Appendix B: Vehicle Dynamics Simulation Results

Vehicle dynamic analyses were undertaken for the three barrier types under each of the curve, shoulder, and barrier placement factors identified. This led to many tables and graphs depicting the vehicle to barrier interface under different road-section profiles performance. Table B-1 summarizes the vehicle to barrier interface when the barrier is placed at the edge of the shoulder. In the table, each of the three barrier types studied is represented in a set of columns for the selected curve radii and superelevations. The findings for the New Jersey Concrete barrier are shown in the blue shaded columns. The MGS W-beam barrier is similarly shown in the grey shaded columns and the G4(1S) W-Beam barrier in the green shaded columns. The rows reflect the range of shoulder width and slope conditions. Each cell in the table shows the minimum and maximum bumper heights that were computed by the VDA software for a vehicle departing the roadway with the corresponding curve features across a range of the likely speeds and angles [namely, speed of 90, 100, 100, 110 km/h and angles of 20, 25, and 30 degrees.] The variations that might be expected in maximum and minimum bumper heights can be noted in the variations across the table.

The effectiveness of a barrier is measured, in part, by the effective interface area each provides. The results map the effective interface areas for each of the three barriers, namely:

- New Jersey concrete barrier - 0.0 to 27.5 inches
- MGS W-beam barrier - 21.0 to 28.75 inches
- G4-1S W-beam barrier – 17.75 to 25.5 inches

The table also indicates where the maximum and minimum barrier heights do not meet these requirements by showing the computed values in bold red. It can be noted that the New Jersey barrier does not have any values in red indicating that the 32-inch height versions of it provides sufficient interface area to prevent override or underride for the range of speed and impact angles noted. The W-beam designs considered here reflect barrier options that have different rail heights and consequently different interface area. The MGS barrier has a rail height of 31 inches while the G4(1S) 27.75 inches. It can be noted that this leads to several cases where the minimum requirements are exceeded by the red/bold values. For the MGS barrier these are all related to the minimums that indicated the risk of underride and wheel snagging effects that might be expected with a greater distance between the ground and the lower side of the rail. This suggests that there needs to be a focus on the underride issues for the MGS barrier. Conversely, the G4(1S) barrier having a lower top rail height is more prone to overrides for the range of CSRS and barrier placement conditions considered. This suggests that overrides be the focus in analyses of the G4(1S) barrier.

In an effort to further investigate the VDA results other sets of graphs were produced. These graphs are generated for each curvature and superelevation combination. Each graph includes the differences in interface points for all shoulder widths (4, 8, and 12 feet) and all shoulder angles (0, 3, 6, and 8%) simulated. Figure B-1 is a typical graph showing the maximum bumper height at impact for all speeds for all angles analyzed. Similar plots are generated for the bumper minimum height at impact. The cross section of the barrier face (in this case the W-shape) is noted on the right side of the graph. The “humps” on the rail define the critical heights when the bumper interacts with the rail. It is assumed (only for VDA analyses) that if, at the initial moment of impact, the bumper interfaced at a point above the maximum critical height then the vehicle is likely to override the barrier. If it was below this point, there was likely to be good capture and redirection of the vehicle by the barrier. Conversely, if at the initial moment of impact, the bumper interfaced at a point below the minimum critical height then the vehicle is likely to push the rail upward and snag with the posts. If it hits above this point, there was likely to be good capture and redirection of the vehicle by the barrier.

The VDA generated maximum and minimum bumper heights at impact for each CSRS case and shoulders with varying widths and angles. Figure B-2 shows sample results for the W-beam barriers (G4(1S) on the right and MGS on the left) installed on a 614 ft radius curve with a 12% superelevation. The blue, red, green, and black lines connecting the data points show the bumper interface heights computed by VDA for the four angles and the three widths analyzed. It can be noted that for 4 and 8 ft shoulders, there is a risk of override for the G4(1S) with the 6% and 8% slope (blue and green lines) as the bumper height is above the Maximum Critical Height (G4(1S) upper hump). Similarly, for 4 ft shoulder, the graph shows that there is a risk of underride for the MGS with the 3%, 6% and 8% slope (blue, green, and red lines) as the bumper height is below the Minimum Critical Height (MGS lower hump).

