarily be generalized for other vehicles.

Conclusions: The research is relevant to understanding side impact performance measures. Structural vehicle modifications that resulted in non-compliance for the FMVSS-214 static test did not cause non-compliance in the dynamic MDB and VTP tests, and vice versa. There are significant limitations of using dynamic performance measurements from the dynamic tests as a surrogate for the static test due to the different main load paths engaged by the respective FMVSS-214 configurations.

INTRODUCTION

FMVSS No. 214 requires doors in applicable vehicles to meet minimum force requirements when the door is statically loaded (crushed) by a rigid steel cylinder or semi-cylinder. Additionally, FMVSS No. 214 requires occupant protection during dynamic MDB and VTP tests. This project explores options for developing performance criteria so that the FMVSS No. 214 dynamic MDB and/or VTP tests could be used as replacements for the static door crush resistance requirements of FMVSS No. 214, thus allowing the static requirements to be eliminated without reducing safety. Neither of the existing dynamic FMVSS No. 214 test procedures measure door crush resistance force.

The scope of this project consisted of developing, validating, and using detailed finite element (FE) models for use in side impact test procedures for two vehicles with different side impact characteristics. The FE models were to be used to compare intrusions, applied forces, and occupant injury metrics among baseline and modified vehicle simulations. The vehicle modifications were to be developed to meet or only partially meet FMVSS No. 214 static and dynamic test requirements. The results were then to be evaluated to consider the feasibility of using the dynamic performance measurements as a surrogate for the static test.

OBJECTIVE

The objective of this research was to develop and use detailed FE vehicle models to simulate FMVSS No. 214 static door crush, dynamic MDB, and VTP test conditions. The baseline FE simulations were to be validated against test data where available. Testing was to be conducted or contracted to provide additional validation data where needed. In addition to the baseline validation, three model variations were to be developed to demonstrate non-compliance with a single test condition. Simulations for each model variation were to be performed in each of the three test conditions. The simulation results for the modified vehicle models had to be analyzed to consider how non-compliance with a single test condition affects the compliance and test performance of the other two test conditions. Additionally, the feasibility of dynamic measurements that could be considered as a surrogate for the static test procedure had to be evaluated, if applicable.

Specifically, the objectives were the following.

- Devise at least two different vehicles for side crash simulation development and testing. The vehicle selection should consider the diversity of vehicle geometry, design, and crash kinematics.
- Where required purchase vehicles, measure and conduct testing to support the development and validation of simulation models.
- FE models shall be developed for the selected vehicles in each of the three test conditions. Each model shall be validated against test data. Objective rating methods shall be used to evaluate the correlation between test and simulation results. For the dynamic tests, it is sufficient to validate against the vehicle intrusion and intrusion velocity measurements rather than the resulting occupant injury criteria.
- Develop, simulate, and evaluate vehicle modifications. The first modifications will demonstrate minimal non-compliance to the static FMVSS No. 214 test. Simulations will be performed to evaluate how non-compliance affects the vehicle response in the MDB and VTP tests.
- Similarly, develop modifications that produce minimal non-compliance with the MDB and VTP dynamic FMVSS No. 214 configurations. Evaluate how this would affect the vehicle response in the static and VTP/MDB test, respectively.
- Evaluate the simulation results for compliant and non-compliant vehicle models and evaluate the feasibility of using measurements from the dynamic tests to predict compliance with the static 214 test requirements.

METHODS

Vehicle Selection

FMVSS No 214 static door crush and dynamic pole requirements apply to vehicles with a Gross Vehicle Weight Rating (GVWR) up to 10,000 pounds, while the FMVSS No. 214-MDB compliance is required for passenger cars with GVWRs up to 10,000 pounds but to multipurpose passenger vehicles, trucks, and buses with a GVWR up to 6,000 pounds. Vehicles with a GVWR above 6,000 pounds were not considered for this research. The identification of two different vehicles was important to assess variations in vehicle designs. The criteria that were used to identify the most suitable vehicle types for this research are outlined below.

The first vehicle selection criteria included the evaluation of design concepts and side crash characteristics. Different vehicle geometries and classes show significantly different behavior in side impact in general and in FMVSS No. 214 configurations in particular. Three vehicle types/classes, which represent the most important differences in crash kinematics due to vehicle and sill height, vehicle mass, and door length were considered.

Four-door sedan

This vehicle class was important for this research, representing a large percentage of vehicles on the road. Typically, the MDB partially overrides and does not engage the sill of the vehicle and loads are transferred into the door and B-pillar.

Pickup or SUV

This vehicle class can be less critical with respect to occupant protection in the MDB configuration. Due to the different vehicle dimensions and higher occupant seating position, the MDB typically engages with the sill area of the vehicle. Loads are transferred into the sill/floor, the door, and the B-pillar. In contrast, VTP configurations can be more critical compared to sedans, due to the higher vehicle mass, which can result in higher forces and intrusions. Two different pole locations can be tested according to FMVSS No. 214: the first one is aligned with the head of the 5th percentile occupant in a more forward seating position, the second one is positioned to hit the head of a 50th percentile occupant in a longitudinal mid position. The more forward position was considered more critical with respect to vehicle intrusion criteria.

Two-door sedan coupe or convertibles

While the overall sales numbers are smaller than for the previously described vehicle types, the two-door coupe type vehicles often have longer doors and can present challenges in side impact protection. Specific structural countermeasures and restraint system solutions are needed to overcome these challenges.

Sales numbers and rating results

The second vehicle selection criteria included sales numbers and rating results. An analysis was performed on how well a candidate vehicle represents cars in the US market and how well the vehicle performed in side impact consumer information crash tests. A vehicle with higher sales numbers was considered a better candidate vehicle for this study. All applicable vehicles on U.S. roads fulfill the FMVSS No. 214 requirements. Differences exist in side impact NCAP (SINCAP) and Insurance Institute for Highway Safety (IIHS) rating tests. Vehicles with higher ratings were considered to have better structural design and are therefore more likely to be used in future vehicle structures and hence were judged better candidates for inclusion in this research.

Availability of FE models

Several publicly accessible FE vehicle models are available from NHTSA (www.nhtsa.gov/crash-simulation-vehicle-models). The models were developed using a reverse engineering process. FE model examples include the 2015 Toyota Camry, the 2014 Honda Accord, and the 2018 Dodge Ram. A candidate vehicle model for this study was the detailed Toyota Camry FE model. A vehicle would be a good candidate for this study if a baseline model is already available and has been used and validated in previous studies. An available FE model of the 2018 Ram was considered, but dismissed because of a GVWR above 6,000 lbs. Instead, a FE model of the popular crossover SUV vehicle class, a 2020 Nissan Rogue was developed, using a reverse engineering process in course of this research.

Selected sedan vehicle: 2015 Toyota Camry

Based on the criteria defined above, the 2015 Toyota Camry was selected for this research, representing the 4-door sedan vehicle class with a low sill as well as a door and B-pillar design characterizing many sedan vehicles. It has

been one of the top selling vehicles in the United States in recent years. The Toyota Camry received a 5-Star SINCAP and a “GOOD” IIHS crash rating for the 2015 as well as for the 2020 model year. FMVSS No. 214-pole and SINCAP MDB test data exists, and a detailed FE model of a Toyota Camry was previously developed using a reverse engineering process.^{1,2}

Selected SUV vehicle: 2020 Nissan Rogue

A 2020 Nissan Rogue was selected as a second vehicle to conduct the FMVSS No. 214 simulation study to understand the effect of mutual non-compliance. It represents the crossover vehicle class, which is a type of SUV with unibody structure. It has been one of the top selling SUV vehicles in the United States in recent years. The 2020 Nissan Rogue received a 5-Star SINCAP and a “GOOD” IIHS crash rating. FMVSS No. 214-pole and SINCAP MDB test data exists. A detailed FE model of a 2020 Nissan Rogue was developed using a reverse engineering process.³

SUV versus sedan side impact characteristics

SUV-type vehicles have significantly different side impact characteristics, especially in the 214-MDB test configuration, due to higher sill and occupant seating position, as shown in Figure 1. The higher seating position in a SUV affects load-paths and mitigates occupant loads in MDB side impact. It can be noticed from the cross-section view that the MDB bumper directly impacts the SUV’s sill area, as highlighted by the red circle in Figure 1 (a), making the rocker and floor structural cross members a more significant load path for the SUV in the 214-MDB side impact configuration, compared to the sedan vehicle class. In contrast, the MDB honeycomb barrier face geometrically overlaps the entire chest and pelvis region of the occupant seated in the sedan vehicle, as shown in Figure 1 (b), while it only overlaps with the pelvis for the SUV-type vehicle. The bumper typically only partially overlaps with the sedan rocker area and overrides the sill in many cases, making the B-pillar and door the main load paths.

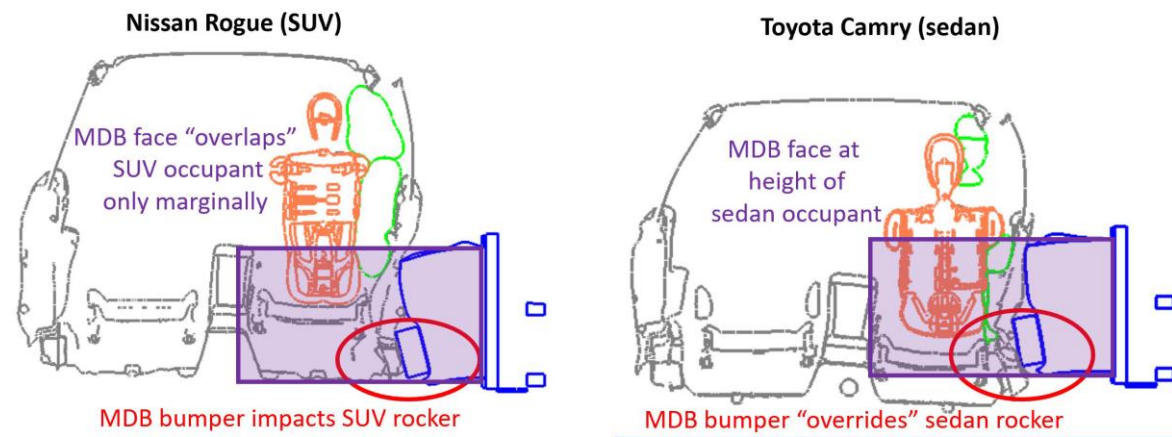


Figure 1. MDB impact location relative to sill and occupant (a) SUV; (b) sedan.

Methodology to Study the Effect of Mutual Non-Compliance

¹ Reichert, R., Mohan, P., Marzougui, D., Kan, C., & Brown, D. (2016, April 12-14), Validation of a Toyota Camry finite element model for multiple impact configurations (SAE Technical Paper 2016-01-1534). SAE 2016 World Congress and Exhibition, Detroit, MI. doi:10.4271/2016-01-1534.

² Reichert, R., & Kan, C.-D. (2017, May 9-11), Development of a 2015 mid-size sedan vehicle model. 11th European LS-DYNA conference, Salzburg, Austria.

³ Reichert et. al. (2022). Nissan Rogue FE Model – Version 2, doi:10.13021/xb7g-8z06.

The baseline simulation model was validated using test data from the three FMVSS No. 214 impact configurations, and then modified to produce non-compliance for one of the requirements. Using the modified simulation model, the effect on the other two impact configurations was studied, as shown in Figure 2.

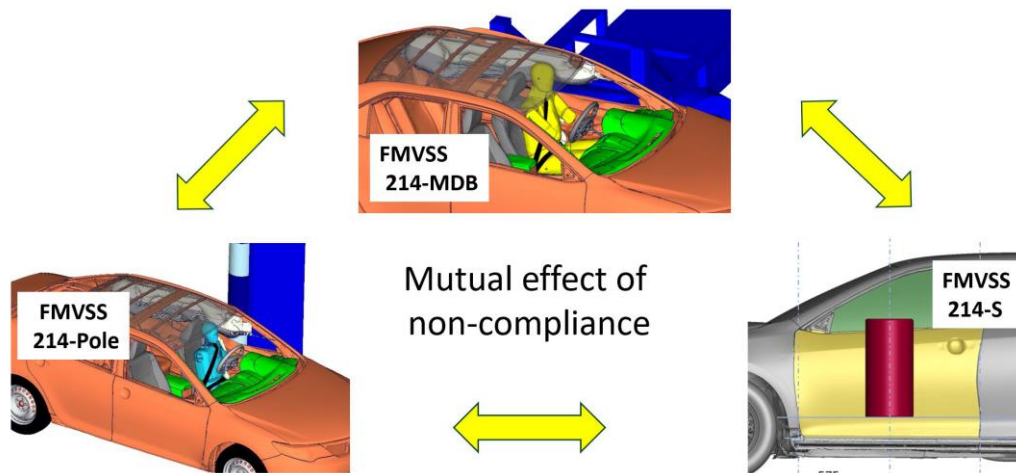


Figure 2. Process to study effect of mutual non-compliance.

The first modifications demonstrated minimal non-compliance to the static FMVSS No. 214 condition. Simulations were then performed to evaluate, how this non-compliance affected the vehicle response in the MDB and VTP conditions. Similarly, FE model variations that showed non-compliance for the MDB and VTP dynamic FMVSS No. 214 configurations were developed, and an evaluation was performed on how this would affect the vehicle response in the static and other dynamic impact configuration.

Observations that were made during the validation process and experience from previous side impact projects were used to determine reasonable structural modifications that produced the intended non-compliance for the respective impact condition. The simulation studies included the analysis of vehicle intrusion, vehicle pulse, and force criteria for the baseline and the modified simulation models.

Since dynamic FMVSS No. 214-MDB and pole impact compliance is based on anthropomorphic test device (ATD) metrics, simulations were conducted using validated models of 5th and 50th percentile side impact dummies, to verify the trends observed from the structural analyses.

