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Subject: MASH TL-3 Compliance Assessment of Single Slope Concrete Barriers with Slump and Increased Slope

Dear Mr. Torres,

Thank you for your recent inquiry seeking an engineering opinion on MASH Test Level 3 (TL-3) compliance of MDOT's single slope barrier installations that deviate from design standards due to the presence of concrete slump and/or increased face-slope.

As you stated in your email (October 20, 2021), the current MDOT standard series R-49 and R-76 provide details of the DOT's 42-inch tall unreinforced single slope median barriers, to which monolithically-cast concrete glare screen and concrete footing may also be added (Figure 1). The standard face-slope of MDOT's single slope barrier is 10.8 degrees from the vertical.

You also provided dimensional data of various barrier installations that was collected using LiDAR at select points in areas of relatively straight roadways, with zero or minimal height differential between opposing lanes of traffic. The dimensional data includes several measurement variables, however, for the purpose of my assessment for MASH TL-3 compliance, the slump values (D_1 and D_2) and the face slope values (S_1 and S_2) are the most relevant (Figure 2).

Prior to discussing the MASH compliance of the barriers with the slump and/or slope deviations, I would like to note that the single slope barrier with 10.8-degree face slope is a MASH TL-3 compliant system based on past testing. MASH TL-3 requires that longitudinal barriers meet testing requirements of MASH Test 3-11 (with a pickup truck) and Test 3-10 (with a small passenger sedan).