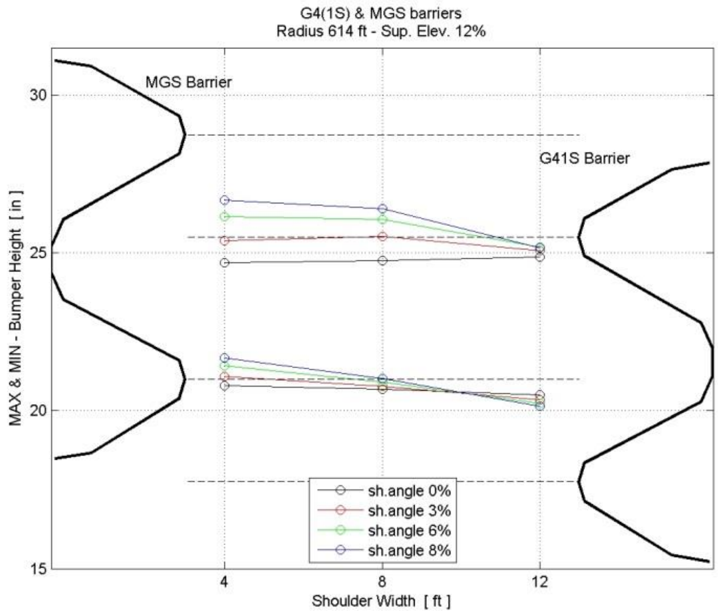

Figure B-1 – Example Vehicle to Barrier Interface Analyses for W-beam Barrier

A similar analysis is depicted for the New Jersey concrete barrier in Figure B-2. This shape may be considered the "worst case" for all concrete barriers because it has the greatest face slope of concrete barriers in common use. The Maximum Critical Height reflects the point near the top of the barrier at 27.5 inches that is considered critical. The bumper heights computed in the VDA are noted for the varying shoulder widths and slopes. It is readily noted that there is no risk of override indicated for any of the shoulder configurations shown. The full-set of results from the difference CSRS profiles are shown in Figure B-3 for the W-beam barrier and in Figure B-4 for NJ-shape barrier.

The VDA results were also used to generate 3D plots visualizing the effects of the different parameters investigated (curvature, shoulder width, and shoulder angle) on the vehicle to barrier interface. Figure B-5 shows the Maximum bumper height of the vehicle as it contacts the barrier and Figure B-6 shows the Minimum vehicle bumper height for various speeds and angles simulated. Several observations where extracted from these figures and used to study the effects of the varied parameters on the bumper height and consequently the vehicle to barrier interface. As an example, looking at the 615 ft curvature / 12 % superelevation 3D plot in Figure B5, it can be noted that the bumper height increases with increased shoulder angle. This may lead to the observation that increased shoulder angle would lead to improved interface for the G41S since increased bumper height would reduce the likelihood of vehicle overriding the barrier. Conversely, it can be reasoned that increased shoulder angle would lead to worsened interface for the MGS since increased bumper height would increase the chances of vehicle underriding the barrier and snagging with the posts. These types of observations were used to minimize the number of FE simulations ran.