Structural Performance Metric and Injury Mechanism

Velocity pulses at relevant vehicle locations, recorded by accelerometers, are a good indicator of structural performance in the FMVSS No. 214-MDB configuration, where the MDB impacts the stationary vehicle. From the author's experience working in industry and with major car manufacturers it is known that the B-pillar thorax location is used by some OEMs to judge the structural side impact performance of a vehicle. An accelerometer positioned at the middle of the B-pillar provides important information with respect to occupant loads caused by vehicle deformation and vehicle kinematics. In frontal impact configurations, interaction of the occupant with the seat and seat belt results in deceleration of the occupant coupled with the vehicle deceleration, called ride-down effect. Side impact injury mechanisms are different. In a collision where an occupied stationary vehicle is impacted by a striking vehicle from the side, occupant loads are mainly induced by the deformation of the vehicle structure and interior and the motion of the near side structure. The absolute B-pillar velocity describes the combination of the vehicle deformation and vehicle motion and is therefore a good indicator for loads relevant for occupant injury risk, which are then mainly mitigated by optimized air bags and interior components. To further explain the side impact characteristic, we can assume two extreme cases, (1) a small vehicle with low mass and no significant deformation, and (2) a heavy vehicle with a significant amount of deformation. The light vehicle would be pushed away during an impact and the heavy vehicle would not move but experience near-side structural deformation, while the occupant predominantly remains at the initial location without significant ride-down effect. The absolute velocity measured at the B-pillar is a good structural metric in side impact, because it captures well the load the occupant experiences for both cases, in the first case caused by vehicle motion, and in the second case mainly caused by vehicle deformation. Similarly, absolute velocities measured at the doors can be a good indicator for a vehicle's side impact performance,

while measurements from the doors are more likely to show questionable data in full-scale testing, due to local buckle effects and higher oscillations, compared to the B-pillar location.

The B-pillar and door locations are of special interest due to their proximity with the occupant's contact areas. Figure 3 shows an example of a door velocity and a driver's pelvis force profile. Later contact, i.e., larger initial dummy to interior clearance and lower velocity typically correlates with lower injury risk. Local effects, due to interior design and restraints also play an important role.

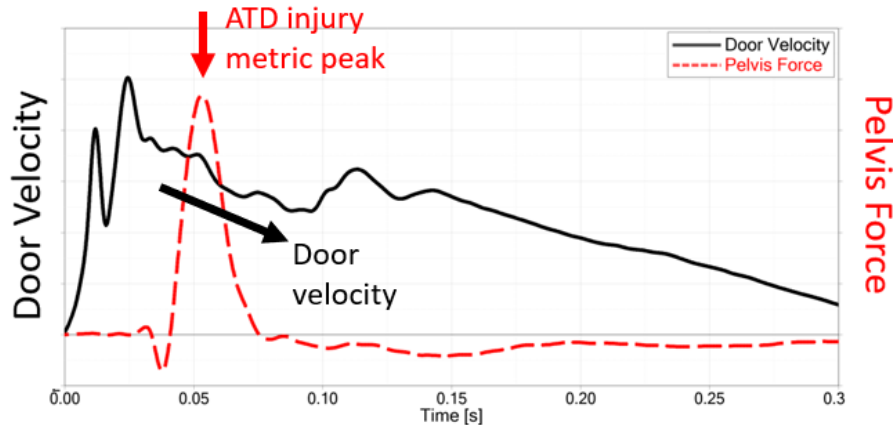


Figure 3. MDB velocity and ATD metric characteristics.

In contrast, during the FMVSS No. 214-pole configuration, the vehicle is positioned on a so-called “flying floor” and moves into the stationary rigid pole, which is aligned with the driver's head center of gravity. The vehicle is promptly decelerated and the velocity profiles at the door and B-pillar highly depend on the distance from the impact location. Therefore, the velocity profiles are less relevant in this configuration. Local effects involving the ATD, interior, and restraints play an important role.

Deformation and force versus deformation characteristics were monitored. Remaining occupant compartment space is another criterion, which is often used to judge the structural performance during a side impact, whereas deformation and contact characteristics in the early phase of the impact are relevant for FMVSS No. 214 ATD criteria. The force versus deformation criteria was used to judge the performance in the FMVSS No. 214 static (S) configuration.

Toyota Camry Sedan - Vehicle FE Model Validation

Toyota Camry sedan - MDB impact validation

Results from an existing MDB SINCAP test (NHTSA test # 9001, 2015 Toyota Camry) were used to validate the existing Toyota Camry FE model. The MDB was positioned according to the FMVSS No. 214 test procedure. Simulations were conducted with an impact velocity of 62 km/h. Crash pulses from test and simulation were compared using the objective rating tool CORA.⁴ CORA rating scores range between 0 and 1, where 0 means no correlation and 1 means (close to) perfect correlation. Specifically, a CORA rating greater than 0.94 was considered excellent, values between 0.8 and 0.94 represented good, and values between 0.58 and 0.8 represented fair correlation.⁵

CORA values of 0.86 and 0.94 for vehicle and barrier acceleration pulses documented good to excellent correlation between test and simulation, respectively, as shown in Figure 4.

⁴ Thunert, C. (2012), CORA Release 3.6 User's Manual, Version 3.6. GNS mbH, and Partnership for Dummy Technology and Biomechanics.

⁵ Barbat, S., Fu, Y., Zhan, Z., Yang, R.-J., & Gehre, C. (2013, May 27-30). Objective rating metric for dynamic systems (Paper Number 13-0448). 23rd Enhanced Safety of Vehicles Conference, Seoul, Republic of Korea.

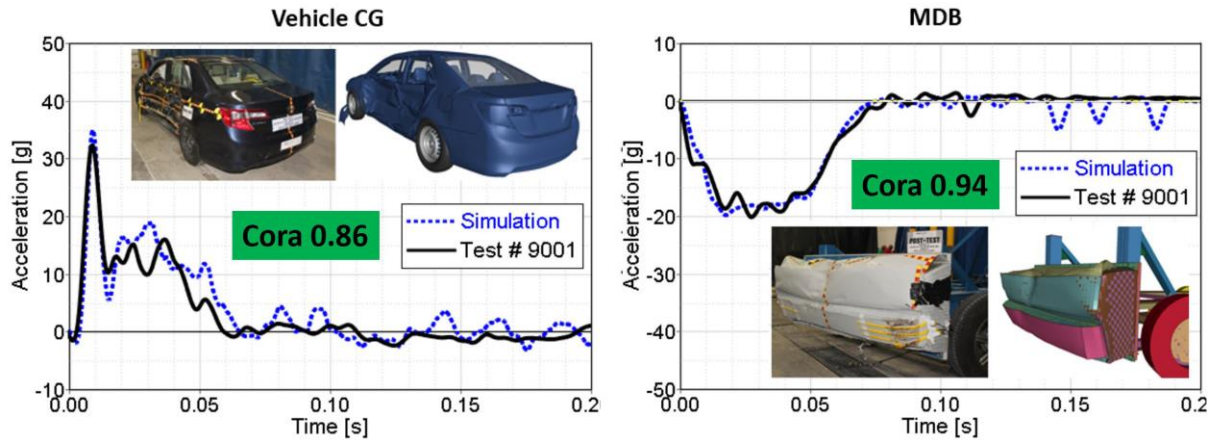


Figure 4. Toyota Camry acceleration pulse test versus simulation correlation for (a) vehicle and (b) MDB.

Deformation of the MDB honeycomb face showed similar characteristics for test and simulation, such as (1) downward tilting of the bumper and (2) higher deformation at the area that impacted the B-pillar. Exterior crush was measured at five different heights of the vehicle. The maximum value of 264 mm in the simulation compared reasonably well with the maximum value of 249 mm from the full-scale test.

Toyota Camry sedan - pole impact validation

Results from an existing FMVSS No. 214-pole test (NHTSA # 8558, 2014 Toyota Camry), were used to validate the existing Toyota Camry FE model. The vehicle was positioned at a 75° angle and impacted the stationary rigid pole according to the FMVSS No. 214-pole impact specification with 32 km/h. Figure 5 shows a top view of the exterior crush profile. The maximum value of 380 mm in the simulation compared well with the maximum value of 379 mm from the full-scale test.

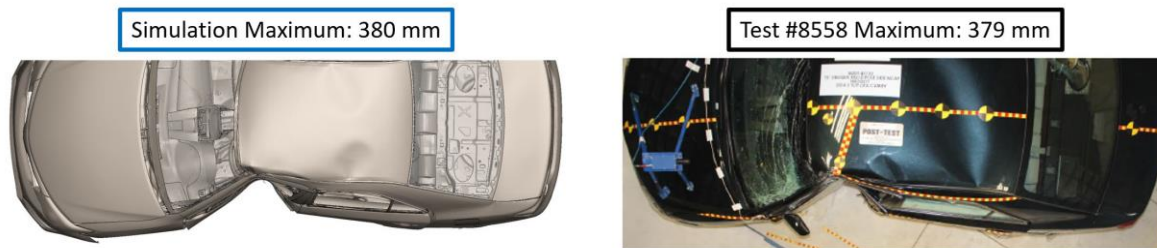
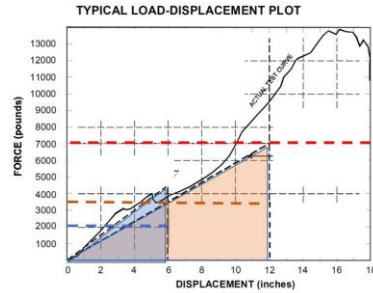


Figure 5. Toyota Camry pole impact post-crash (a) simulation and (b) test.

Crash pulses from test and simulation were compared using the objective rating tool CORA. A value of 0.96 for the comparison of the velocity pulse at the vehicle center of gravity documents excellent correlation.

Toyota Camry sedan – static door crush validation

FMVSS No. 214-static requires doors in applicable vehicles to meet minimum force requirements when the front and rear door is quasi-statically loaded with a rigid steel cylinder, as shown in Figure 6 (a). A typical force versus displacement plot is shown in Figure 6 (b). The initial and intermediate crush resistance values represent the average force to deform the door (area under force versus displacement curve divided by 6 / 12 inches). Minimum resistance force criteria depend on the test setup, i.e. with or without seats installed. A higher door crush resistance force is required for setups with seats installed, as shown in Figure 6 (c).



Crush resistance	Without seat	With seat
Initial (0-6)	> 2,250	> 2,250
Intermediate (0-12)	> 3,500	> 4,375
Peak (0-18)	> 6,380*	> 11,165**

* 2 x curb weight or 7,000 lb
 **3.5 x curb weight or 12,000 lb

Figure 6. Sedan static door crush test (a) FMVSS 214-static setup; (b) typical force displacement plot; (c) criteria.

FMVSS No. 214-static door crush tests were conducted at the TRC in Ohio. A 2017 Toyota Camry representing the 2015 model year was purchased. The left front driver door was used to conduct the quasi-static door crush test with seat installed and the right front door was used to generate test data without seat. Figure 7 (a) and (b) show the comparison of test and baseline simulation with and without seat, respectively. The entire range of displacement until 18 inches was evaluated. Good correlation of the force versus displacement time history data was achieved represented by CORA scores of 0.90 and 0.93. Initial, intermediate, and peak resistance forces were well captured and showed values above the relevant required minimum criteria in test and simulation.

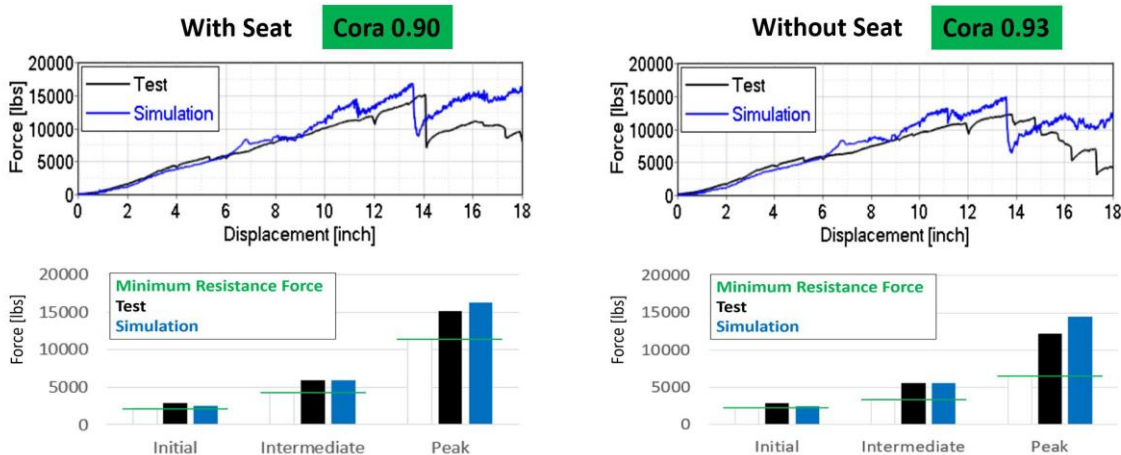


Figure 7. Sedan FMVSS 214-static validation (a) with seat; (b) without seat.

The baseline FE model was also validated using test data for the rear door. The test was automatically stopped after about 8 inches because the load cell had reached 95 percent of its capacity. Simulation and test results correlated well, represented by a CORA score of 0.91. All simulations were conducted using explicit time integration method used for dynamic crash applications. The Toyota Camry baseline FE model, which represents the 2012 and 2015 physical vehicles with respect to side impact performance, can be downloaded from GMU/CCSA's vehicle model website.⁶

Nissan Rogue SUV - Vehicle FE Model Validation

Nissan Rogue SUV - MDB impact validation

A FMVSS No. 214-MDB side impact test with a 2020 Nissan Rogue was conducted at Calspan to generate data for FE model validation. The vehicle was struck on the left side by a MDB, which was moving forward in a 27° crabbed position to the tow road guidance system at a velocity of 53 km/h. The target vehicle was stationary and was

⁶ <https://www.ccsa.gmu.edu/models>

positioned at an angle of 63° to the line of forward motion. A perspective view of the conducted FMVSS No. 214-MDB test is shown in Figure 8.