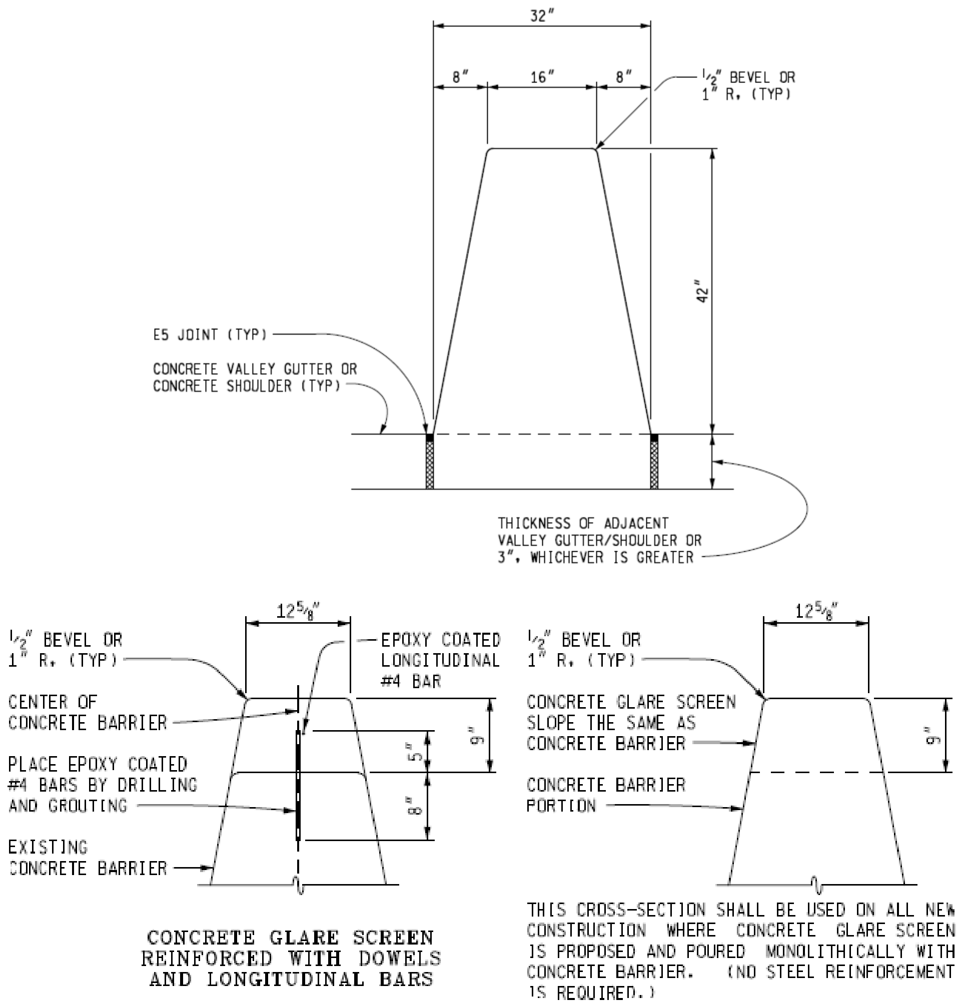

Figure 1. MDOT's Single Slope Barrier Details (Source: MDOT Standards R-49-G and R-76-E).

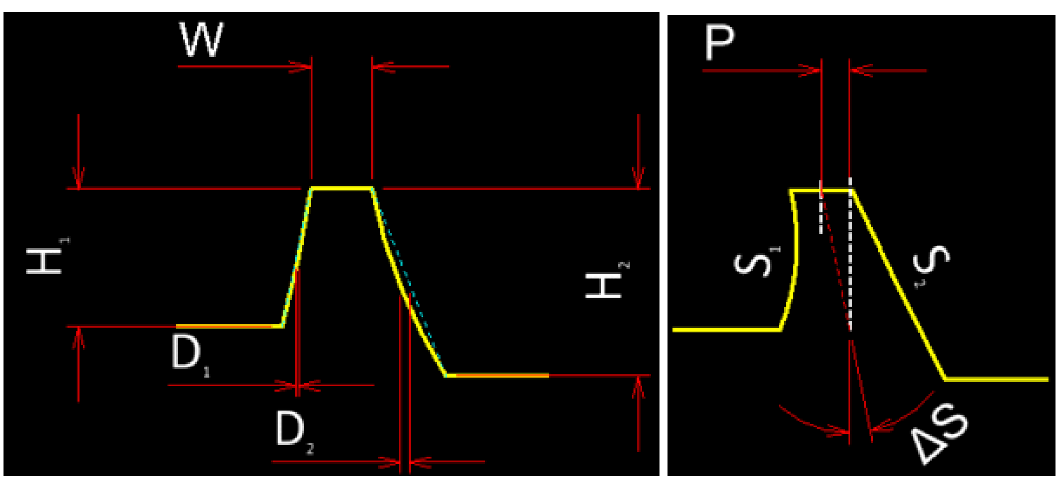

Figure 2. Dimensions measured for existing installations (Source: MDOT).

In the case of the single slope barrier, several past tests have been performed that successfully demonstrate its MASH Test 3-11[1] and Test 3-10[2,3] compliance.

In assessing the MASH compliance of the barriers that deviate from the standard design, I looked at the measurements data to learn about the extent of the deviation. Two key parameters that I used for this purpose were the slope of the barrier's face and the slump in the face of the barrier. Higher slope (measured from the vertical) and/or higher slump can lead the vehicle to have an easier and higher climb during the barrier impact, which can lead to kinematic instability in the vehicle. The occupant risk from the impact (i.e., maximum occupant impact velocity (OIV) and ride-down acceleration (RA)) are not expected to change significantly from the impact with the higher slope and slump values. For the purpose of this evaluation, I therefore focused on the vehicle's kinematic stability due to the deviations in the barrier profile described above.

Figure 3 shows the slump measurements in the data provided, plotted in the descending order of slump values. Figure 4 shows the slope measurements, plotted in the descending order of the slope values. It can be observed that majority of the slump and slope values are within reasonable construction tolerance of the standard design. However, there are several points that indicate high slump and/or slope values.