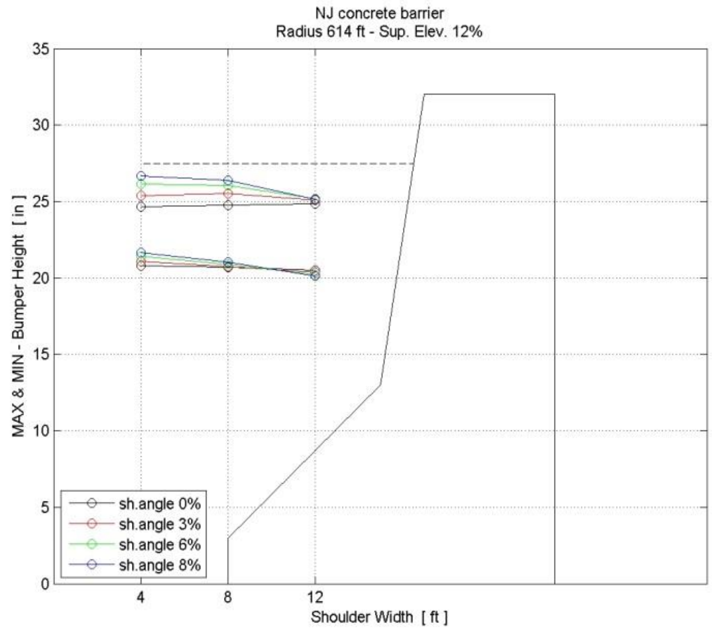

Figure B-2 – Example Vehicle to Barrier Interface Analyses for W-beam Barrier

The key findings from the VDA are:

- There are no apparent override or underride issues for New Jersey concrete barriers with critical heights of 27.5 inches for the CSRS, barrier placement, and impact conditions considered.
- The increased space between the rail and ground that results from the rail height of the MGS barrier shows underride issues for some cases for the CSRS, shoulder configuration, and impact conditions considered.
- The lower rail height of the G4-1S W-beam barrier shows potentials for override for some cases for the CSRS, shoulder configuration, and impact conditions considered.

Critical cases, based on these VDA graphs and results, were identified for investigation using finite element analyses (where the impact between the vehicle and barrier is simulated).