Figure 8. 2020 Nissan Rogue FMVSS No. 214-MDB full-scale test.

Figure 9 shows the top view of the respective simulation using the developed 2020 Nissan Rogue FE model. Overall vehicle and barrier deformation was well captured, represented by the maximum exterior crush value of 190 mm for the test and 181 mm for the simulation. The y-velocity crash pulse time history data, which is in the dominant impact direction, showed “excellent” correlation represented by a CORA value of 0.96. The velocity time history measured at the CG of the MDB, showed excellent correlation with a CORA value of 0.96, as well.

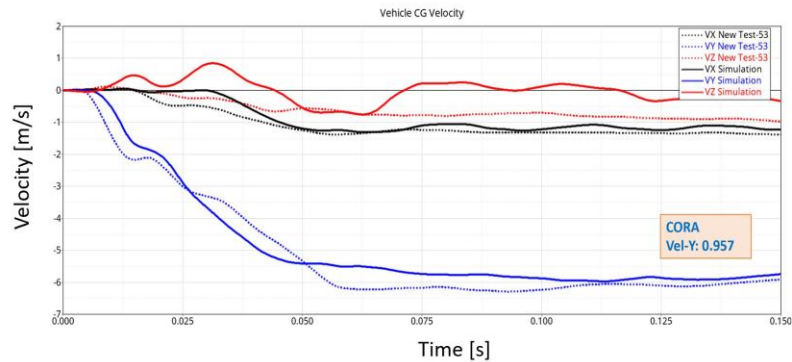
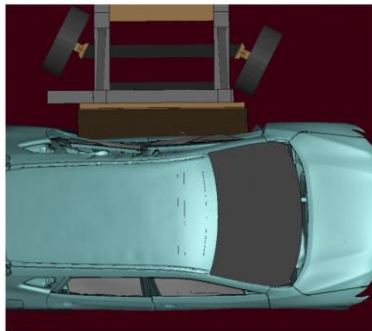


Figure 9. FMVSS No. 214-MDB validation (a) top view; (b) vehicle velocity crash pulse.

The developed 2020 Nissan Rogue FE model was also exercised at an impact velocity of 62 km/h according to the SINCAP rating procedure and compared to results from an existing full-scale test, NHTSA test #9786. Good correlation of FE model and respective test data was observed for the higher impact speed as well. The maximum exterior crush was 220 mm and 234 mm in test and simulation, respectively. The lateral velocity crash pulse time history compared well, represented by a “good” CORA value of 0.90. The MDB’s velocity pulse time-history showed excellent correlation, characterized by a CORA value of 0.95.

The structural FE model was equipped with relevant interiors and restraints and the state-of-the-art 50-percent WorldSID FE model developed by PDB and distributed by Dynamore and Humanetics.⁷ Figure 10 shows a comparison of characteristic values from test and simulation for the 53 km/h configurations. The maximum values compare well for all body regions. Green and red lines represent reference values for respective body regions.

⁷ <https://www.humaneticsgroup.com/products/virtual-models/side-impact-atd-virtual-models/worldsid-50m-fe>

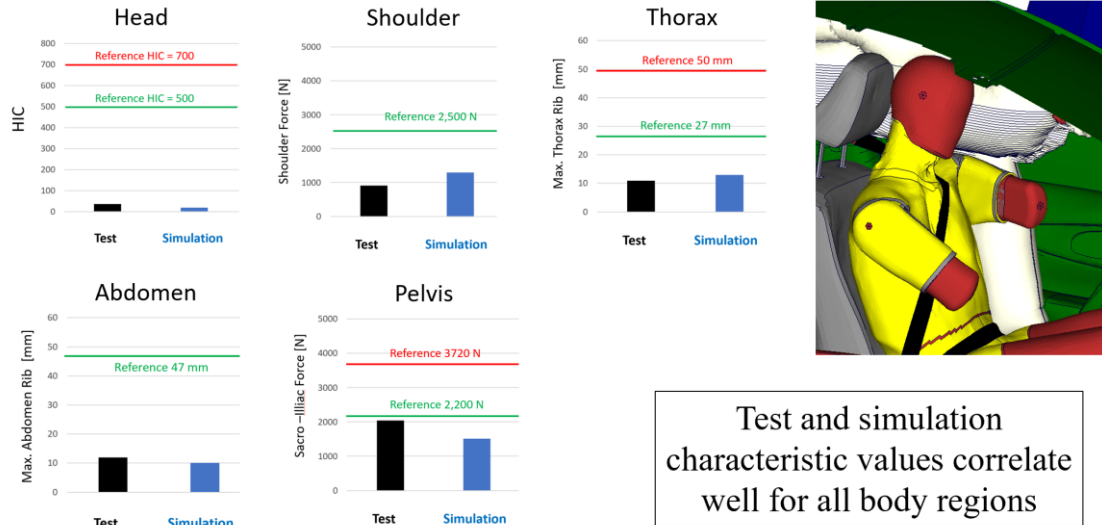


Figure 10. 53 km/h FMVSS No. 214-MDB occupant test versus simulation.

Figure 11 shows a comparison of characteristic values from test and simulation for the 62 km/h MDB configuration. Again, maximum values compared well for all body regions.

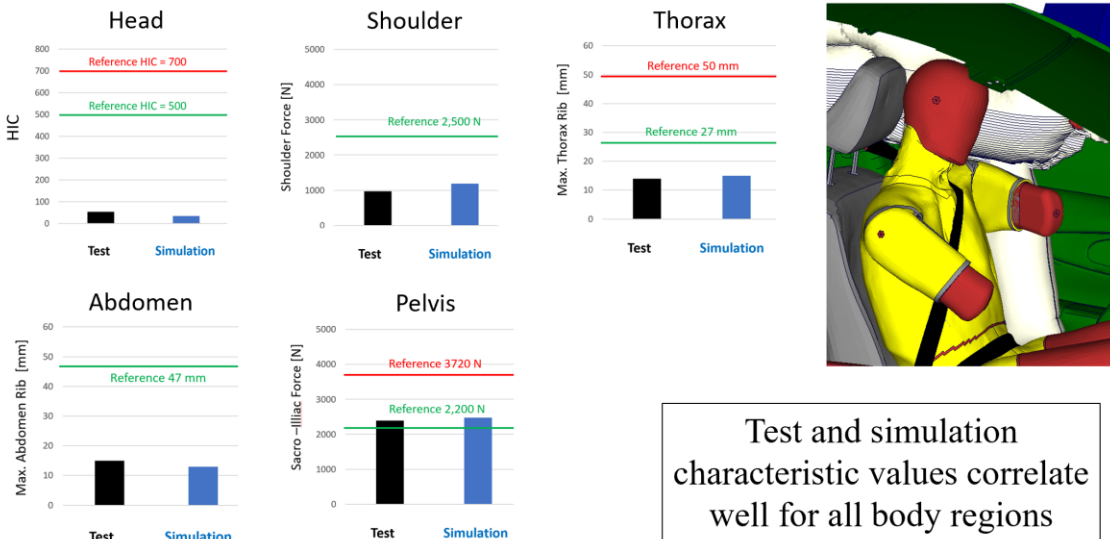


Figure 11. 62 km/h MDB occupant test versus simulation.

Nissan Rogue SUV - pole impact validation

A FMVSS No. 214-pole side impact test with a 2020 Nissan Rogue SUV was conducted at Calspan to generate data for FE model validation. The same vehicle that was previously impacted on the driver side with the MDB at 53 km/h was used. The vehicle showed no structural damage on the passenger side and could therefore be used again to conduct the FMVSS No. 214-pole impact. The subject vehicle was towed into the rigid pole at an angle of 75 degrees and a velocity of 31 km/h. One WorldSID dummy was placed in the front passenger designated seating position.

A perspective and side view of the conducted FMVSS No. 214-pole test is shown in Figure 12 (a) and (b), respectively.

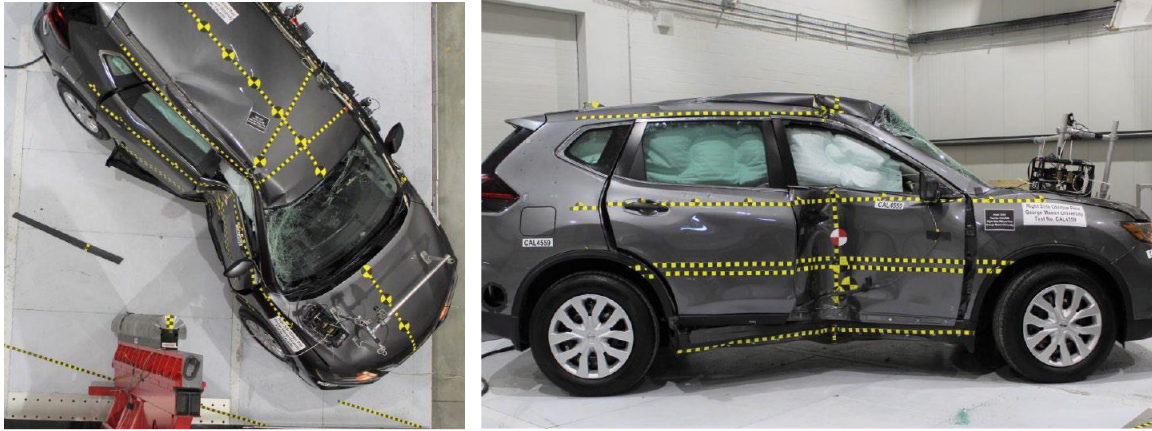


Figure 12. Nissan Rogue FMVSS No. 214-pole post-crash (a) top; (b) side view.

Figure 13 (a) shows the velocity crash pulse time history comparisons between test and simulation, which showed “good” correlation for x- and y-pulse based on a CORA value of 0.74 and 0.87, respectively. Figure 13 (b) depicts a top view of the simulation using the developed 2020 Nissan Rogue FE model. Overall vehicle deformation was reasonably well captured, represented by the maximum exterior crush of 420 mm for the simulation and 379 mm for the test. NHTSA test #9780, which was conducted at 32 km/h, showed a maximum exterior crush of 390 mm.

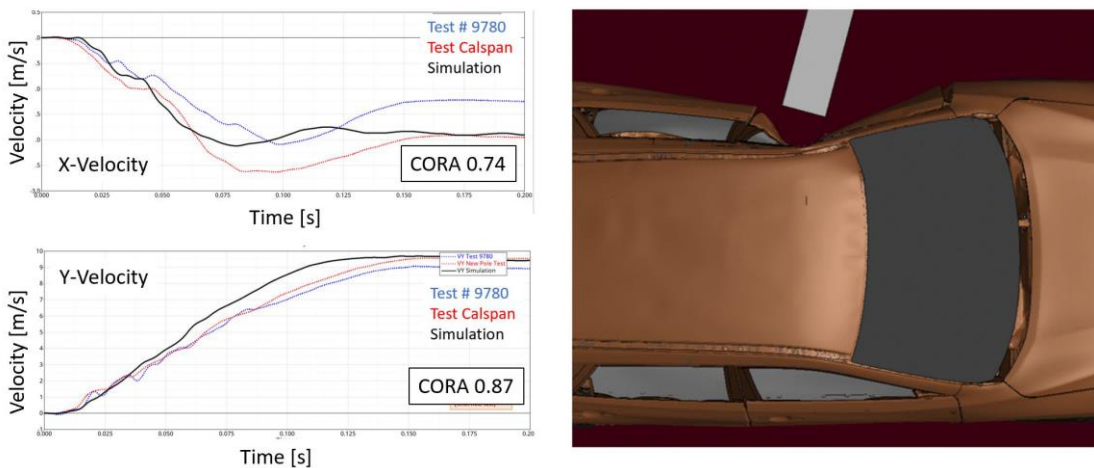


Figure 13. FMVSS No. 214-pole validation (a) velocity crash pulses; (b) top view.

Nissan Rogue SUV – static door crush validation

FMVSS No. 214-static requires doors in applicable vehicles to meet minimum force requirements when the doors are quasi-statically loaded with a rigid steel cylinder. Tests at the front and rear door of a 2020 Nissan Rogue were conducted and documented in cooperation with TRC, as shown in Figure 14.



Figure 14. Nissan Rogue FMVSS No. 214 static post crash front door.

The left front driver door was used to conduct the quasi-static door crush test with seat installed. Figure 15 shows the comparison of test and simulation.

