HIGHWAY FACTORS GROUP CHAIRMAN'S FACTUAL REPORT

Mountain View, CA

HWY18FH011

(40 pages)

NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C.

HIGHWAY FACTORS GROUP CHAIRMAN'S FACTUAL REPORT

A. CRASH INFORMATION

Location:	Southbound US Highway 101 (US-101) south of North Shoreline Boulevard at the exit ramp transition to State Route 85 (SR-85), milepost 48.38, Santa Clara County, Mountain View, California.
Vehicle 1:	2017 Tesla Model X
Vehicle 2:	2010 Mazda 3
Vehicle 3:	2017 Audi A4
Date:	March 23, 2018
Time:	Approximately 9:27 a.m. PDST
NTSB #:	**HWY18FH011**

B. HIGHWAY FACTORS GROUP

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C. CRASH SUMMARY

For a summary of the crash, refer to the *Crash Summary Report* in the docket for this investigation.

D. DETAILS OF THE HIGHWAY FACTORS INVESTIGATION

- Section 1 provides prefatory information regarding the description, design, and measurements of the roadway environment.

- Section 2 documents the signing used to guide motorists on the approach to the interchange. Included in this section is an overview of the HOV preferential guide signage and findings from prior NTSB investigations regarding left exits.

- Section 3 documents the pavement markings used to guide motorists and the delineation of the highway gore area.

- Sections 4 and 5 examine weather, sun, speed limit and traffic metric information.

- Section 6 provides a description of the crash cushion at the US-101−State Route 85 interchange.

- Section 7 reviews the crash and maintenance history at the crash location and includes a discussion regarding delayed repairs of the crash cushion following prior accidents.

- Section 8 discusses the response and reporting of damage to state property.

- Section 9 provides an overview of Caltrans maintenance of traffic safety devices.

1. Prefatory Data

The crash occurred at milepost 48.38 on US Highway 101 (US-101) southbound in the gore area that separates the left high-occupancy-vehicle (HOV) exit only lane (flyover exit) to California State Route 85 (SR-85) southbound from the southbound US 101 HOV lane.[1] The highway is operated and maintained by the California Department of Transportation (Caltrans). US-101 is designated as a north-south roadway but aligned in a northwest-southeast direction at the crash location.[2] Figure 1A illustrates the crash location in Mountain View, Santa Clara County, California.

Figure 1A – Image of US-101 interchange at SR-85. (Source: Google Earth, image date March 28, 2018)

The description of US-101 southbound, south of North Shoreline Boulevard overcrossing, was based upon NTSB on scene observations and measurements taken by Caltrans / California Highway Patrol (CHP). As shown in figure 1B, at the US-101−State Route 85 interchange, the highway consists of:

- A single left exit HOV lane for SR-85 southbound (yellow arrow)[3]
- A single US-101 HOV lane (green arrow)
- Three conventional US-101 mainline lanes (red arrows)
- Two right exit conventional lanes for SR-85 southbound (blue arrows)

[1] A gore area is a triangular-shaped boundary created by white lines marking an area of pavement formed by the convergence or divergence of a mainline "channelizing" travel lane and an exit/entrance "channelizing" lane.
[2] The alignment angle of US-101 southbound at the crash location was about 117 degrees (E of N).
[3] The two HOV lanes were not active at the time of the crash. Active hours are from 5:00 a.m. to 9:00 a.m. and 3:00 p.m. to 7:00 p.m. (Monday – Friday).

A 630-foot-long gore with an unmarked inside area separates the left exit HOV lane from the US-101 HOV lane. The gore widens to about 17 feet at the point where a Smart Cushion Innovation (SCI) 100GM crash attenuator is in place, in advance of a 36-inch tall, California Type 60SC concrete median barrier.[4] Crash attenuators (crash cushions) are devices intended to reduce damage to structures, vehicles and motorists from a collision by absorbing the colliding vehicle's kinetic energy.