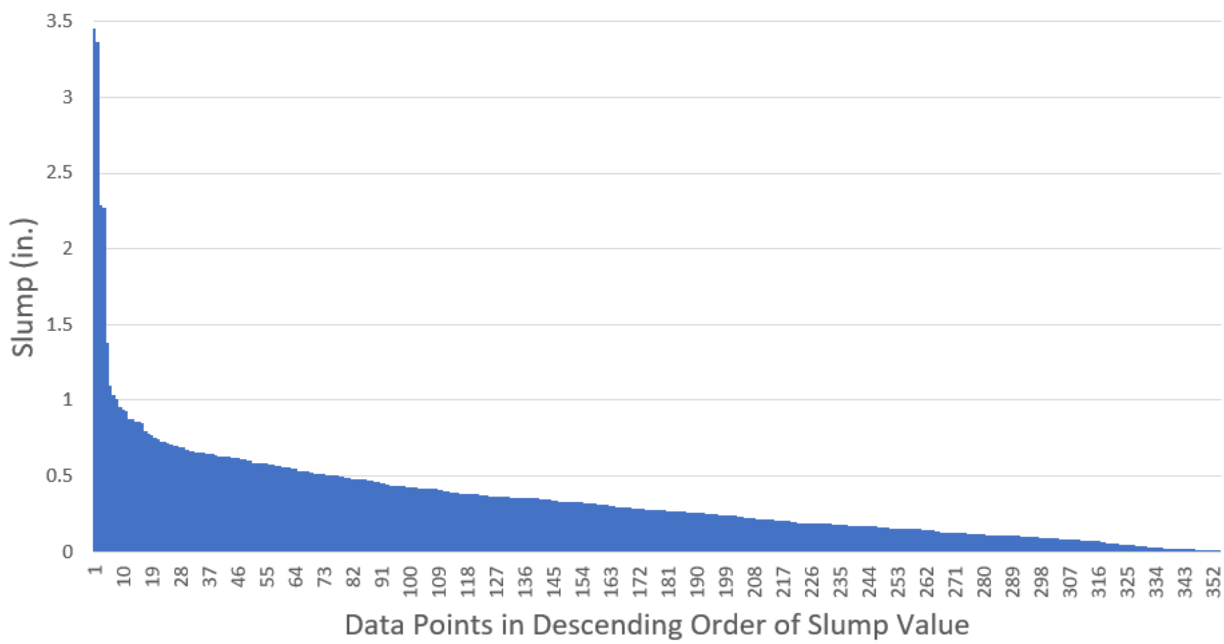

Figure 3. Slump measurements in the order of decreasing slump values.

[1] W.F. Williams, R.P. Bligh, and W.L. Menges, "Mash Test 3-11 of the TxDOT Single Slope Bridge Rail (Type SSTR) on Pan-Formed Bridge Deck." Report 9-1002-3. Texas A&M Transportation Institute, College Station, Texas, 2011.

[2] FHWA Letter of Eligibility, Letter Number HSST-1/B-338, Issued May 26, 2020. (TTI Test 690900-ITG4-6)

[3] D. Whitesel, J. Jewell, and R. Meline, Compliance Crash Testing of the Type 60 Median Barrier, Test 140MASH3C16-04. Research Report FHWA/CA17-2654, Roadside Safety Research Group, California Department of Transportation, Sacramento, CA, May 2018.