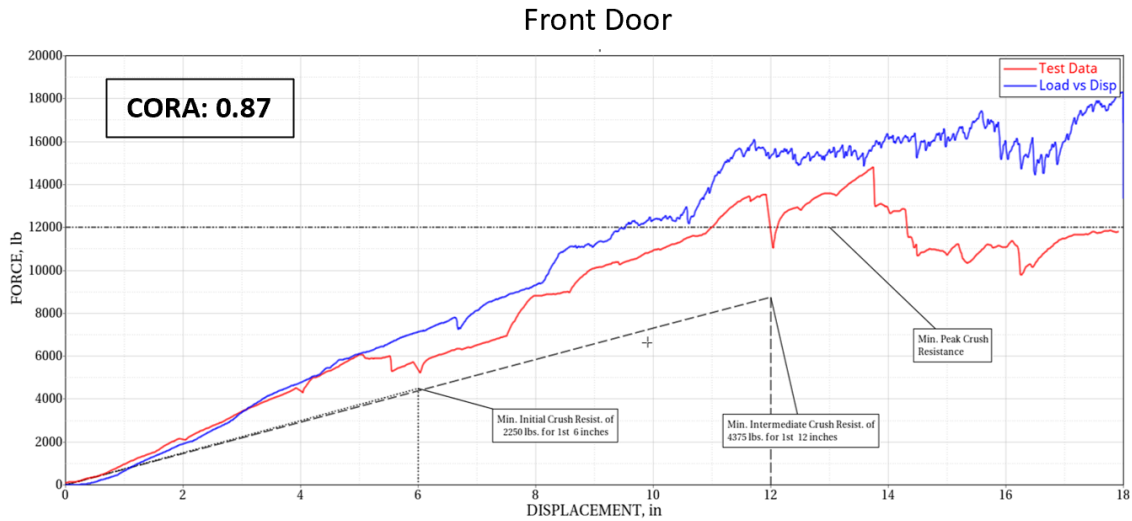


Figure 15. FMVSS No. 214 static door crush validation front door.

The entire range of displacement until 18 inches was evaluated. The FE model showed good correlation of the force versus displacement time history data, represented by a CORA value of 0.87 for the front door. Initial, intermediate, and peak resistance forces showed values above the relevant required minimum criteria in test and simulation, as shown in Figure 16.

Front Door

	Initial Force [lbs]	Intermediate Force [lbs]	Peak Force [lbs]
Requirement	2250	4375	12208 *
Test # 201103	3219	6358	14825
Simulation	3605	7878	18000

* 3.5 times the curb weight of the vehicle (3488 lbs)

Figure 16. Rogue FMVSS No. 214 static door crush resistance forces front door.

RESULTS

2015 Toyota Camry Sedan - Effect of Mutual FMVSS No. 214 Non-Compliance

2015 Toyota Camry sedan - effect of FMVSS No. 214-static non-compliance

The validated sedan baseline model was first modified in such a way that it showed non-compliance based on the minimum door crush resistance force criteria. It was found from the validation results that the initial FMVSS No. 214-static force requirement, defined for the first six inches of deformation, had the smallest margin to the minimum resistance force criteria, compared to the intermediate and peak resistance force criteria. According to the defined test procedure, the cylindrical impactor does not overlap with the sill of the vehicle, as shown in Figure 17 (a). The door beam and the integrity of the door to B-pillar lock connections were found to have a significant effect on the FMVSS No. 214-static performance. Consequently, non-compliance was achieved by reducing the strength of the door beam, as shown in Figure 17 (b). The resulting initial resistance force for the first 6 inches of deformation using the modified FE model was below the required minimum force criteria, as shown by the red bar in Figure 17 (c). The intermediate resistance force showed a borderline value and was lower than in the baseline simulation. The peak resistance force was lower than in the baseline simulation as well but above the required minimum peak force requirement. Similar observations were made for the analysis with removed seat.

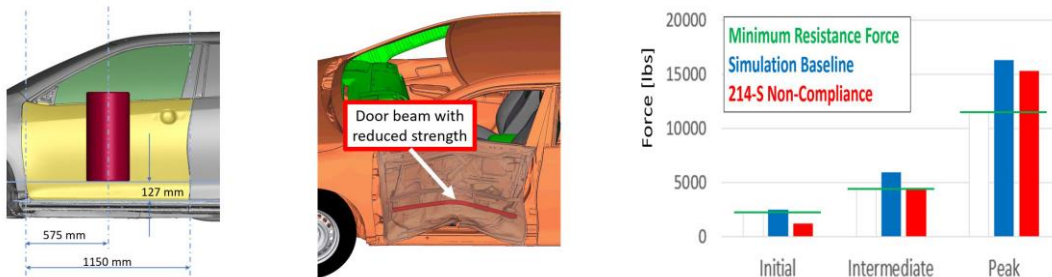


Figure 17. Sedan FMVSS No. 214-static (a) setup; (b) structural modifications; (c) force comparison.

The model that showed non-compliance for the FMVSS No. 214-static test configuration, depicted in Figure 18 (a) was then exercised in the FMVSS No. 214-MDB condition, as shown in Figure 18 (b). Structural modifications that resulted in FMVSS No. 214-static non-compliance resulted in marginally higher maximum velocity at the B-pillar and front door. Similarly, simulations with a 50th percentile WorldSID dummy in the driver seat indicated that the maximum chest deflection was marginally higher, while clearly below the defined reference criteria. The conducted simulations indicated FMVSS No. 214-MDB compliance despite 214-static non-compliance.

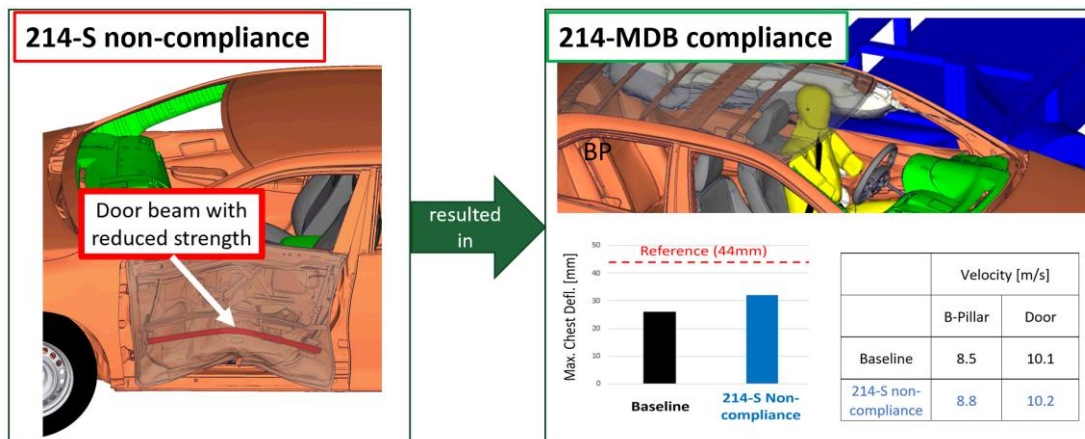


Figure 18. Sedan – Effect of FMVSS No. 214-static non-compliance for FMVSS No. 214-MDB.

The model that showed non-compliance for the FMVSS No. 214-static test configuration, depicted in Figure 19 on the left was then exercised in the FMVSS No. 214-pole condition, as shown in Figure 19 on the right. Structural modifications that resulted in FMVSS No. 214-static non-compliance resulted in similar structural deformation in

the 214-pole configuration as the FMVSS No. 214-static compliant baseline version. The maximum exterior crush was marginally higher. Similarly, simulations with a 5th percentile SID-II's dummy model, developed by ANSYS LST, in the driver seat indicated that the maximum combined pelvis force was similar to the baseline simulation, clearly below the defined reference criteria. The conducted simulations indicated FMVSS No. 214-pole compliance despite 214-static non-compliance.

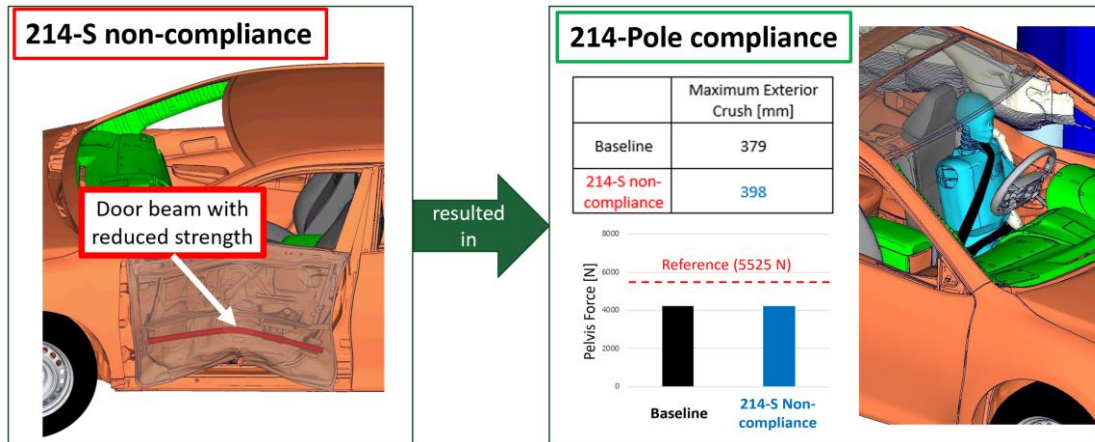


Figure 19. Sedan FMVSS No. 214-static non-compliance for FMVSS No. 214-pole.

The reduced strength for door beam, that resulted in 214-static non-compliance did not significantly affect the performance in the 214-MDB condition which mainly relies on B-pillar components. Similarly, it did not significantly affect the performance in the 214-pole condition, where the vehicle impacts the pole at the front door overlapping with the sill.

2015 Toyota Camry sedan - effect of FMVSS No. 214-MDB non-compliance

The validated Toyota Camry FE baseline model was modified in such a way that it showed non-compliance for the FMVSS No. 214-MDB configuration. Figure 20 (a) shows the parts with reduced strength in red. The structural B-pillar components play an important role for the MDB condition. This is especially true for the sedan vehicle with no significant overlap of the vehicle sill and the barrier bumper, as shown in the cross-section view in Figure 20 (b).

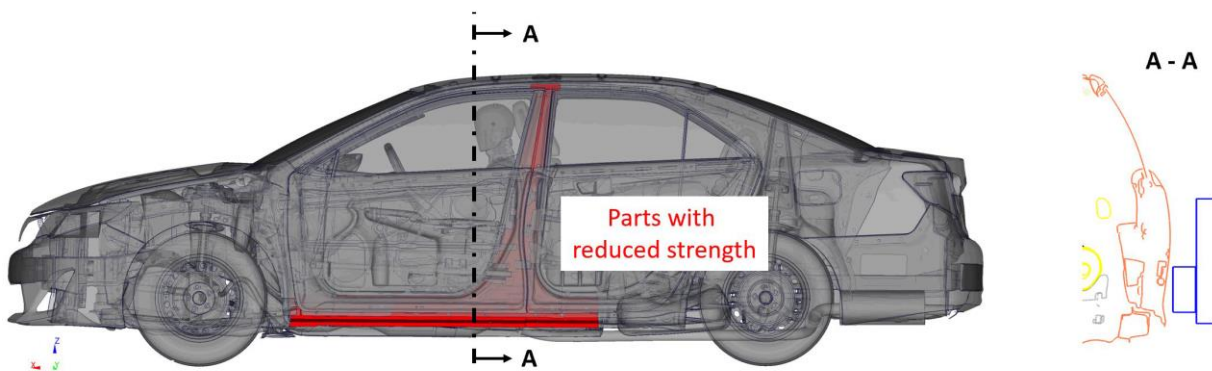


Figure 20. Sedan – FMVSS No. 214-MDB (a) modifications and (b) crosssection view.

A detailed comparison of modified parts in this and following simulation studies is documented in the corresponding NHTSA research report.⁸ The model that showed non-compliance for the FMVSS No. 214-MDB configuration, shown in Figure 21 (a) was then exercised in the FMVSS No. 214-static door crush condition, as shown in Figure 21

⁸ Reichert, R., Kan, C.-D., & Park, C.-K. (2022, September). Crash simulation of FMVSS No. 214 safety performance (Report No. DOT HS 813 276). National Highway Traffic Safety Administration.

(b). Structural modifications that resulted in FMVSS No. 214-MDB non-compliance resulted in marginally lower initial and intermediate force levels in the quasi-static configuration. Values were marginally lower than for the baseline FE model, but above the minimum required resistance force, defined for FMVSS No. 214 compliance. The conducted simulations indicated FMVSS No. 214-static door crush resistance force compliance despite dynamic 214-MDB non-compliance.

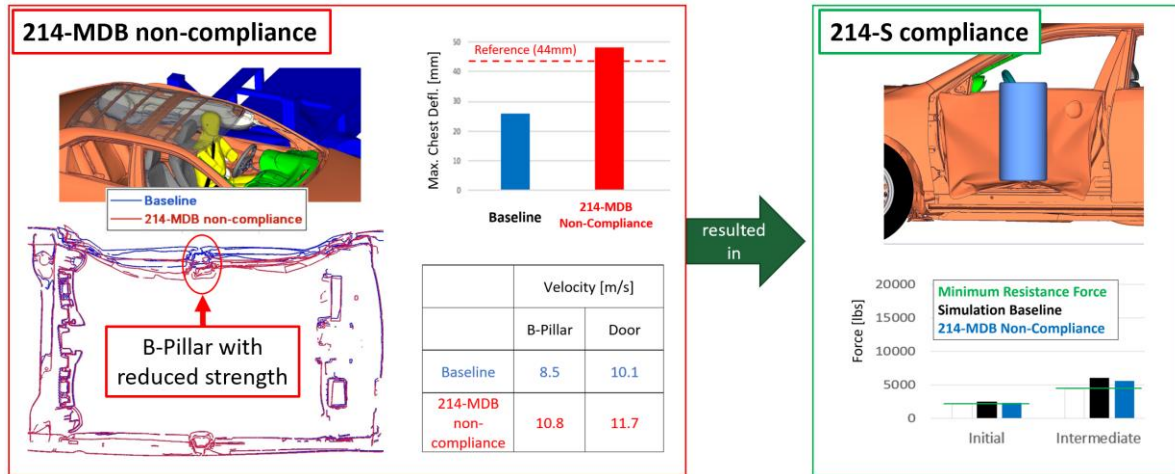


Figure 21. Sedan – effect of FMVSS No. 214-MDB non-compliance for FMVSS No. 214-static.