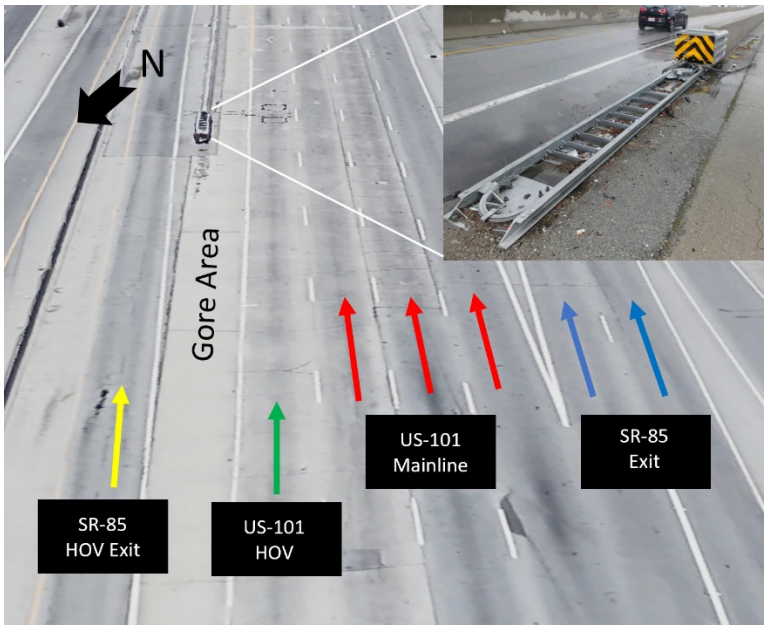

Figure 1B – Depiction of travel lanes and gore area at US-101–State Route 85 interchange. The crash cushion was damaged on March 12, 2018 and had not been repaired at the time of the crash. (Source: Google Earth, image date March 28, 2018. The inset photo was taken by Caltrans on March 20, 2018 – 3 days before the crash)

The southbound and northbound lanes were separated by paved median shoulders and a 36-inch-tall, California Type 60SC concrete median barrier.[5] The width of the traffic lanes varied between about 11.5 to 12.9 feet. A cross section profile of US-101 in the vicinity of the gore area is depicted in figure 1C. The roadway surface was dry at the time of the crash and paved with both asphalt concrete and portland cement concrete in various lanes.

[4] The SCI1000 GM impact attenuator is manufactured and marketed by Work Area Protection Corporation. On the date of the crash, the crash cushion was non-operational due to prior damage sustained in a crash on March 12, 2018.

[5] The barrier is crash tested to the requirements of Test Level 3 found in National Cooperative Highway Research Program Report 350 (NCHRP 350) and the American Association of State and Highway Transportation Officials (AAHSTO) Manual for Assessing Safety Hardware (MASH).

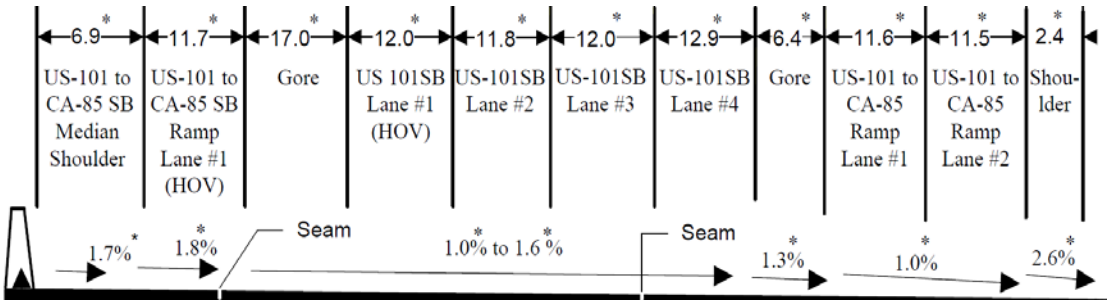

Figure 1C – Cross section of US-101− State Route 85 interchange in the vicinity of milepost 48.38. Measurements denoted with asterisks are approximate and based upon survey data collected by the CHP and Caltrans.