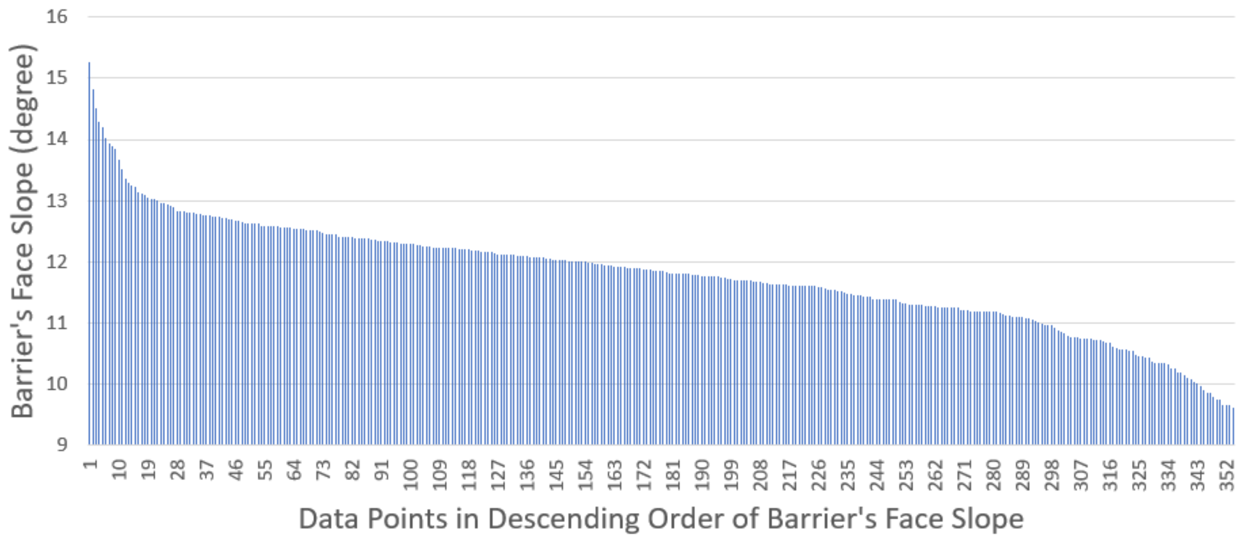

Figure 4. Barrier slope measurements in the order of decreasing slope values.

The maximum slump and barrier slope in the data were 3.45 inches and 15.27 degrees, respectively. Even though these maximum values did not occur simultaneously in the same barrier location in the data, I used these maximum values to assess the performance of the single slope barrier. A positive assessment would have resulted in all the barrier locations as being deemed MASH compliant.

Figure 5 shows the comparison of the barrier profile constructed using the maximum slump and slope values (red) with the standard MDOT 42-inch tall single slope barrier (blue). Also shown in this figure is a comparison of the maximum slump and slope value profile with the standard 32-inch tall New Jersey safety shape profile barrier.

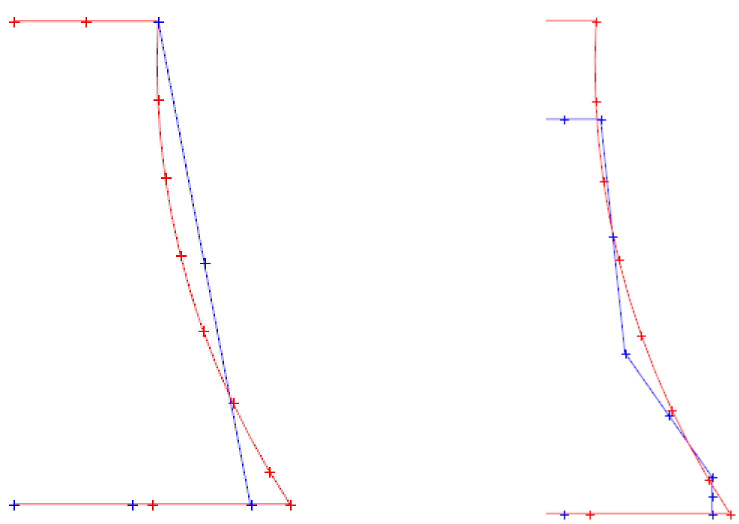

Figure 5. Comparison of maximum slump and slope profile (red) with standard single slope and NJ barrier profiles.

It can be seen that the deviated single slope barrier profile resembles the NJ safety shape profile, which, even though is MASH TL-3 compliant, is known to instigate high vehicle climb in Test 3-10 with the small passenger sedan.[4]

To evaluate the performance of the single slope barrier with the maximum slump and slope values, I performed finite element (FE) impact simulations using MASH Test 3-11 and Test 3-10 impact conditions. The barrier profile was modeled as a rigid material. The vehicle models were public domain models developed by Center for Collision Safety and Analysis (CCSA) with FHWA and NHTSA funding, modified over the course of several projects by TTI researchers to improve their validation and robustness. The simulations were performed using LS-DYNA, which is a commercial FE software commonly used for crash analysis.

Figure 6 shows the kinematics of the pickup truck (Test 3-11 conditions) as it impacted the barrier and redirected. The vehicle in this case is redirected in a stable manner with very little climb of the barrier. The vehicle also does not have excessive roll or pitch as it redirects. The results of the Test 3-11 simulation with the maximum slump and slope barrier profile indicate that the pickup truck is likely to meet MASH requirements.