The model that showed non-compliance for the FMVSS No. 214-MDB configuration, shown in Figure 22 on the left was then exercised in the FMVSS No. 214-pole condition, as shown in Figure 22 on the right. Structural modifications that resulted in FMVSS No. 214-MDB non-compliance resulted in similar structural deformation in the FMVSS No. 214-pole configuration as the baseline. The maximum exterior crush was marginally higher. Similarly, simulations with a 5th percentile ATD in the driver seat indicated that the maximum combined pelvis force was marginally higher than in the baseline simulation, while clearly below the defined reference criteria.

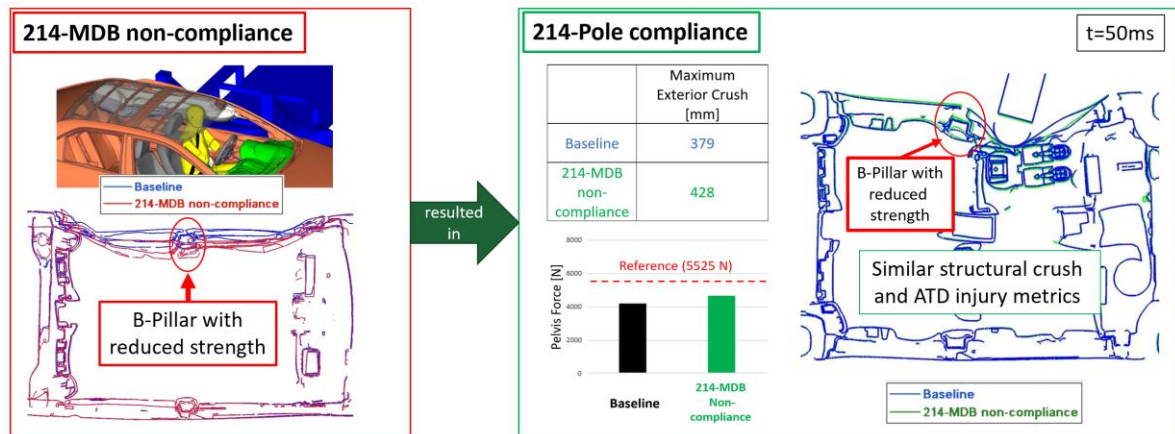


Figure 22. Sedan – effect of FMVSS No. 214-MDB non-compliance for FMVSS No. 214-pole.

The conducted simulations indicated FMVSS No. 214-pole compliance despite 214-MDB non-compliance. The reduced strength for B-pillar components, that resulted in 214-MDB non-compliance did not significantly affect the performance in the 214-static condition, which mainly relies on the door components. Similarly, it did not significantly affect the performance in the 214-pole condition, where the vehicle impacts the pole at the front door overlapping with the sill and vehicle floor.

2015 Toyota Camry sedan - effect of FMVSS No. 214-pole non-compliance

The validated Toyota Camry FE baseline model was then modified in such a way that it showed non-compliance for the FMVSS No. 214-pole configuration. Figure 23 shows the parts with reduced strength in red and yellow,

compared to the baseline model. The sill components and the driver seat cross member play an important role for the oblique side pole impact condition. The Toyota Camry and some other vehicles also use an additional reinforcement component, which is specifically designed and positioned for the pole impact configuration, shown in yellow in Figure 23.

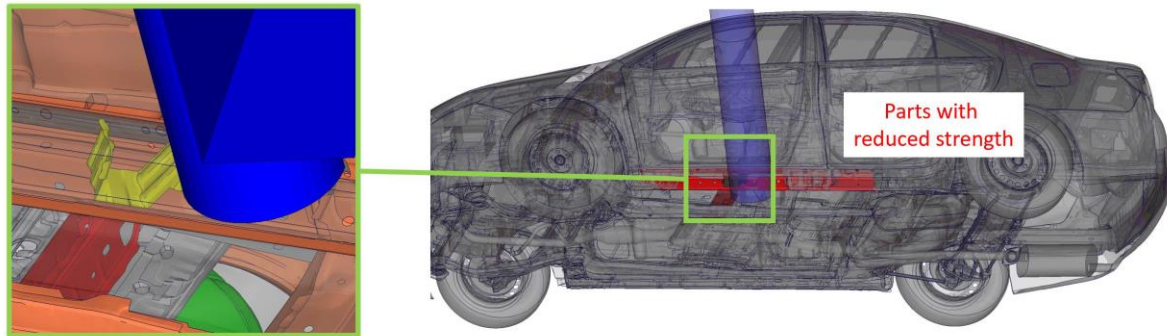


Figure 23. Sedan – parts with reduced strength resulting in FMVSS No. 214-pole non-compliance.

The applied modifications, resulted in higher maximum exterior crush and higher occupant pelvis force in the FMVSS No. 214-pole impact, as shown in Figure 24 on the left. The model that showed non-compliance for the FMVSS No. 214-pole configuration was then exercised in the FMVSS No. 214-static door crush condition, as shown in Figure 24 on the right. Structural modifications that resulted in FMVSS No. 214-pole non-compliance resulted in marginally lower initial and intermediate door crush resistance force levels in the 214-static test configuration. Values were above the minimum required resistance force. The conducted simulations indicated FMVSS No. 214-static door crush compliance despite dynamic FMVSS No. 214-pole non-compliance.

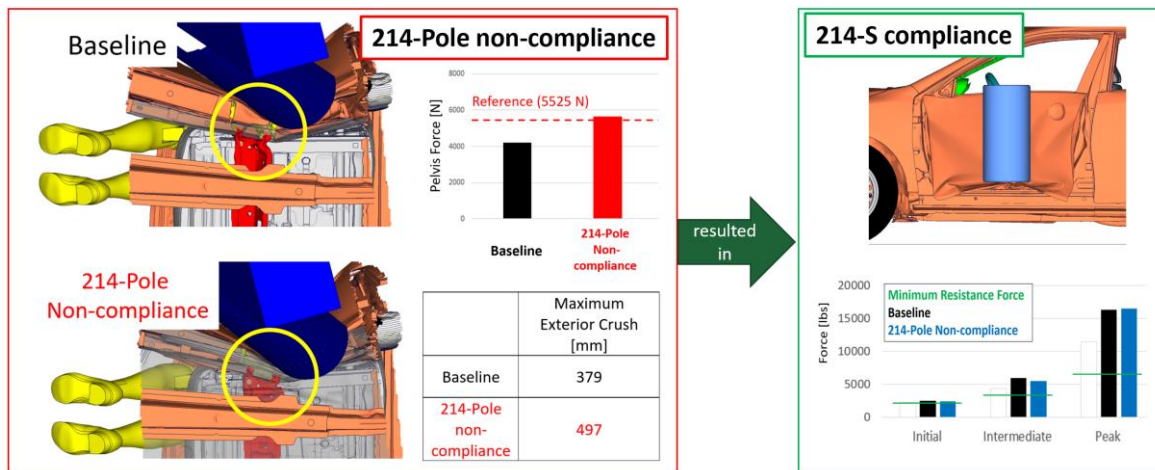


Figure 24. Sedan – effect of FMVSS No. 214-pole non-compliance for FMVSS No. 214-static.

The model that showed non-compliance for the FMVSS No. 214-pole configuration, depicted in Figure 25 on the left was then exercised in the FMVSS No. 214-MDB condition, as shown in Figure 25 on the right.

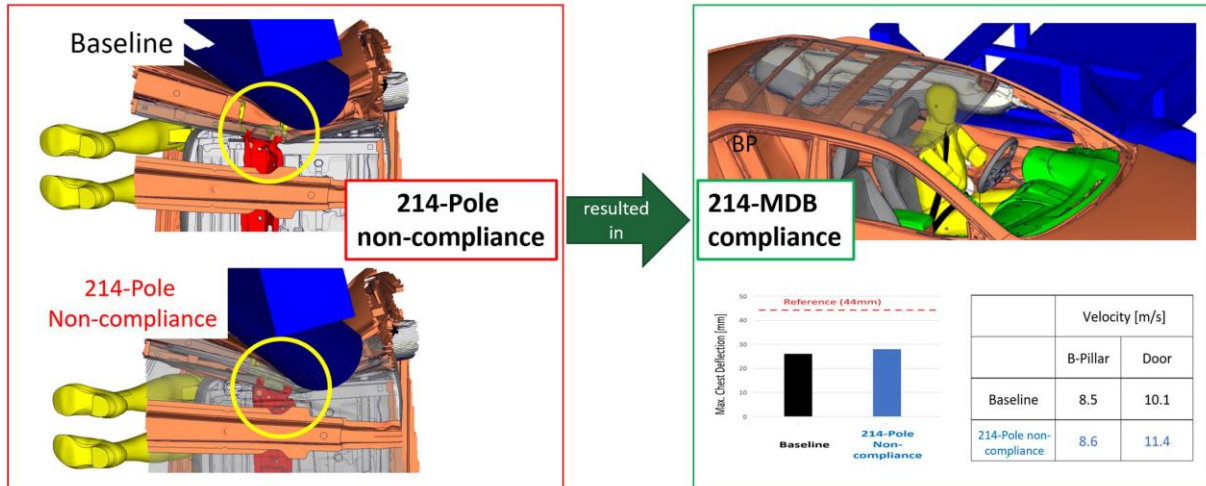


Figure 25. Sedan – effect of FMVSS No. 214-pole non-compliance for FMVSS No. 214-MDB.

Structural modifications that resulted in FMVSS No. 214-pole non-compliance resulted in similar maximum B-pillar and higher door velocity in the MDB configuration when compared to the baseline simulation. The simulations with a 50th percentile dummy in the driver seat indicated that the maximum chest deflection was marginally higher compared to the baseline simulation, while clearly below the defined reference criteria. The conducted simulations indicated FMVSS No. 214-MDB compliance despite pole non-compliance.

The reduced strength for sill and seat cross member components, that resulted in FMVSS No. 214-pole non-compliance did not significantly affect the performance in the 214-static condition which mainly relies on the door components. Similarly, the 214-MDB condition, which mainly relies on the B-pillar strength, was only affected to an extent that did not result in 214-MDB non-compliance.

2020 Nissan Rogue SUV - Effect of Mutual FMVSS No. 214 Non-Compliance

2020 Nissan Rogue SUV - effect of FMVSS No. 214-static non-compliance

The validated 2020 Nissan Rogue FE baseline model, representing the SUV vehicle category, was first modified in such a way that it showed non-compliance for the FMVSS No. 214-static static door crush resistance requirement. According to the defined test procedure, the cylindrical impactor does not overlap with the sill of the vehicle. The two door beams, two door outer cross members, and the integrity of the door to B-pillar lock connections were found to have a significant effect on the FMVSS No. 214-static performance. Consequently, non-compliance was achieved by reducing the strength of the door beams and door cross members, as shown in Figure 26 (a). The resulting initial resistance force for the first 6 inches of deformation and the intermediate door resistance force between 6 and 12 inches of intrusion using the modified FE model was below the required minimum force criteria, as shown by the red bar in Figure 26 (a). The peak resistance force was also significantly lower than in the baseline simulation, but above the required minimum peak force requirement. The model that showed non-compliance for the FMVSS No. 214-static test configuration was then exercised in the FMVSS No. 214-MDB condition, as shown in Figure 26 (b).

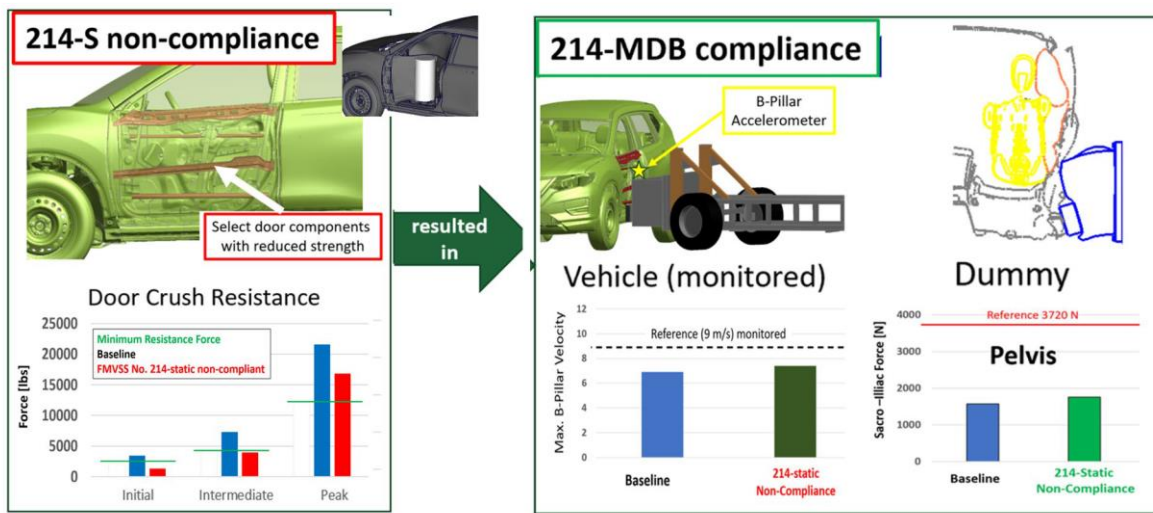


Figure 26. SUV – (a) FMVSS No. 214-static non-compliance; (b) effect for FMVSS No. 214-MDB.

Structural modifications that resulted in FMVSS No. 214-static non-compliance resulted in marginally higher maximum velocity at the B-pillar. Similarly, simulations with a 50th percentile ATD in the driver seat indicated that the maximum chest deflection and pelvis loads were marginally higher, while clearly below defined reference criteria. The conducted simulations indicated FMVSS No. 214-MDB compliance despite 214-static non-compliance for the SUV-type vehicle.