2. Traffic Controls and Signage

This section of the report documents the signage used to guide motorists on the approach to the interchange. The overhead guide signage in advance of the US-101− State Route 85 interchange were installed prior to 2008. NTSB completed a drive through of the crash location on March 27, 2018, at about 9:30 a.m. to examine the signage and roadway markings.[6] Additionally, Google Maps Street View captured imagery of the crash location on March 28, 2018. NTSB investigators reviewed the imagery captured by Google and determined that the aerial and street view images reflect the highway signage and roadway pavement markings which were present at the time of the crash. Figures 2A – 2D depict several of the signs that guide motorists on the approach to the interchange.[7]

[6] See Highway Attachment 1, Video Drive Through of Crash Scene on March 27, 2018.
[7] Refer to the video drive through and Google Maps Street View imagery of the crash location on March 28, 2018 to see additional signage and environmental conditions.

Figure 2A – This guide sign was in the median of US-101 southbound at milepost 48.98 about 0.60 miles north of the crash location (Source: Google Maps Street View image from March 28, 2018).

Figure 2B – This guide sign was in the median of US-101 southbound at milepost 48.67 about 0.29 miles north of the crash location (Source: Google Maps Street View image from March 28, 2018).

Figure 2C – This guide sign was attached to the north edge of the North Shoreline Boulevard overcrossing at milepost 48.61 about 0.23 miles north of the crash location (Source: Google Maps Street view image from March 28, 2018).

Figure 2D – These guide signs extend across the southbound US-101 travel lanes and were located about 460 feet north of the previously damaged crash cushion (Source: Google Maps Street View image from March 28, 2018).[8]

2.1 HOV Preferential Guide Signage

As a result of an NTSB investigation of a motorcoach crash in Atlanta, Georgia, in which a bus driver mistook a left exit lane for an HOV through lane, resulting in seven fatalities, the NTSB issued two recommendations to the Federal Highway Administration (FHWA) pertaining to left exit signs.[9] Safety Recommendations H-08-3 and -7 requested that FHWA amend the *Manual on Uniform Traffic Control Devices for Streets and Highways* (*MUTCD*) to require that left exit signs, particularly at left HOV exits, include a "LEFT" plaque atop.

The FHWA acknowledged that left-side exits, in general, tend to violate driver expectations because of their infrequency. [10] In 2009, the FHWA revised the *MUTCD* and included new standards pertaining to left exit and preferential lane signage. The compliance date for the ruling was December 21, 2014. As shown in the left image of figure 2E, the sign for the left exit HOV lane for SR-85 was not in compliance with the *MUTCD* standard for left exit plaques; the "LEFT" plaque should have been added to the top of the sign by December 21, 2014.[11] Figure 2F is a graphic from the California *MUTCD* depicting an example of advance guide signs and exit direction signs at a left HOV exit.

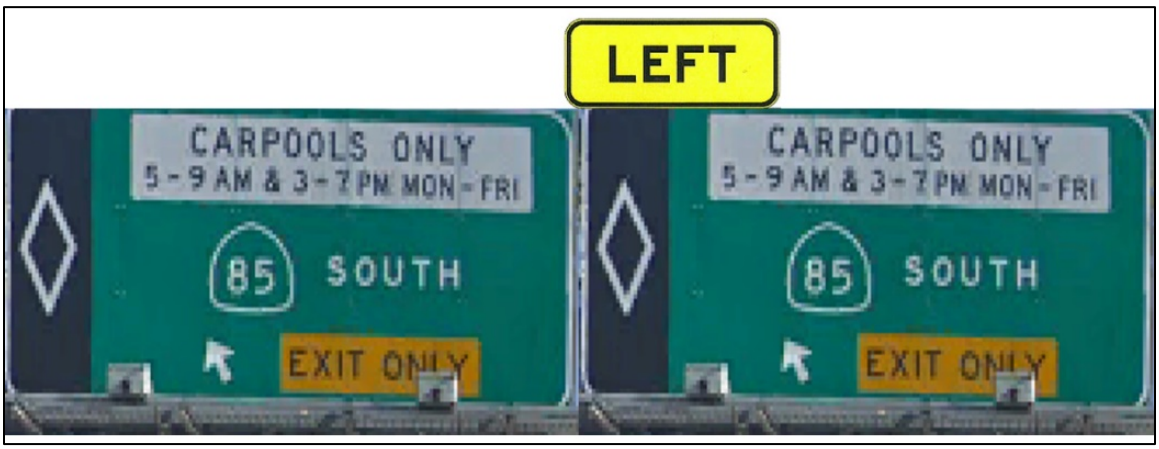

Figure 2E – Sign for left exit HOV lane at crash location (left) and example of compliant sign with required "LEFT" plaque (right).