Table B-1 –Vehicle to Barrier Interface Summary Table

			NJ Concrete Barrier						MGS W-beam Barrier						G4(1S) W-beam barrier					
	Curvature Radius (ft)		614	2130	758	2670	833	3050	614	2130	758	2670	833	3050	614	2130	758	2670	833	3050
	Super Elevation (%)		12	12	8	8	6	6	12	12	8	8	6	6	12	12	8	8	6	6
4 ft Shoulder Width	Shoulder Angle 0%	Min (in)	20.80	22.05	20.79	21.76	20.75	21.59	**20.80**	22.05	**20.79**	21.76	**20.75**	21.59	20.80	22.05	20.79	21.76	20.75	21.59
		Max (in)	24.68	25.39	24.55	25.13	24.51	24.98	24.68	25.39	24.55	25.13	24.51	24.98	24.68	25.39	24.55	25.13	24.51	24.98
	Shoulder Angle 3%	Min (in)	21.08	22.11	21.07	21.83	21.04	21.62	21.08	22.11	21.07	21.83	21.04	21.62	21.08	22.11	21.07	21.83	21.04	21.62
		Max (in)	25.39	25.87	25.27	25.60	25.23	25.46	25.39	25.87	25.27	25.60	25.23	25.46	25.39	**25.87**	25.27	**25.60**	25.23	25.46
	Shoulder Angle 6%	Min (in)	21.42	22.18	21.39	21.93	21.38	21.72	21.42	22.18	21.39	21.93	21.38	21.72	21.42	22.18	21.39	21.93	21.38	21.72
		Max (in)	26.15	26.37	26.04	26.10	25.99	25.92	26.15	26.37	26.04	26.10	25.99	25.92	**26.15**	**26.37**	**26.04**	**26.10**	**25.99**	**25.92**
	Shoulder Angle 8%	Min (in)	21.67	22.57	21.63	22.10	21.61	21.85	21.67	22.57	21.63	22.10	21.61	21.85	21.67	22.57	21.63	22.10	21.61	21.85
		Max (in)	26.68	26.72	26.58	26.42	26.53	26.24	26.68	26.72	26.58	26.42	26.53	26.24	**26.68**	**26.72**	**26.58**	**26.42**	**26.53**	**26.24**
8 ft Shoulder Width	Shoulder Angle 0%	Min (in)	20.69	22.01	20.67	21.70	20.64	21.54	**20.69**	22.01	**20.67**	21.70	**20.64**	21.54	20.69	22.01	20.67	21.70	20.64	21.54
		Max (in)	24.76	25.46	24.64	25.20	24.59	25.07	24.76	25.46	24.64	25.20	24.59	25.07	24.76	25.46	24.64	25.20	24.59	25.07
	Shoulder Angle 3%	Min (in)	20.77	21.79	20.75	21.49	20.72	21.28	**20.77**	21.79	**20.75**	21.49	**20.72**	21.28	20.77	21.79	20.75	21.49	20.72	21.28
		Max (in)	25.53	25.86	25.37	25.57	25.30	25.39	25.53	25.86	25.37	25.57	25.30	25.39	25.53	**25.86**	25.37	**25.57**	25.30	25.39
	Shoulder Angle 6%	Min (in)	20.91	21.59	20.89	21.33	20.87	21.13	**20.91**	21.59	**20.89**	21.33	**20.87**	21.13	20.91	21.59	20.89	21.33	20.87	21.13
		Max (in)	26.06	26.06	25.94	25.77	25.88	25.58	26.06	26.06	25.94	25.77	25.88	25.58	**26.06**	**26.06**	**25.94**	**25.77**	**25.88**	**25.58**
	Shoulder Angle 8%	Min (in)	21.03	21.25	21.00	20.92	20.97	20.72	21.03	21.25	21.00	**20.92**	**20.97**	**20.72**	21.03	21.25	21.00	20.92	20.97	20.72
		Max (in)	26.40	26.17	26.24	25.84	26.19	25.65	26.40	26.17	26.24	25.84	26.19	25.65	**26.40**	**26.17**	**26.24**	**25.84**	**26.19**	**25.65**
12 ft Shoulder Width	Shoulder Angle 0%	Min (in)	20.51	21.93	20.48	21.61	20.44	21.43	**20.51**	21.93	**20.48**	21.61	**20.44**	21.43	20.51	21.93	20.48	21.61	20.44	21.43
		Max (in)	24.86	25.56	24.73	25.29	24.65	25.15	24.86	25.56	24.73	25.29	24.65	25.15	24.86	**25.56**	24.73	25.29	24.65	25.15
	Shoulder Angle 3%	Min (in)	20.35	21.64	20.34	21.30	20.30	21.08	**20.35**	21.64	**20.34**	21.30	**20.30**	21.08	20.35	21.64	20.34	21.30	20.30	21.08
		Max (in)	25.07	25.41	24.95	25.12	24.88	24.96	25.07	25.41	24.95	25.12	24.88	24.96	25.07	25.41	24.95	25.12	24.88	24.96
	Shoulder Angle 6%	Min (in)	20.23	21.40	20.23	21.02	20.20	20.80	**20.23**	21.40	**20.23**	21.02	**20.20**	**20.80**	20.23	21.40	20.23	21.02	20.20	20.80
		Max (in)	25.19	25.16	25.03	24.85	24.99	24.66	25.19	25.16	25.03	24.85	24.99	24.66	25.19	25.16	25.03	24.85	24.99	24.66
	Shoulder Angle 8%	Min (in)	20.15	21.26	20.17	20.87	20.14	20.63	**20.15**	21.26	**20.17**	**20.87**	**20.14**	**20.63**	20.15	21.26	20.17	20.87	20.14	20.63
		Max (in)	25.16	24.98	25.05	24.64	24.99	24.42	25.16	24.98	25.05	24.64	24.99	24.42	25.16	24.98	25.05	24.64	24.99	24.42