The model that showed non-compliance for the FMVSS No. 214-static test configuration, depicted in Figure 27 (a) was then exercised in the FMVSS No. 214-pole condition, as shown in Figure 27 (b). Structural modifications that resulted in FMVSS No. 214-static non-compliance resulted in similar structural deformation in the FMVSS No. 214-pole test configuration. The maximum exterior crush was marginally higher. Similarly, simulations with a 50th percentile ATD in the driver seat indicated that the maximum combined pelvis force was similar to the baseline simulation, clearly below the defined reference criteria. Rocker and floor cross members were found to be the main load path in the pole impact configuration, and roof components also contributed to mitigate deformation. The structural design changes, which were limited to door components, had therefore only a limited effect for the FMVSS No. 214-pole configuration. The conducted simulations indicated FMVSS No. 214-pole compliance despite 214-static non-compliance.

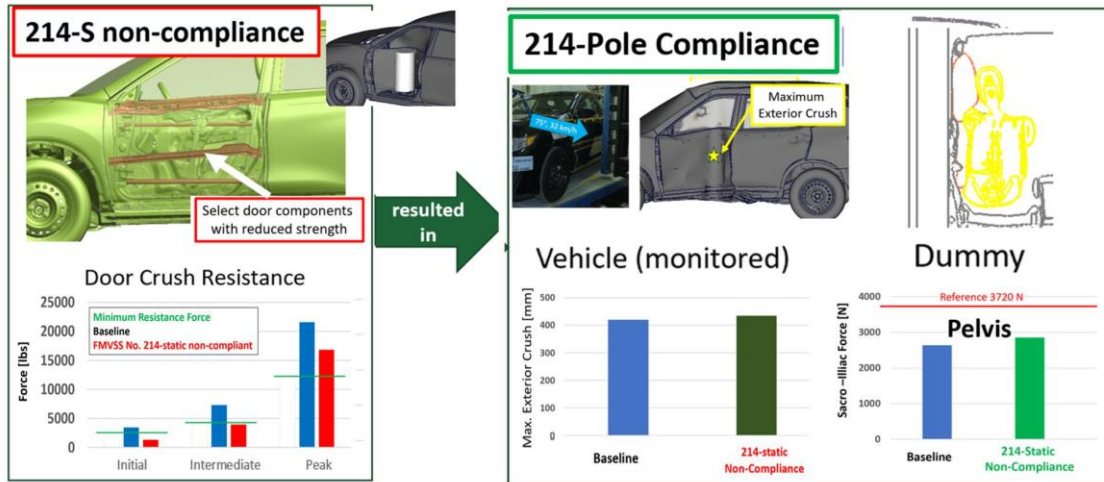


Figure 27. SUV – (a) FMVSS No. 214-static non-compliance; (b) effect for FMVSS No. 214-pole impact.

The reduced strength for door components, that resulted in 214-static non-compliance did not significantly affect the performance in the 214-MDB condition, which mainly relies on B-pillar and sill components. Similarly, it did not significantly affect the performance in the FMVSS No. 214-pole impact.

2020 Nissan Rogue SUV - effect of FMVSS No. 214-MDB non-compliance

The validate Nissan Rogue baseline model was then modified in such a way that it showed non-compliance for the FMVSS No. 214-MDB configuration. Figure 28 (a) shows the parts with reduced strength in red. The structural B-pillar components play an important role for the MDB condition like the sedan vehicle class. In addition, due to a significant overlap of the vehicle sill and the barrier bumper, as illustrated in the cross-section view shown Figure 28 (a), the lower door beam and rocker components affected performance in the MDB configuration. Some of the rocker parts extended to the A-pillar. Reducing the material strength and thickness for the components shown in red, resulted in higher structural deformation and consequently higher occupant loads. The pelvis load for the modified SUV simulation model impacted by the MDB at 53 km/h, represented by the red bar, significantly increased compared to the baseline model, represented by the blue bar. When impacting the modified FE model at the rating speed of 62 km/h, even higher pelvis forces were recorded, as expected, and represented by the dark red bar. The model with significantly increased pelvis forces was considered non-compliant with respect to the FMVSS No. 214-MDB configuration.

The model that showed non-compliance for the FMVSS No. 214-MDB impact was then exercised in the FMVSS No. 214-static door crush condition, as shown in Figure 28 (b).

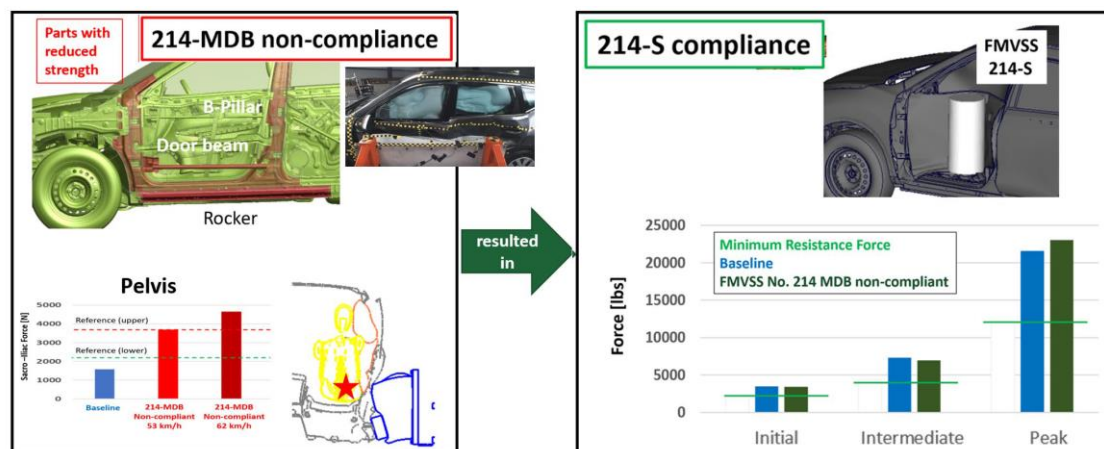


Figure 28. SUV – (a) FMVSS No. 214-MDB non-compliance; (b) effect for FMVSS No. 214-static.

Structural modifications that resulted in FMVSS No. 214-MDB non-compliance resulted in marginally lower initial and intermediate force levels in the quasi-static configuration. Values were marginally lower than for the baseline FE model, but clearly above the minimum required resistance force, defined for FMVSS No. 214 compliance. The peak resistance force was clearly above the required force level for the baseline and modified model. The conducted simulations indicated FMVSS No. 214-static door crush resistance force compliance despite dynamic 214-MDB non-compliance.

The model that showed non-compliance for the FMVSS No. 214-MDB configuration, depicted in Figure 29 (a) was then exercised in the FMVSS No. 214-pole condition, as shown in Figure 29 (b). Structural modifications that resulted in FMVSS No. 214-MDB non-compliance resulted in higher structural deformation and pelvis loads in the FMVSS No. 214-pole configuration. Simulations with a 50th percentile ATD in the driver seat indicated that the maximum combined pelvis force for the modified model, represented by the brown bar, was significantly higher than in the baseline simulation, represented by the blue bar. It exceeded the reference value, represented by the horizontal, red dashed line.

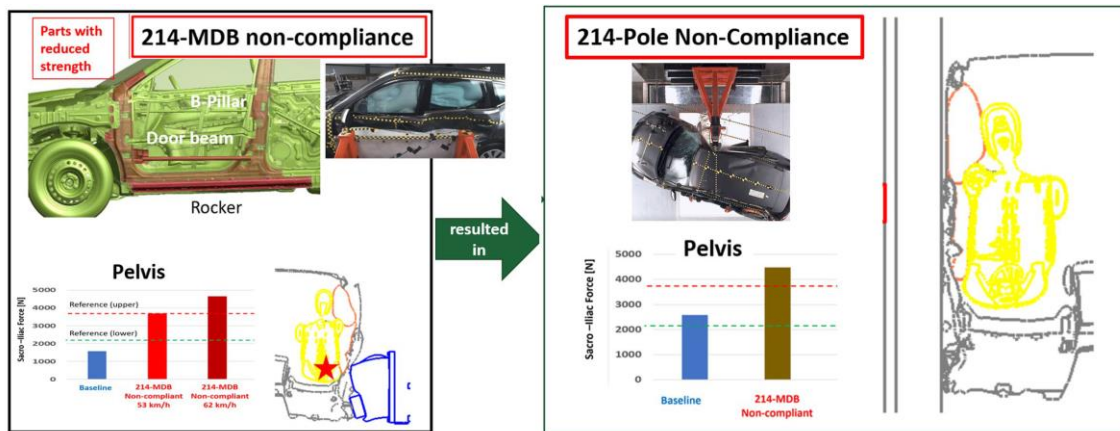


Figure 29. SUV – (a) FMVSS No. 214-MDB non-compliance; (b) effect for FMVSS No. 214-pole.

The conducted simulations indicated FMVSS No. 214-pole non-compliance for a model that showed 214-MDB non-compliance. The reduced strength for rocker and lower door beam parts in addition to the reduced strength of the B-pillar components, that resulted in 214-MDB non-compliance did not significantly affect the performance in the 214-static condition which mainly relies on the door components. However, it did significantly affect the performance in the FMVSS No. 214-pole condition, where the vehicle impacts the pole at the front door overlapping with the sill and vehicle floor. Occupant loads are typically higher in the pole impact configuration than in the MDB configuration for SUV vehicles with higher occupant seating positions, which contributed to the observed effects. While the MDB only marginally overlaps with the occupant, the rigid pole that extends from the floor to above the roof, can generally cause higher occupant loads for the SUV-type vehicle.

2020 Nissan Rogue SUV - effect of FMVSS No. 214-pole non-compliance

The validate 2020 Nissan Rogue SUV FE baseline model was then modified in such a way that it showed non-compliance for the FMVSS No. 214-pole configuration. Figure 30 (a) shows the parts with reduced strength in red, compared to the baseline model. The sill components and the driver seat cross member play an important role for the oblique side pole impact condition. A combination of weakening these components together with the upper door cross member and lower door bar, select roof parts, and rocker parts that extend to the B-pillar, resulted in non-compliance in the side pole impact configuration. This is illustrated by the increased pelvis loads for the modified SUV model, represented by the brown bar in Figure 30 (a), compared to the baseline FE model, represented by the blue bar. The applied modifications resulted in higher maximum exterior crush and higher occupant pelvis force in the FMVSS No. 214-pole impact, as shown in Figure 30 (a).

The model that showed non-compliance for the FMVSS No. 214-pole configuration was then exercised in the FMVSS No. 214-static door crush condition, as shown in Figure 30 (b).

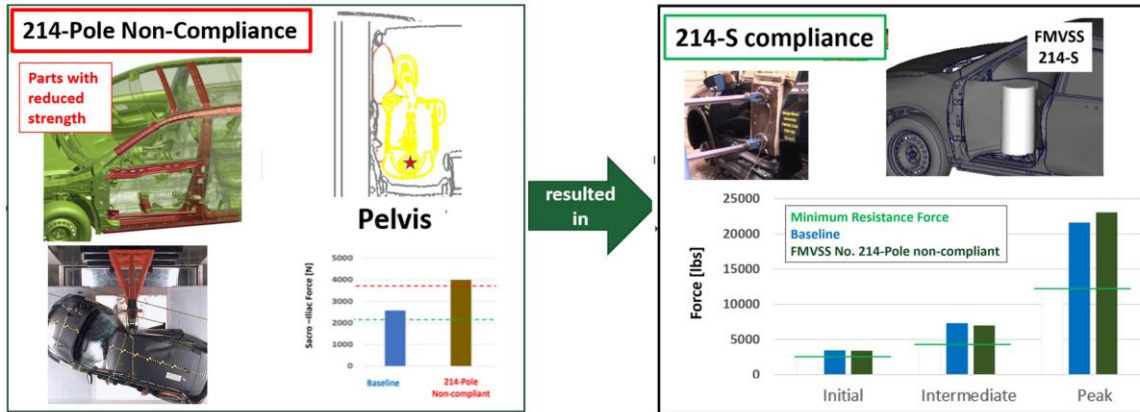


Figure 30. SUV – (a) FMVSS No. 214-pole non-compliance; (b) effect for FMVSS No. 214-static.

Structural modifications that resulted in FMVSS No. 214-pole non-compliance resulted in marginally lower initial and intermediate door crush resistance force levels in the 214-static test configuration. The peak resistance force was clearly above the required force level for the baseline and modified model. All values were above the minimum required resistance force. The conducted simulations indicated FMVSS No. 214-static door crush compliance despite dynamic FMVSS No. 214-pole non-compliance.

The model that showed non-compliance for the SUV FMVSS No. 214-pole configuration, depicted in Figure 31 (a) was then exercised in the FMVSS No. 214-MDB condition, as shown in Figure 31 (b).

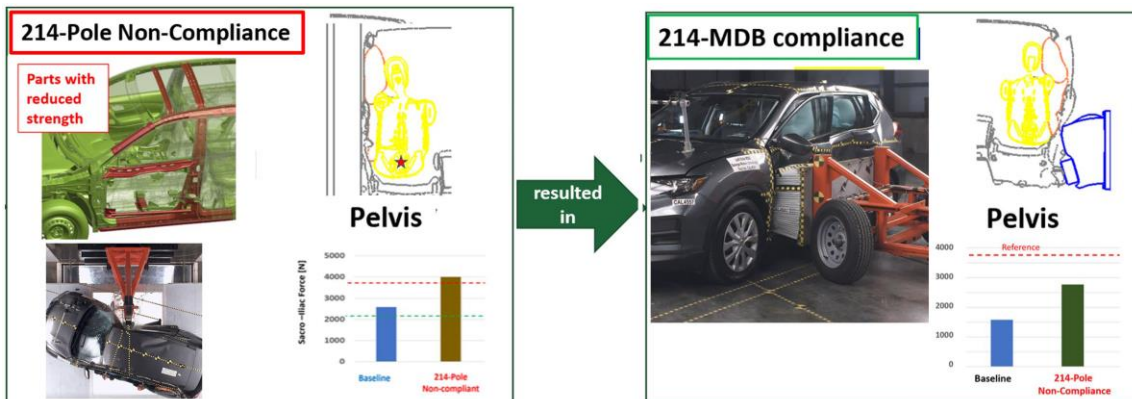


Figure 31. SUV – (a) FMVSS No. 214-pole non-compliance; (b) effect for FMVSS No. 214-MDB.