[8] The orange "Road Work Ahead" signs were from a prior work project completed earlier in 2018. The area of the crash was not an active work zone at the time of the crash.
[9] NTSB 2008. *Motorcoach Override of Elevated Exit Ramp, Interstate 75, Atlanta, Georgia, March 2, 2017*, NTSB/HAR-08/01. Washington, DC: NTSB.
[10] See Highway Attachment 2, FHWA 2007 Guidance Memo on Preferential Lane Traffic Control Devices
[11] Guide signs depicted in figures 2A and 2B were also out of compliance with the MUTCD requirements pertaining to left exit plaques. The fact that the signs were out of compliance does not mean that this condition contributed to the cause of the crash.

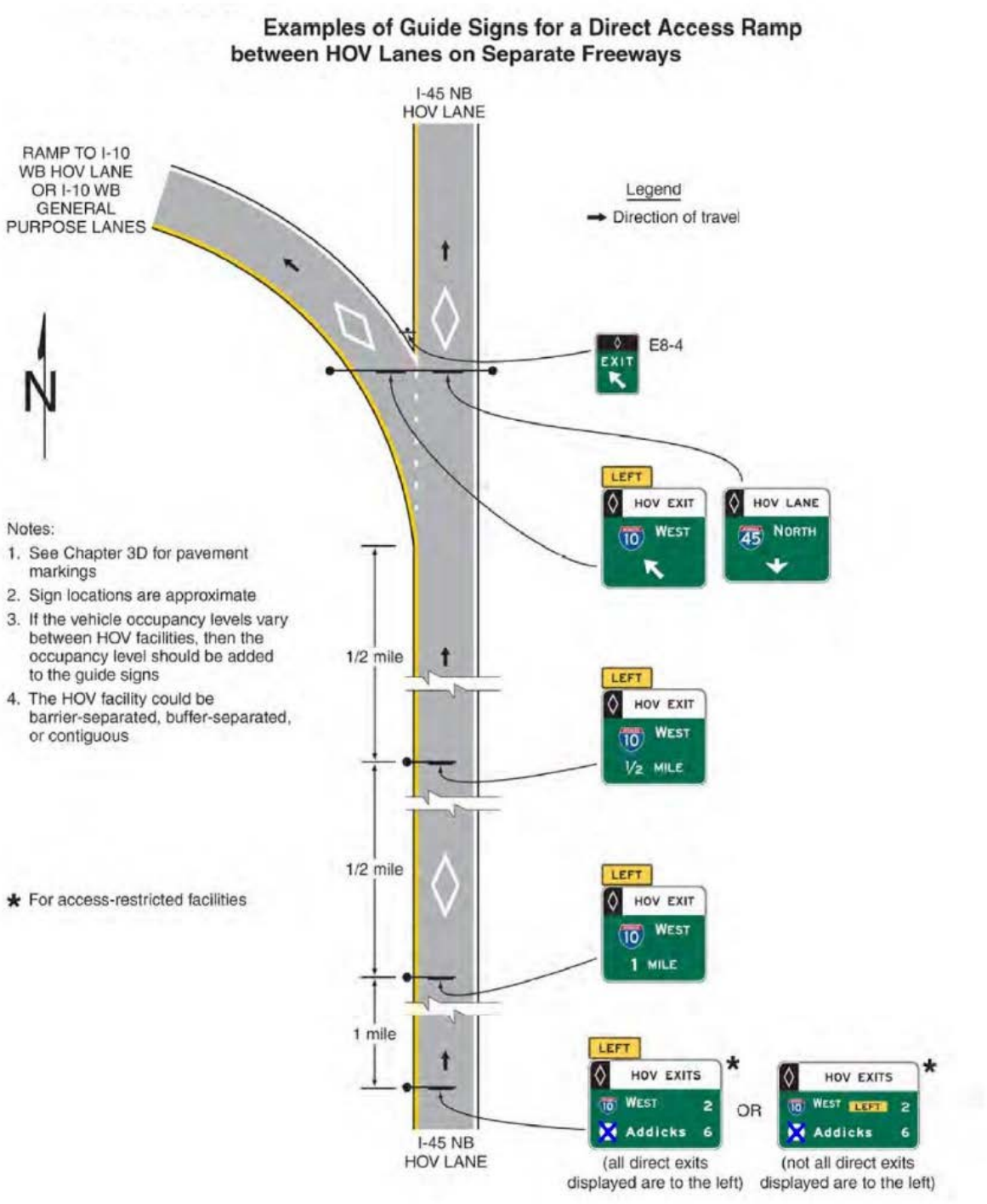

Figure 2F – Graphic from the California *MUTCD* showing an example of advance guide signs and exit direction signs at a left HOV exit.

On January 19, 2016, a motorcoach operated by Greyhound Lines, Inc., was traveling north on US-101 in San Jose, California. At the US-101 and SR-85 interchange, the bus moved left and entered a 990-foot-long gore area that separated the US-101 lanes from the left HOV lane for SR-85. The bus driver maintained the vehicle's path through the gore and collided with the crash attenuator and the concrete barrier. As a result of the crash, two passengers were ejected and died, and the driver and 13 passengers were injured.[12]

As part of the investigation of the San Jose fatal motorcoach crash, the NTSB concluded that "had the sign for the left exit HOV lane for SR-85 been in compliance with the *MUTCD*, it would have provided the bus driver with improved traffic guidance and may have prevented the crash." The NTSB issued Safety Recommendation H-17-5 to Caltrans recommending the agency: "Add the left exit plaque to the left exit sign at the crash location and to all left exit guide signs on California highways, as required by the Federal Highway Administration."[13]