Figure 7 shows the kinematics of the small car (Test 3-10 conditions) as it impacted the barrier and redirected. As expected (based on the past results of the NJ barrier testing), the vehicle in this case had a significant climb. Furthermore, the vehicle also had a much higher roll. Even though the vehicle was successfully contained and redirected in the FE simulation, in my opinion, the kinematic instability of the vehicle is slightly greater than what was observed in the NJ safety shape barrier testing.[4] For this reason, the maximum slump and slope conditions should not be used without additional testing. If testing is to be performed for critical MASH tests, it would only require performing Test 3-10 with the small car. Test 3-11 with the pickup is not critical due to the stable redirection results of the pickup impact simulation (Figure 6).

To arrive at the barrier profile that is more likely to pass MASH TL-3, I next simulated a 42-inch tall single slope barrier profile with a 14.25-degree slope and a slump of 1.5 inches. Only six of the measured locations in the database exceed either of these slope or slump values. Figure 8 compares the barrier profile using these slope and slump values to the standard single slope profile.

Since the pickup truck simulation indicated successful performance with the more stringent profile (with maximum slump and slope), I only performed a simulation of the MASH Test 3-10 with the small car. Figure 9 shows the results of the simulation. The kinematic stability of the vehicle improved compared to the previous profile. The small car vehicle still has high climb, however, testing experience with the small car shows that this is expected. Based on the results of this simulation, it is my opinion that this barrier profile is expected to pass MASH Test 3-10.

[4] K.A. Polivka, R.K. Faller, D.L. Sicking, J.R. Rohde, B.W. Bielenberg, J.D. Reid, and B.A. Coon, Performance Evaluation of the Permanent New Jersey Safety Shape Barrier – Update to NCHRP 350 Test No. 3-10 (2214NJ-1), Report No. TRP-03-177-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 13, 2006.