Structural modifications that resulted in FMVSS No. 214-pole non-compliance resulted in higher structural deformation and velocities also in the MDB configuration when compared to the baseline simulation. B-pillar velocity increased marginally from 8.5 m/s to 8.6 m/s, while the door velocity increased significantly from 10.1 m/s for the baseline model to 11.4 m/s for the model that did not comply with FMVSS No. 214-pole requirements. The simulations with a 50th percentile dummy in the driver seat indicated that the maximum combined sacroiliac pelvis force was significantly higher compared to the baseline simulation. Since the baseline simulation showed a relatively moderate value, which is often the case for SUV-type vehicles in the MDB configuration and even more so for chest load, the pelvic load for the modified model was still clearly below the defined reference criteria. The conducted simulations indicated FMVSS No. 214-MDB compliance despite pole non-compliance.

The reduced strength of relevant sill, roof, door, and B-pillar components, that resulted in FMVSS No. 214-pole non-compliance did not significantly affect the performance in the 214-static condition which mainly relies on the door components. However, it significantly affected the performance in the 214-MDB condition, resulting in higher structural and occupant loads. Due to the relatively low MDB baseline loads, values were below reference criteria resulting in 214-MDB compliance for the model that did not comply with FMVSS No. 214-pole.

DISCUSSION

Mutual Effect of FMVSS No. 214 non-compliance

The three FMVSS No. 214 configurations mainly rely on different vehicle structural areas, as shown in Figure 32.

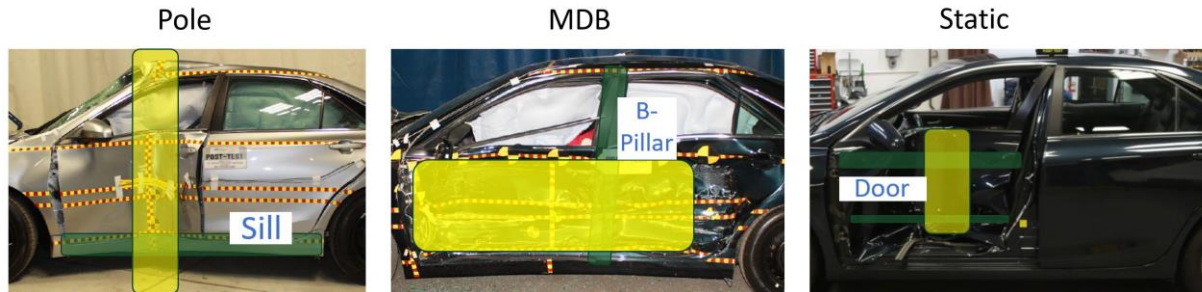


Figure 32. Main load paths during FMVSS No. 214 (a) pole; (b) MDB; and (c) static door crush.

- (1) FMVSS No. 214-static door crush, where a cylindrical impactor does not overlap with the sill or the B-pillar, is mainly affected by door strength characteristics.
- (2) FMVSS No. 214-MDB, where the moving barrier only marginally overlaps with the sill of a sedan vehicle, is mainly affected by B-pillar strength and deformation characteristics; and
- (3) FMVSS No. 214-pole, where the moving vehicle impacts the stationary rigid pole at the front door, is mainly affected by sill and adjacent reinforcement components.

Hence, non-compliance of one of the FMVSS No. 214 configurations did not result in non-compliance for the respective other two load cases for the sedan vehicle. Similarly, non-compliance of the FMVSS No. 214-static configuration did not significantly affect the MDB and VTP load cases. In contrast to the sedan vehicle class, MDB and VTP configurations use sill and floor components as relevant load paths, due to the higher sill of the SUV type vehicle relative to the ground and relative to the MDB. As a result, non-compliance of the FMVSS No. 214-MDB configuration resulted in non-compliance in the FMVSS No. 214-pole load case for the Nissan Rogue vehicle. While non-compliance of the SUV VTP scenario also resulted in higher loads for the SUV MDB configuration, it did not result in MDB non-compliance due to the relatively low MDB baseline vehicle and occupant loads. These differences for the Toyota Camry and Nissan Rogue vehicles are considered to be representative for the sedan and SUV vehicle classes. Note that the differences in vehicle sill and seating position height for the sedan and SUV vehicle classes, only resulted in differences with respect to mutual effects for the MDB and Pole modifications. The FMVSS No. 214-static configuration was not significantly affected by non-compliant MDB and pole configurations for either vehicle class. Similarly, FMVSS No. 214-static non-compliance did not significantly affect MDB and VTP configurations for sedan and SUV vehicle classes, due to the different load paths used.

In addition to metrics relevant for FMVSS No. 214 compliance, additional metrics were studied during this research to understand, if dynamic performance measurements from the MDB or pole impact could be used as surrogate for the FMVSS No. 214-static configuration, as discussed in the next section.

Dynamic Performance Measurements as a Surrogate for the Static Test

In addition to evaluating the effect of mutual non-compliance for each of the three FMVSS No. 214 impact scenarios, the results of this study were used to explore options for developing performance criteria so that the FMVSS No. 214 dynamic MDB and/or VTP tests could be used as replacements for the static door crush resistance requirements. Currently, neither of the dynamic 214 test procedures measure door crush resistance force.

Candidate dynamic performance metrics

Results from the sedan and SUV simulation studies were used to evaluate if it is feasible to use a dynamic performance measurement as a surrogate for the static test. Figure 33 depicts potential structural metrics from the FMVSS No. 214-MDB and FMVSS No.214-pole impact tests.

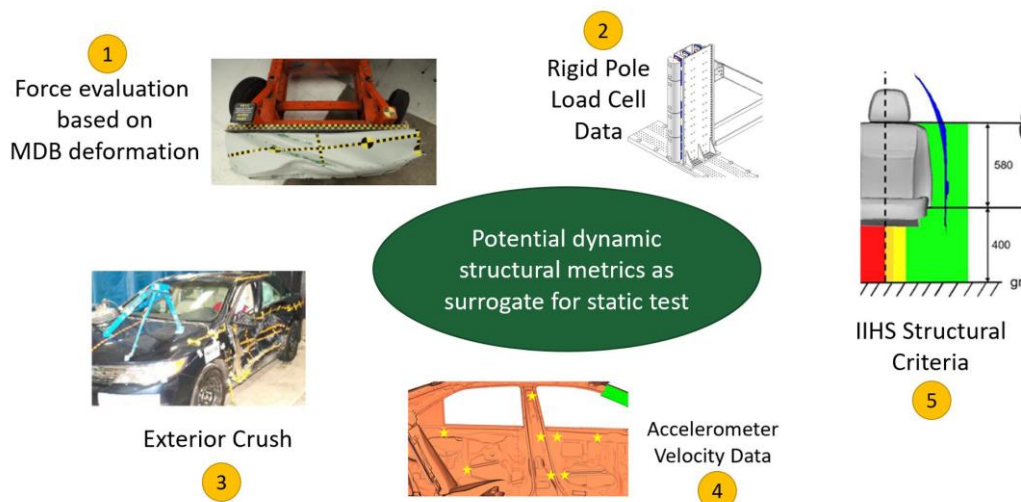


Figure 33. Candidate structural metrics from dynamic tests as surrogate for static test.

Deformation, load cell forces, and acceleration-based data can be recorded during the dynamic MDB and pole impact configurations. Five candidate structural metrics are outlined below and discussed in the following sections.

- 1) The MDB’s honeycomb face has well-defined force-deformation characteristics. Digitizing the MDB barrier surface, pre- and post-crash, allows to calculate the deformation at relevant areas, for example where the door is being struck. From the residual deformation, the force can be calculated. A similar approach has been used for the Progressive Deformable Barrier in a frontal offset configurations.⁹
- 2) Rigid pole load cells at different heights are standard instrumentation during most FVMSS No. 214-pole impact tests. The force time history data combined with vehicle accelerometer data, which can be used to calculate the displacement and deformation of the vehicle exterior, permits generation of a force versus displacement graph, similar to the one used for the FMVSS No. 214-static door crush resistance tests.
- 3) Residual exterior crush is typically measured at five different heights of the vehicle, i.e. the sill, the height of the occupant hip point, the mid door location, close to window opening, and at the roof for dynamic FMVSS No. 214-MDB and pole full-scale tests. The largest exterior crush is observed at the front door in many cases. These residual exterior crush measurements can indicate the structural side impact performance and were considered as candidate metric to indicate door crush resistance.
- 4) Accelerometer data, specifically absolute velocity time history data recorded at the near-side B-pillar and doors, is a good structural indicator for side impact performance of a vehicle, used by many car manufacturers during the vehicle development process.
- 5) The Insurance Institute for Highway Safety has a well-defined structural criterion that measures the remaining occupant compartment space after a IIHS MDB side impact crash based on B-pillar deformation relative to the middle of the seat.

Metrics based on vehicle accelerometer data

Velocity time history data derived from accelerometers located at the impact-side B-pillar and doors during a barrier side impact configuration is used by many OEMs as a structural performance metric. In addition to interior design and air bag performance, absolute velocity measured at these locations are an important factor for occupant loads. Occupants positioned in the front and rear seats during a side impact typically do not benefit from the so-called “ride-down.” During frontal impact scenarios, a distinct crash-energy absorption structure, also called frontal crumple zone, causes the vehicle to decelerate more slowly. Occupant loads are then significantly mitigated by the frontal air bags and seat belts before a potentially injurious contact with the vehicle interior occurs. In contrast, the

⁹ Park, C.-K., Hong, S.-W., Mohan, P., Morgan, R. M., Kan, C.-D., Lee, K., Park, S., & Bae, H. (2016). Simulation of progressive deformable barrier (PDB) tests. 10th International LS-DYNA Users Conference, Detroit, MI.

occupants in side impact are more directly loaded by contacting the vehicle’s structure, interiors, and side air bags. Seat and seatbelts can only generate a much smaller ride-down benefit due to the lateral motion and missing crumple zone.

To determine relevant vehicle metrics for side impact scenarios, it is important to note that vehicle motion relative to the occupant is typically a combination of intrusion and global vehicle kinematics. For example, a vehicle with a low mass can produce high structural velocity in the absence of significant intrusion. From the author’s experience working in industry and with major car manufacturer’s, it is known that quantitative criteria for the structural velocity exist at many OEMs to judge the side impact performance of a vehicle in U.S. NCAP, IIHS, and EuroNCAP side impact barrier configurations.

Accelerometer locations at the middle of the B-pillar and at the door are close to the occupant-to-vehicle contact areas. The B-pillar location can be considered the most reliable accelerometer location with respect to full-scale testing, while the accelerometers at the door, mounted to relatively thin structural components, can produce high oscillations and questionable data. Figure 34 (b) depicts the B-pillar and door accelerometer locations evaluated during the Nissan Rogue simulation study. The results from two simulations were used to evaluate the usability of accelerometer data from the FMVSS No. 214-MDB test as a surrogate for the static test. Maximum absolute velocity values are compared for the SUV baseline model and the model variation that did not comply with the FMVSS No. 214-static door crush resistance requirement. Note that the maximum velocity at the middle of the B-pillar was identical, as shown in Figure 34 (a), and only marginally higher at the door location, as shown in Figure 34 (c), with values of 6.9 m/s versus 6.7 m/s, for the baseline and 214-static non-compliant model, respectively.

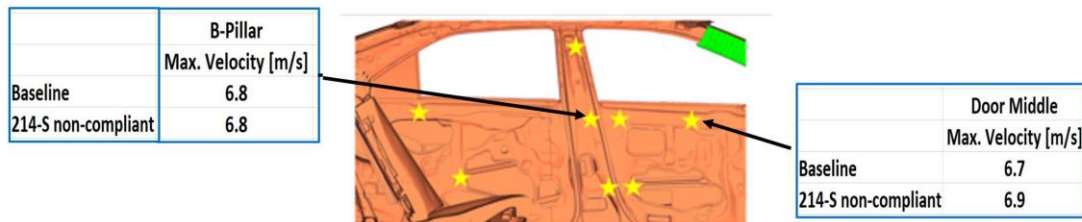


Figure 34. SUV accelerometer data - baseline versus 214-static non-compliant (a) B-pillar velocity; (b) relevant locations; (c) door velocity.

The analyses indicated that accelerometer data from the dynamic MDB configuration is not adequate to serve as a surrogate metric for the static test, due to the different load paths engaged during the FMVSS No. 214-MDB and static door crush tests. In addition, it was found that SUV-type vehicles with a relatively high rocker location and seating position, have a relatively low barrier to vehicle impact location. This geometric characteristic can produce higher deformations and velocities at the lower part of the vehicle for different structural designs, while deformation and velocities at the middle of the B-pillar and upper door, which are relevant for most occupant metrics, are the same or even lower for a baseline vehicle compared to a FMVSS No. 214 static non-compliant vehicle, as shown in Figure 34 (a) and Figure 34 (c).

It was concluded that accelerometer-based velocity time history data from the FMVSS No. 214-MDB dynamic test condition is not adequate to be used as a surrogate for the quasi-static minimum door crush resistance force requirements.