[12] See Highway Attachment 3, *Motorcoach Collision with Crash Attenuator in Gore Area, US Highway 101, San Jose, California, January 19, 2016*, NTSB/HAR-17/01. Washington, DC: NTSB.

[13] The safety recommendation letter (Highway Attachment 4) was sent to the Director of Caltrans on April 18, 2017. The letter requested a response within 90 days detailing the actions taken or intended. As of June 30, 2019, the NTSB has received no correspondence in response to the recommendation.

3. Roadway Pavement Marking

This section of the report documents the pavement markings used to guide motorists at the interchange.[14] As indicated earlier, there were seven lanes of travel at the crash location; a left exit HOV lane for transition to SR-85 southbound, a single HOV lane for continued travel on US-101, three US-101 mainline lanes, and two right exit lanes for SR-85 southbound. Since the involved passenger vehicle (2017 Tesla Model X P100D) was traveling in the second lane from the left (US-101 HOV lane), the following description will focus on the roadway pavement markings leading to the gore area and the condition/delineation of marking in this area.

Roadway delineation of the left exit HOV lane for SR-85 southbound formed about 1,540 feet from the crash cushion. The exit lane, the gore area, and the US-101 HOV lane were delineated as follows:

- 1,540 feet from the crash cushion: standard 4-inch wide painted broken white lane lines separating the two left HOV lanes transition to 8-inch wide painted broken white lane drop markings.[15] The lane drop pavement markings continue for about 600 feet and provide information to motorists that the leftmost HOV lane is not a through lane and exits at the interchange ahead (see figure 3A and 3B).

- 940 feet from the crash cushion: the lane drop markings transition to an 8-inch wide solid white line.[16] The solid white line continues for about 310 feet until it reaches the apex (bifurcation) of the gore (see figure 3D).