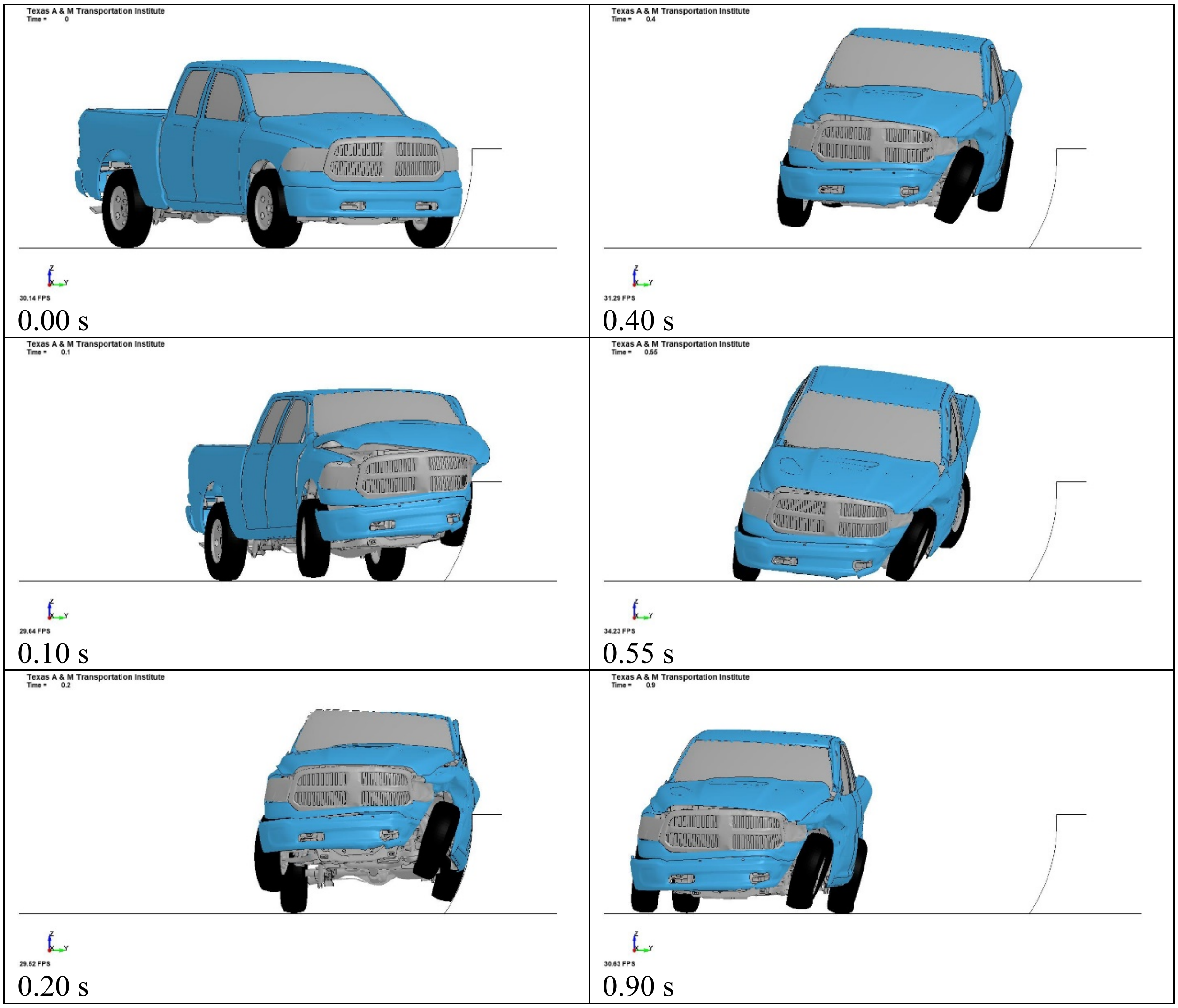

Figure 6. FE simulation of MASH Test 3-11 with the barrier profile with maximum slump and slope.