Metrics based on vehicle and barrier deformation

Vehicle and barrier deformation measurements, including residual MDB honeycomb crush, the IIHS side impact structural criteria, based on B-pillar intrusion and remaining occupant compartment space, and exterior crush measurements available from FMVSS No. 214-MDB and pole tests, as shown in Figure 35, have been evaluated. It was examined if they can indicate door crush resistance forces, as defined in the FMVSS No. 214-static requirement.

The MDB’s honeycomb face has well-defined force-deformation characteristics. Digitizing the MDB barrier surface pre- and post-crash, allows to calculate the deformation at relevant areas, for example where the door is being impacted. From the residual deformation, the resulting force can be calculated.

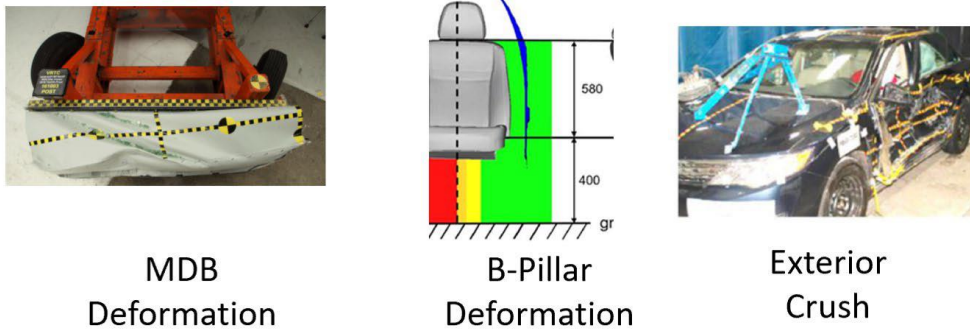


Figure 35. Deformation-based metrics (a) MDB deformation; (b) IIHS structural criteria; (c) exterior vehicle crush.

Due to the different load paths engaged for the respective FMVSS No. 214 configurations, no significant difference in honeycomb deformation was observed for the baseline model and the model that did not comply with FMVSS No. 214-static. The MDB configuration for the SUV vehicle category resulted in no significant barrier face deformation for the area impacting the door, since the main load was transferred through the barrier bumper and vehicle rocker area, as shown in Figure 1 (a).

The evaluation of test and simulation results indicated that deformation-based measurements from the FMVSS No. 214 dynamic MDB and pole test conditions have significant limitations to indicate minimum door crush resistance force metrics, as defined in the static test.

Metrics based on rigid pole load cell data

Locations and contact times between pole and vehicle, as well as between occupant and vehicle, were studied in detail, for the FMVSS No. 214-pole impact test, as shown in Figure 36. After initial contact of the moving vehicle with the stationary rigid pole at 0 ms, the outer door is deformed after about 10 ms and the sill area starts to be impacted and deformed. After 20 ms air bags are mostly inflated, depending on the sensors used; the door has been significantly crushed, and the sill area is partially deformed at this time. After 40 ms initial contact of the pole with the roof area can occur, depending on the design of a vehicle; air bags have used most of the available package space between occupant and interior to mitigate the impact, and maximum occupant loads start to develop. After 60 ms, the front door and rocker have been significantly deformed at the impact location and the roof area shows deformation to some extent.

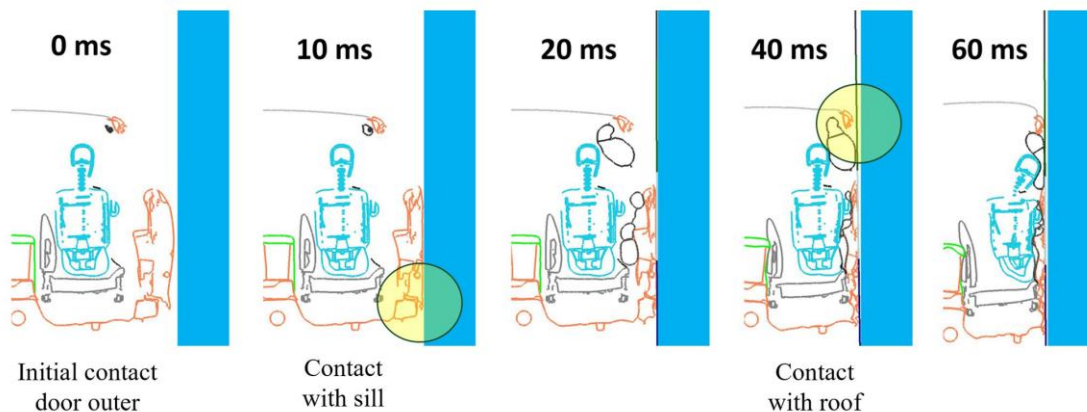


Figure 36. Sequence of FMVSS No. 214-pole characteristic crash events using a cross-section view.

These characteristic crash events can clearly be seen in respective load cell data, recorded at different heights of the rigid pole. Figure 37 shows an example of a sedan pole impact with force time-history data recorded at the sill, door, and roof impact areas. The earliest onset can be observed at the door, due to the geometry of the vehicle and the initial contact with the pole in this area. After about 10 ms, a sudden increase in force in the vehicle rocker area can be observed and engagement of the roof area load path can clearly be identified after about 35 ms.

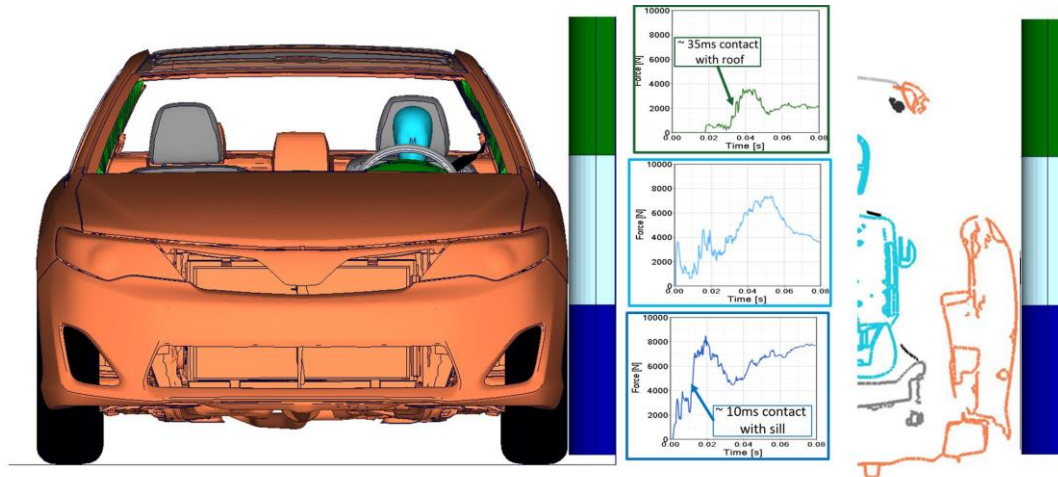


Figure 37. Pole impact force time history data for rocker, door, and roof area.

Existing and recorded pole load cell data from full-scale tests and conducted simulations were carefully studied to determine if the dynamic measurements can be used as surrogates for the static test. Figure 38 (a) shows the comparison of the force versus displacement characteristics in the static door crush resistance condition for the Nissan Rogue baseline model and the model that did not comply with the FMVSS No. 214-static requirement. The distinct difference of the resistance force levels for the baseline model, shown in blue, and the model that did not comply with the static requirement, shown in red, can clearly be noticed. Load cell data from the rigid pole instrumentation located next to the front door, as illustrated in Figure 38 (b), was used in combination with vehicle displacement data, to generate a force versus displacement graph, similar to the one used for the static requirement. Figure 38 (c) shows the force versus displacement characteristics for the SUV baseline model and the model that did not comply with the static requirement in the pole impact in blue and red, respectively.

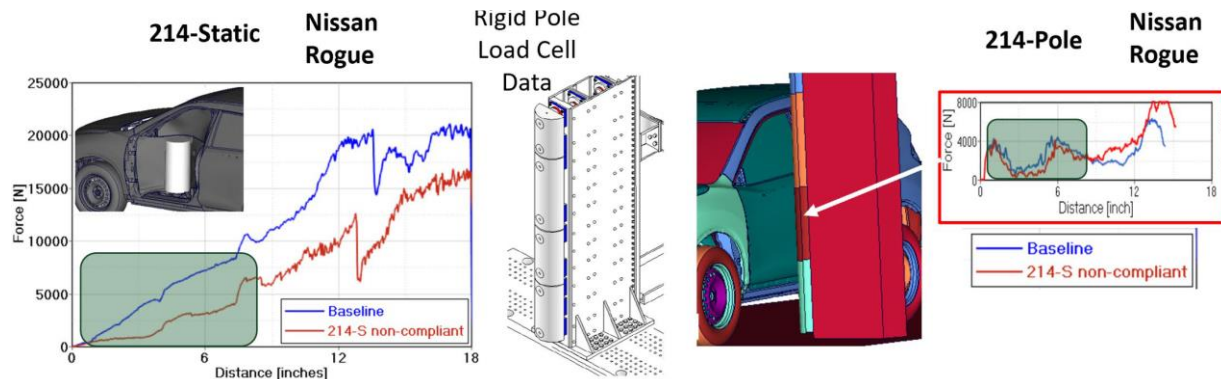


Figure 38. Nissan Rogue baseline versus FMVSS No. 214-static non-compliant model (a) comparison of static door crush resistance force; (b) load cell locations; (c) comparison of force versus deformation at the door location.

From Figure 38 (c), higher maximum exterior crush for the 214-static non-compliant model can be observed. Higher forces can be seen for the baseline model for the first 8 inches of vehicle displacement. This is in qualitative agreement with the force versus displacement characteristics observed in the static door crush condition. Vehicle deformation at the sill and roof affect the loads induced into the door in the pole configuration, in contrast to the static door crush test, where the rigid cylinder intrudes into the door exclusively. Therefore, force versus displacement characteristics for static cylinder and dynamic pole tests, did not show the same qualitative trend after about 8 inches of crush for the baseline model and the FMVSS No. 214-static non-compliant model. In conclusion, the evaluation of rigid pole load cell data measurements showed that they can qualitatively indicate front door crush resistance to some extent, similar to the FMVSS No. 214-static test condition, in the initial deformation phase, but has limitations for higher intrusions.

Surrogate metrics limitations

As outlined in the previous paragraphs, there are significant limitations of using performance measurements from the dynamic FMVSS No. 214-MDB and pole configurations as a surrogate for the static door crush requirement:

- The most obvious limitation is the lower maximum exterior crush, which was about 8.7 inches and 13.7 inches for recent MDB and pole impact full-scale tests, respectively. In contrast, the static door crush test requires front and rear door crush resistance force to be evaluated up to 18 inches of deformation.
- Accelerometer based velocity time history data, which can be a good indicator for MDB side impact performance of a vehicle with respect to occupant metrics, has significant limitations. Different load paths, relevant for the static and dynamic tests, especially for sedan-type vehicles, and characteristic deformation patterns with higher seating positions for SUV-type vehicles, make this dynamic measure not adequate to be used as a surrogate for the quasistatic test.
- Smaller maximum exterior crush was observed for the dynamic FMVSS No. 214-MDB and pole conditions compared to the static requirement. Limited engagement and deformation of upper honeycomb face, especially for “higher” SUV-type vehicles where the MDB bumper engages with the rocker also presented significant limitations. The exterior crush, MDB deformation, and IIHS structural criteria were therefore found not adequate to serve as surrogate measurements for the static test.
- The evaluation of rigid pole load cell data measurements showed that they can qualitatively indicate front door crush resistance to some extent, similar to the FMVSS No. 214-static test condition, in the initial deformation phase, but has limitations for higher intrusions.

Additional limitations, to the ones outlined for the front door, exist for defining a performance metric based on results from the dynamic FMVSS No. 214-MDB and pole configurations, that can be used as surrogate for the static door crush test at the rear door. Pole impacts are only performed at the front door and, therefore, do not provide any data that could indicate the door crush resistance of the rear doors. Similarly, the MDB is positioned relative to the front axis of a vehicle and typically impacts the B-pillar, the entire front door, but only part of the rear door, depending on the wheelbase and length of a vehicle.

CONCLUSION

A validated FE model representing the sedan vehicle category and a validated FE model representing the SUV vehicle type were used to conduct simulation studies that investigated the mutual effect of non-compliance for each of the three FMVSS No. 214 side impact configurations, the quasi-static door crush test, the MDB barrier impact, and the pole configuration.

A validated FE model of a 2015 Toyota Camry was used to conduct the sedan FMVSS No. 214 simulation study. The baseline FE model was modified in such a way, that it resulted in non-compliance with respect to the FMVSS No. 214-static test configuration, based on minimum door crush resistance force requirements. Similarly, FE models were generated, that resulted in non-compliance for the dynamic FMVSS No. 214-MDB and FMVSS No. 214-pole impact configurations, which are based on ATD metrics.

It was found that structural modifications that resulted in non-compliance for one of the FMVSS No. 214 impact configurations did not result in non-compliance for the other two configurations, due to different relevant load paths. A FE model of a 2020 Nissan Rogue SUV was developed applying an established reverse engineering process and used to conduct a similar simulation study, as for the Toyota Camry sedan. It was found that structural modifications that resulted in non-compliance for one of the load cases did not result in non-compliance for the other two configurations, except for 214-MDB non-compliance, which also resulted in 214-pole non-compliance. Different metrics from the FMVSS No. 214-MDB and pole side impact configurations were evaluated to determine the feasibility of using dynamic performance measurements as a surrogate for the FMVSS No. 214 static door crush test. It was found that there are significant limitations, because of the different main load paths relevant for the dynamic and static side impact tests. Dynamic rigid pole load cell data showed the highest potential of indicating initial front door crush resistance.

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