- 630 feet from the crash cushion: the solid white line bifurcated into two 8-inch white channelizing lines which formed a gore area. The neutral area (inside area) of the gore was not marked with optional diagonal cross-hatching or chevrons (see figure 3F).

[14] Refer to *California MUTCD* Chapter 3A for specific details regarding functions, widths, and patterns of longitudinal pavement markings.
[15] Per guidance in *California MUTCD* Section 3B.04, "lane drop markings used in advance of lane drops at freeway and expressway exit ramps should begin at least ½ mile in advance of the theoretical gore." The lane drop markings at the crash location did not follow this guidance as the markings began 910 feet from the theoretical gore.
[16] Per *California MUTCD* Section 3.A.06, the function of a solid white line is to discourage or prohibit crossing (depending on the specific application).

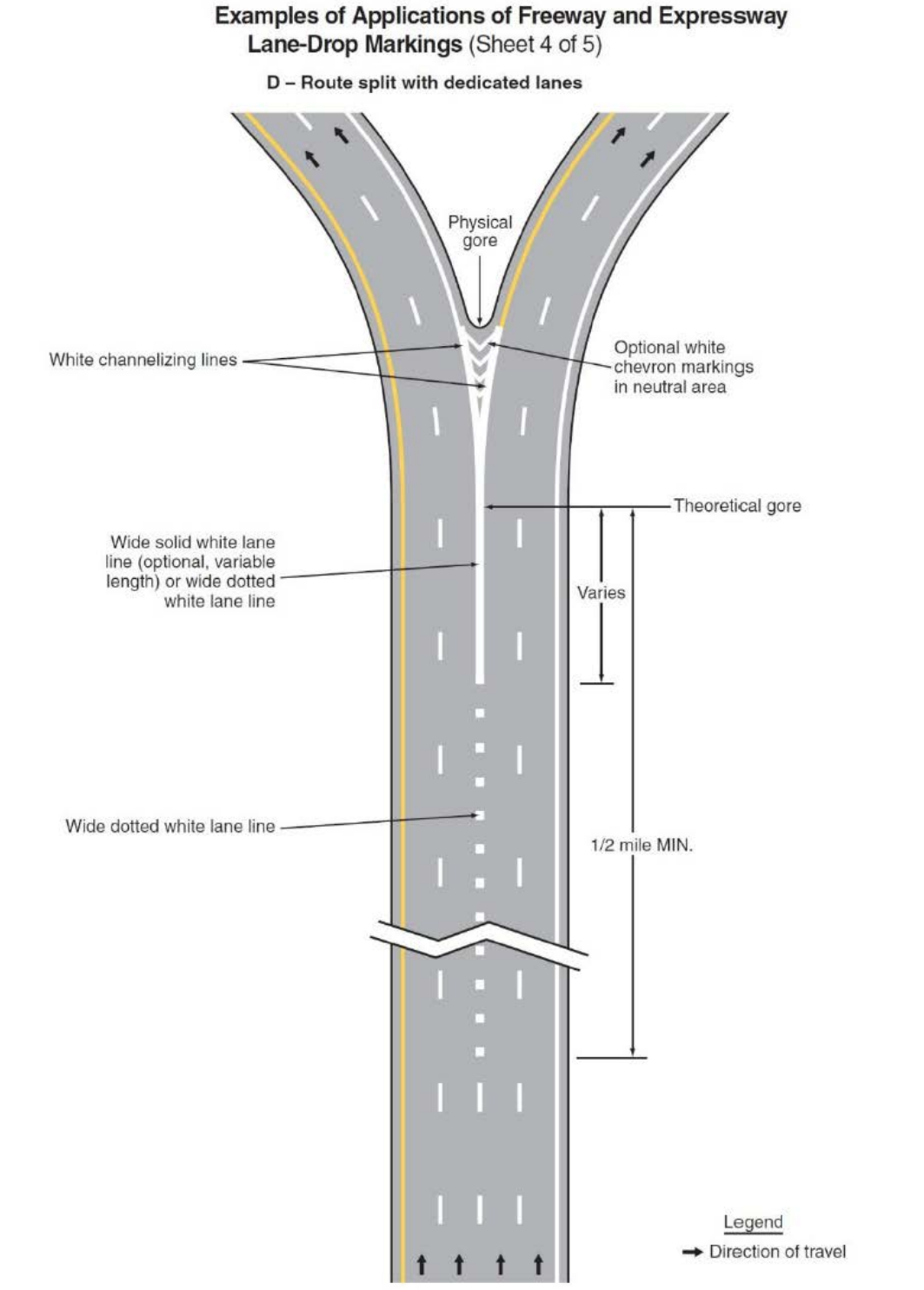

Figure 3A – This graphic is from the FHWA *MUTCD*. The wide dotted white lane lines (lane drop markings) began 910 feet from the beginning of the theoretical gore. Additionally, the optional white chevrons shown were not present at the crash site.

3.1 Visual Inspection of Roadway Markings

NTSB investigators conducted a drive through of the scene and examined scene photographs to ascertain the condition of the roadway pavement markings. The drive through was completed on March 27, 2018 (four days after the crash) at about 9:30 a.m. to approximate the lighting conditions (sun position) present when the collision occurred. Figures 3B – 3G below are still images from the drive through video and depict the condition and visibility of the pavement markings.

Figure 3B – Still image from video drive through at 1,540 feet from crash cushion. 8-inch wide lane drop markings (circled in red) separating the two left HOV lanes begin at this location.

Figure 3C – Still image from video drive through at 1,365 feet from crash cushion. The painted HOV diamond symbols (circled in red) designating the two left lanes were faded and partially obliterated.

Figure 3D – Still image from video drive through at 950 feet from crash cushion. The beginning of the 8-inch wide solid white line can be seen in this image. Portions of the white line are faded with paint obliterated.

Figure 3E – Still image from video drive through at 685 feet from crash cushion. During the drive through the 8-inch wide solid white channelizing line (designated with red arrows) marking the left side of the gore area was the most prominent and visible.