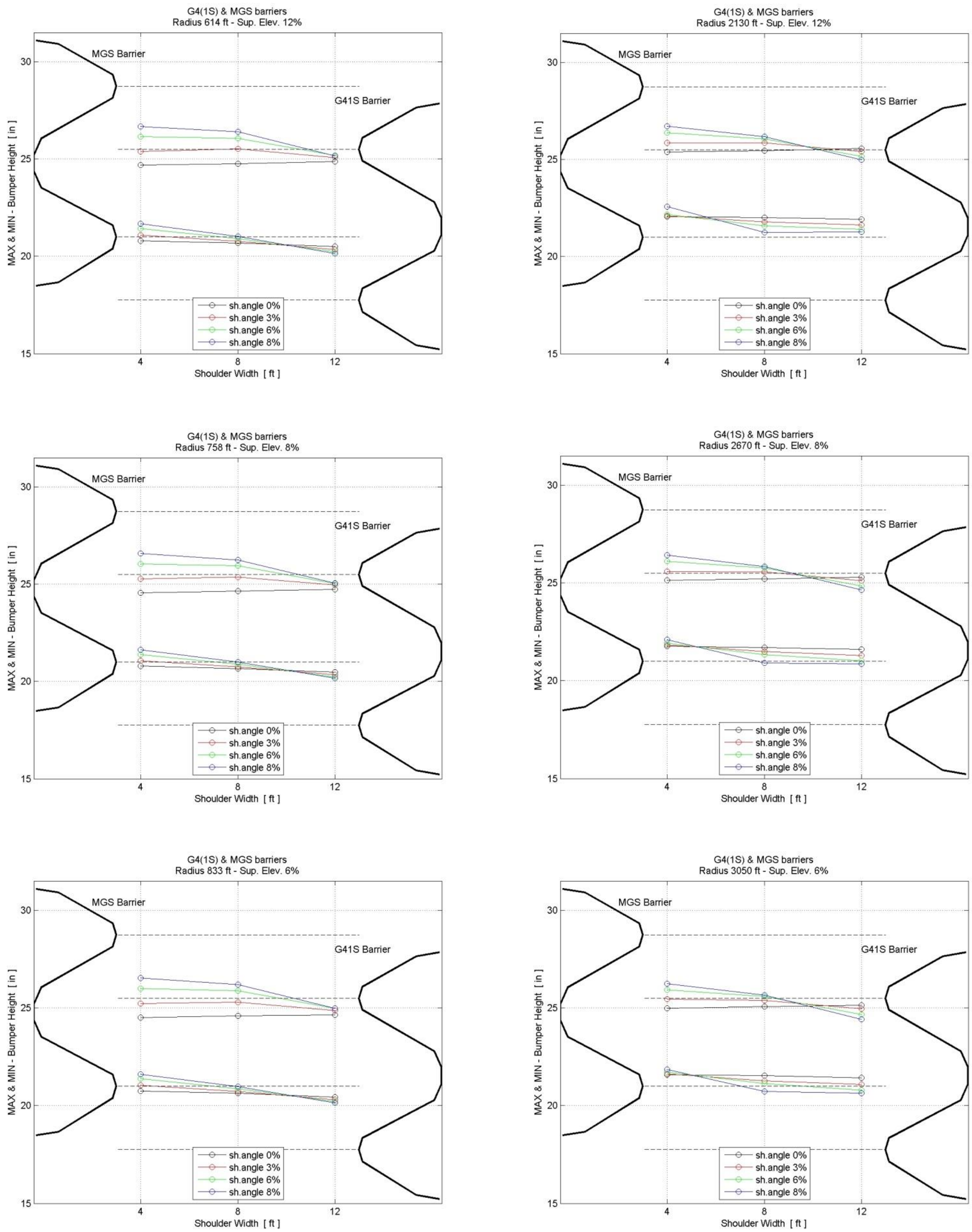

Figure B-3: Vehicle to Barrier Interface Analyses for W-beam Barriers for Different CSRS Profiles