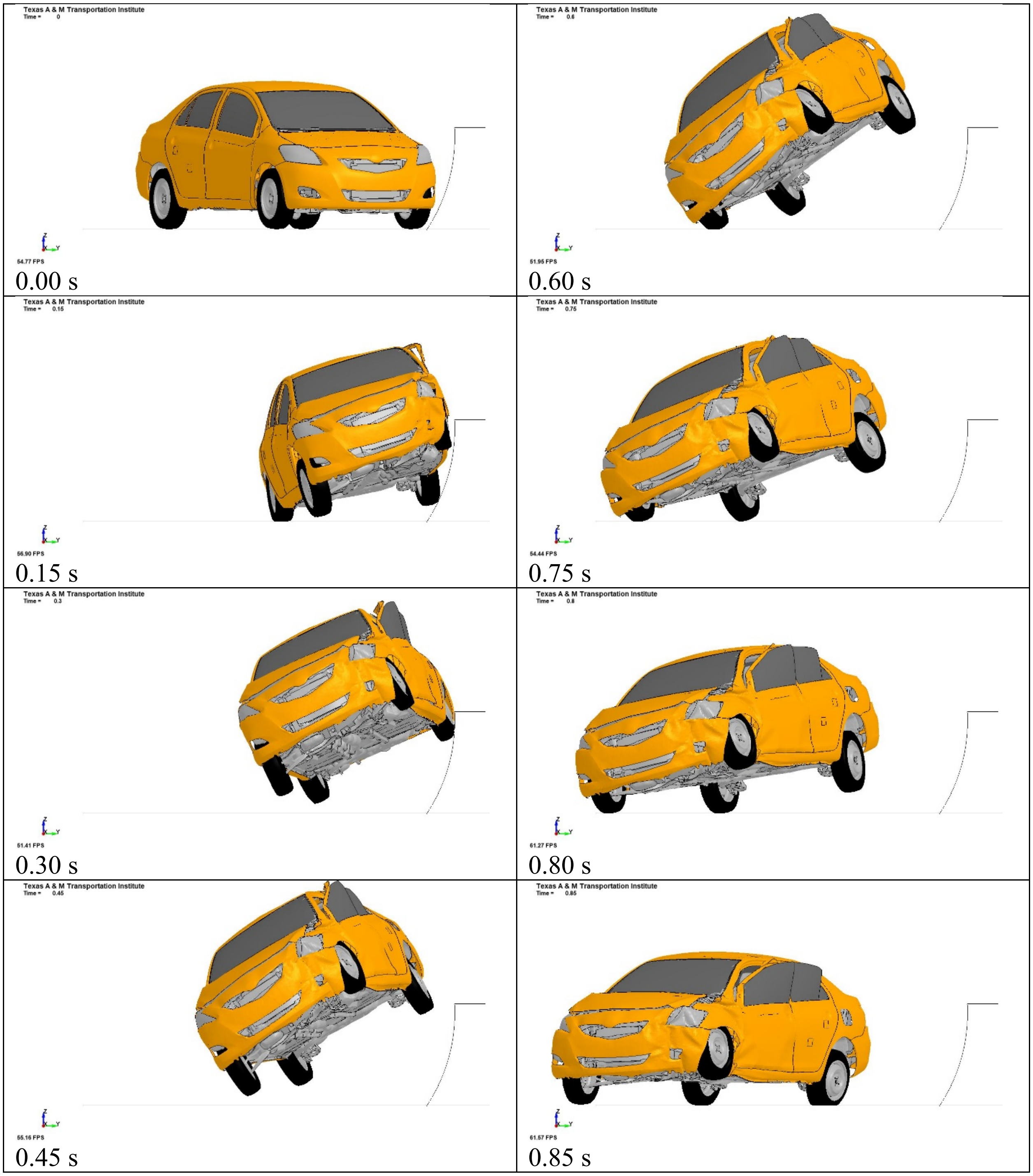

Figure 7. FE simulation of MASH Test 3-10 with the barrier profile with maximum slump and slope.

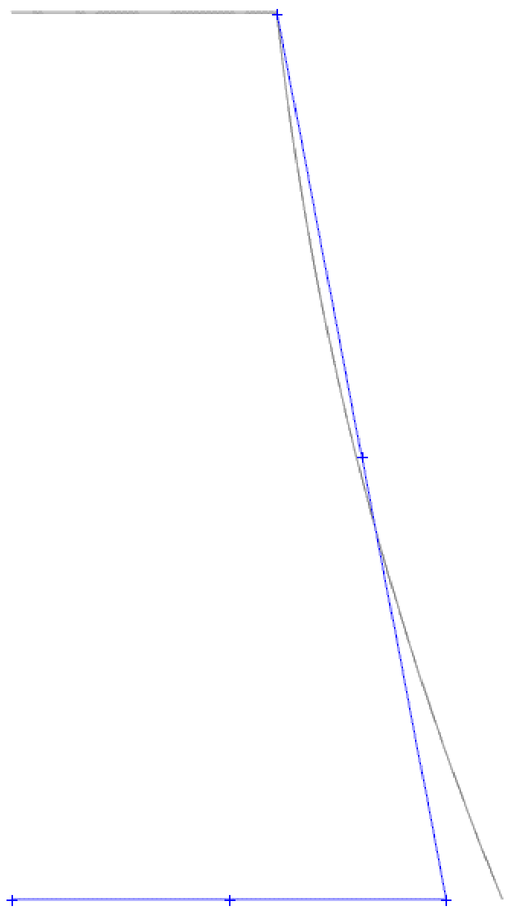

Figure 8. Standard single slope profile compared to the deviated profile with 14.25-degree slope and 1.5-inch slump.