Figure 3F – Still image from video drive through at 630 feet from crash cushion. The 8-inch wide solid white channelizing line marking the left side of the gore area was the most prominent and visible.

Figure 3G – Still image from video drive through at 390 feet from crash cushion.

3.2 Gore Area Delineation

The inside area of the gore was not marked with optional diagonal cross-hatching or chevrons. Section 3B.24 of the California *MUTCD* states: "Chevron and diagonal crosshatch markings may be used to discourage travel on certain paved areas, such as shoulders, gore areas, flush medians between solid double yellow center line markings or between white channelizing lines approaching obstructions in the roadway. . ." The *MUTCD* adds: "Diagonal and chevron markings should be used, when in the opinion of an engineer, it is necessary to add emphasis or to discourage vehicular travel upon a paint-formed roadway feature . . ."

During the investigation of the January 19, 2016, a motorcoach crash in San Jose, California, the NTSB determined that the absence of optional pavement markings in the neutral area of the gore contributed to inadequate traffic guidance which led to the bus driver's error in not following the correct path onto the left exit HOV lane. The NTSB issued Safety Recommendation H-17-6 to Caltrans recommending the agency: "delineate the neutral are of the gore at the crash site using the best traffic guidance practices, such as chevrons or diagonal cross-hatching." Additionally, the NTSB issued Safety Recommendation H-17-7 to Caltrans recommending the agency: "revise the California *MUTCD* to change the delineation of left exit gores, such as by using chevrons or diagonal cross-hatching, from an optional to, at minimum, a recommended guidance practice."[17]

[17] The safety recommendation letter (Highway Attachment 4) was sent to the Director of Caltrans on April 18, 2017. The letter requested a response within 90 days detailing the actions taken or intended. As of June 30, 2019, the NTSB has received no correspondence in response to the recommendation.

The NTSB also issued Safety Recommendation H-17-2 to FHWA recommending the agency "revise the *MUTCD* to change the delineation of left exit gores, such as by using chevrons or diagonal cross-hatching from an optional to, at minimum, a recommended guidance practice."[18]

In July 2018, Caltrans added striping to the neutral area of the gore area at the crash location (see figure 3H).