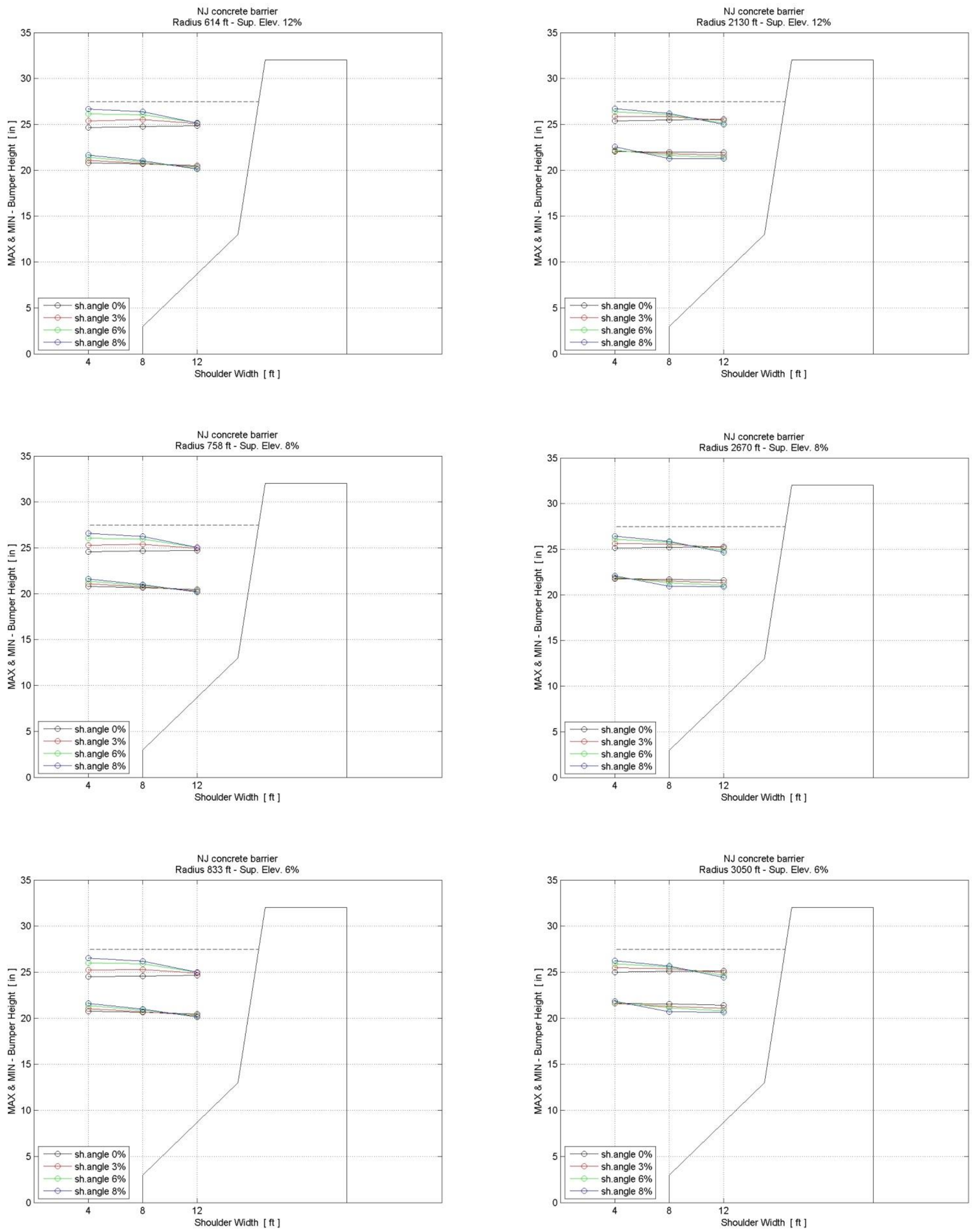

Figure B-4: Vehicle to Barrier Interface Analyses for NJ Barriers for Different CSRS Profiles