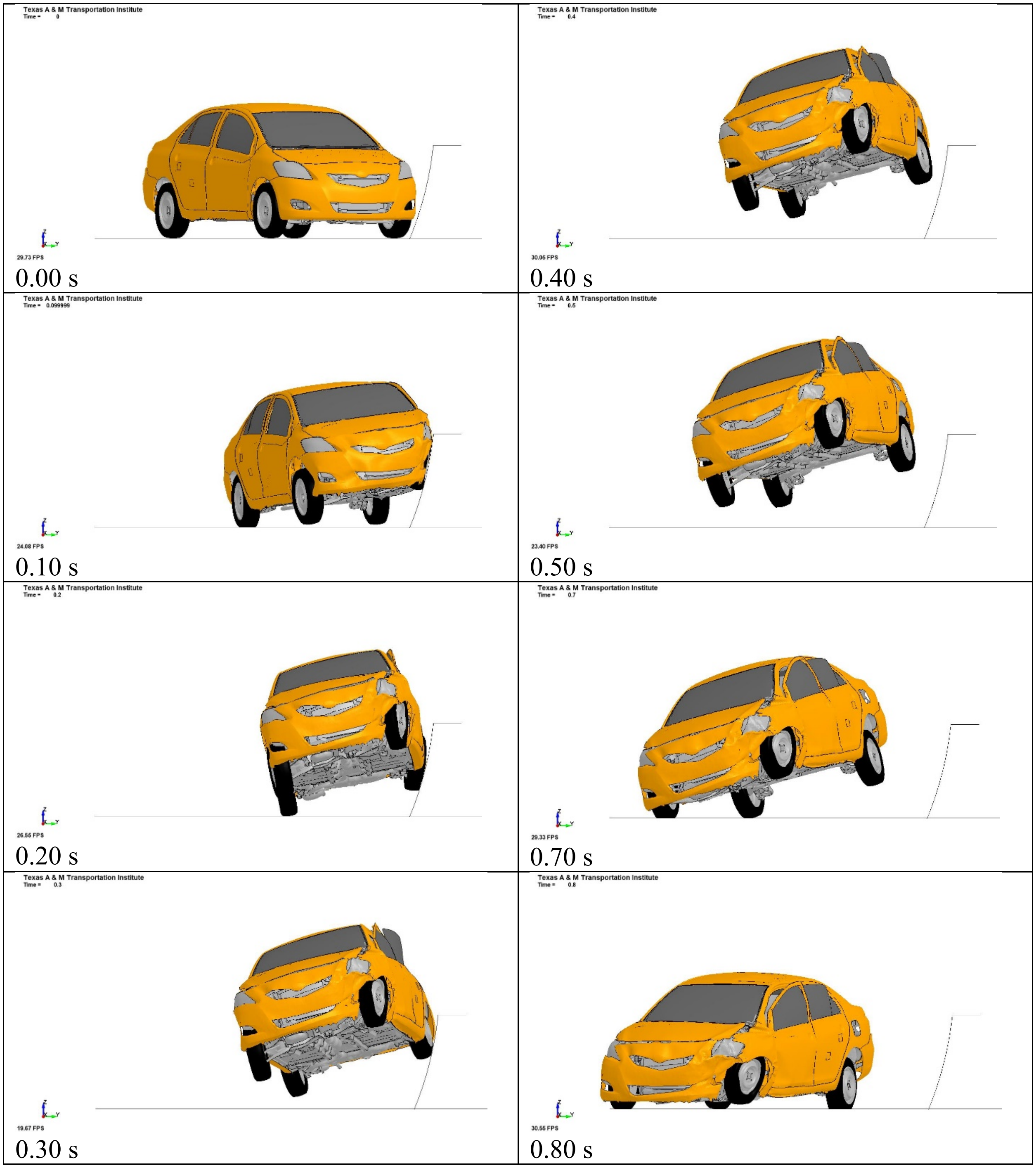

Figure 9: FE simulation of MASH Test 3-10 with the barrier profile with 14.25-degree slope and 1.5-inch slump.

After my assessment of the data presented, results of the past testing referred to herein, and the results of the impact simulations performed, I have formulated following opinions regarding your request.

- Single slope barrier installations in your database that have a barrier slope and concrete slump of less than or equal to 14.25 degrees and 1.5 inches, respectively, may be considered MASH TL-3 compliant based on past testing and the simulation results presented herein.

- Single slope barrier installations that exceed either one of the above-mentioned slope and slump thresholds should not be considered MASH TL-3 compliant without further testing. It would be sufficient to only perform MASH Test 3-10 for such installations with the maximum slope and slump values.

It has been my pleasure to address your inquiry. Should you need more information or have further questions, please do not hesitate to call or email me.

Best regards,

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