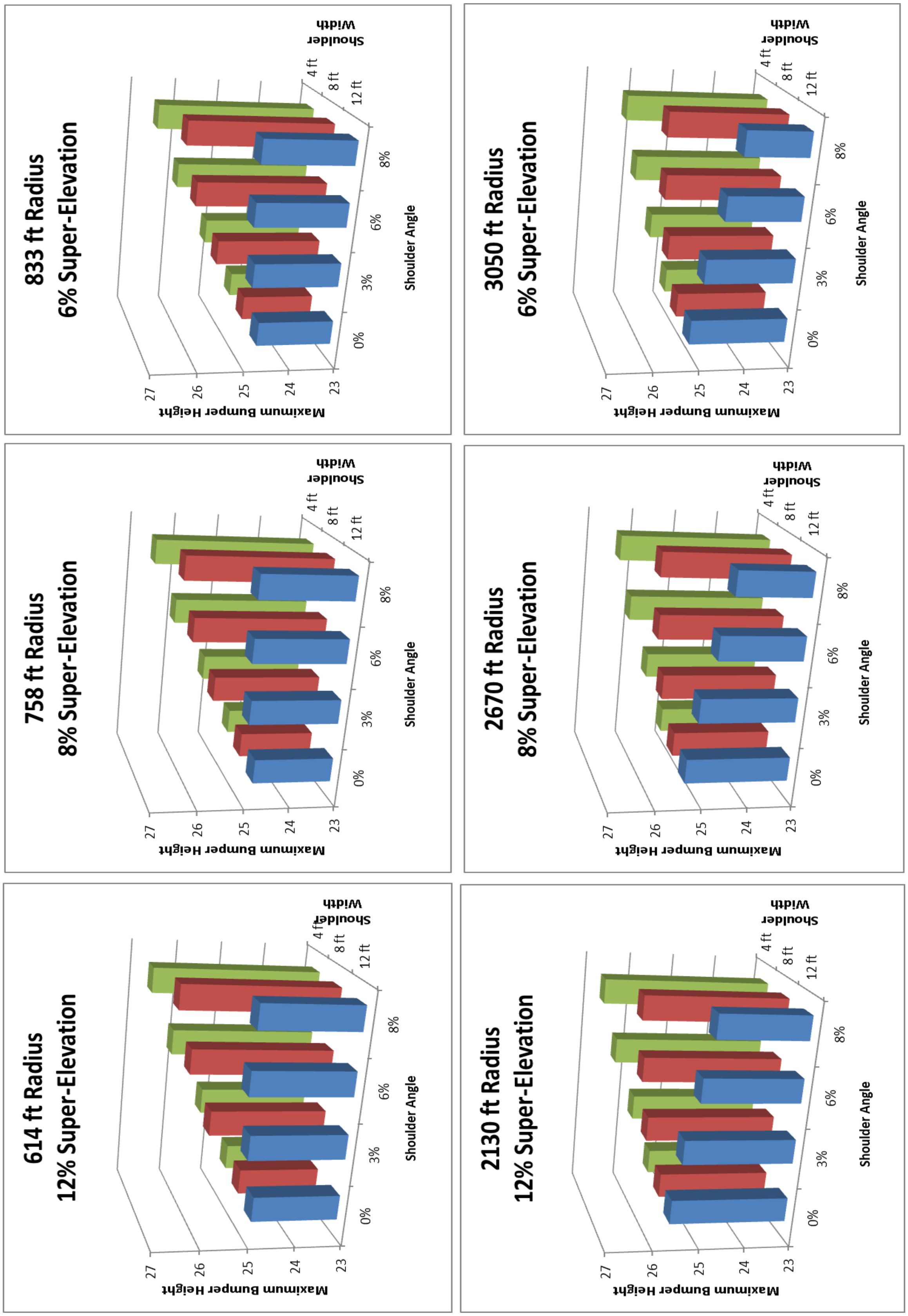

Figure B-5: 3D Plots of Vehicle Maximum Bumper Height at First Contact with Barrier

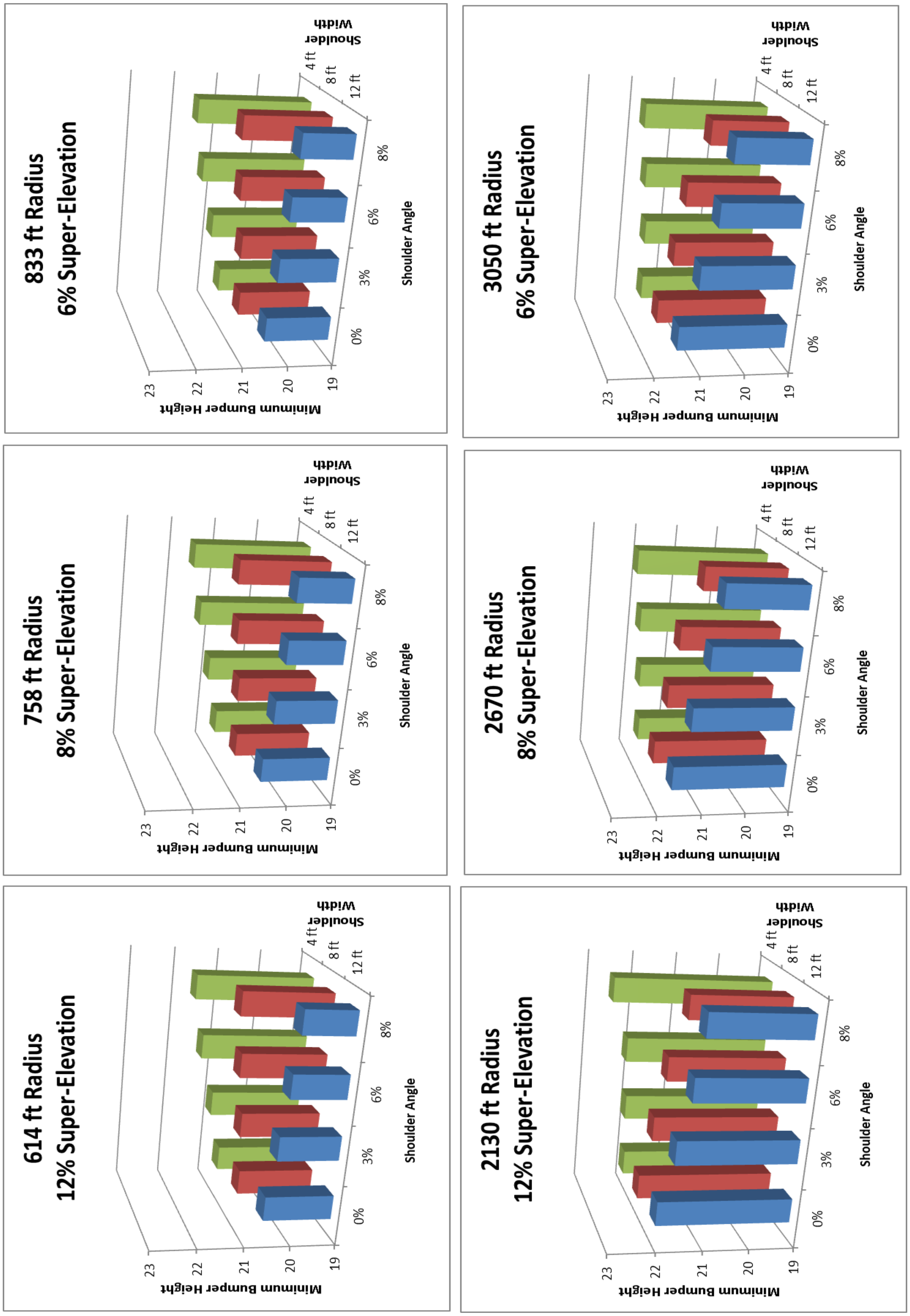

Figure B-6: 3D Plots of Vehicle Minimum Bumper Height at First Contact with Barrier