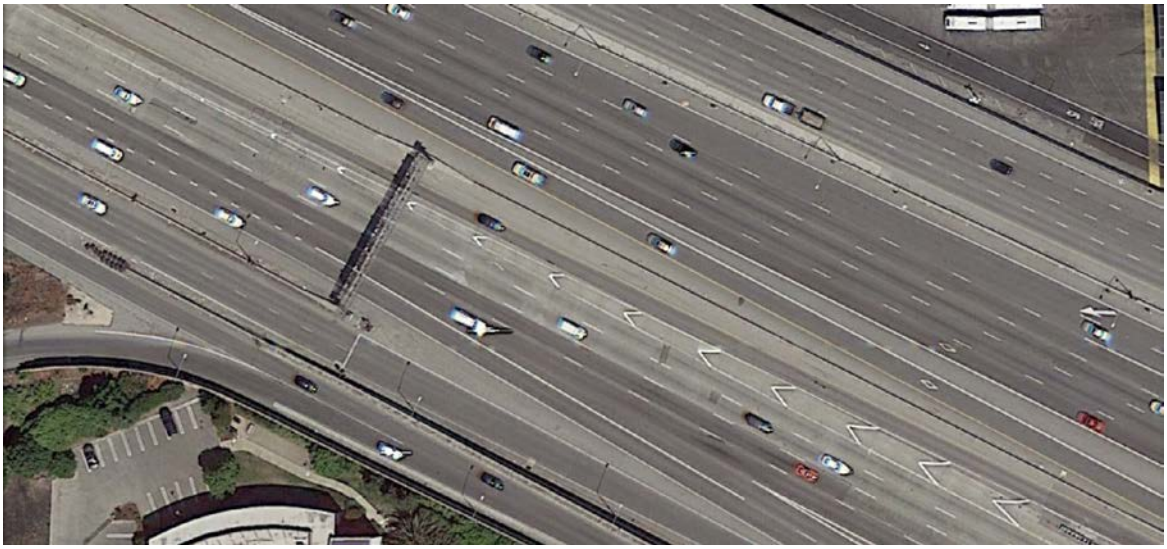

Figure 3H – Aerial view of US-101 at the crash location (Source: Google Earth, image date August 8, 2018).

4. Weather Data and Sun Information

4.1 Weather Data

The closest official NWS weather observations to the crash location was Moffett Federal Airfield (KNUQ), Mountain View, located 1.3 miles north of the scene.[19] Moffett Airfield observations at 8:56 a.m. (31 minutes prior to crash):

- Temperature: 49º F
- Dew point: 39º F
- Wind Direction and Speed: 9 mph from southeast
- Visibility: 10 statute miles

[18] FHWA has advised the NTSB that they are currently reviewing Part 3, Markings, of the *MUTCD* to determine the need to revise provisions pertaining to the marking of exit ramp gore areas. The recommendation is in an Open-Acceptable Response status.

[19] https://www.wunderground.com/history/daily/us/ca/moffett-nas/KNUQ/date/2018-3-23 accessed November 8, 2018

- Humidity: 69%
- Barometric pressure: 30.2 inches of mercury (Hg)

4.2 Sun Information

The United States Naval Observatory (USNO) website was consulted to obtain information regarding the position of the sun at the time of the crash.[20] USNO reported the following information for Mountain View, CA at 9:27 a.m.:

- Sun Altitude: 26.5 degrees (angle up from the horizon)[21]
- Sun Azimuth: 110.6 degrees (angle East of true North along the horizon)

5. Speed Limit and Traffic Metrics

The posted maximum speed limit on US-101 southbound is 65 mph. In 2016 the Average Annual Daily Traffic (AADT) for US-101 at milepost 48.103 (Mountain View, Junction Route 85 South) was 245,000 vehicles per day with a peak hourly total of 17,600 vehicles per hour.[22]

6. Crash Attenuator Information and Damage

The concrete barrier that separates the left exit HOV lane to SR-85 southbound and the pull through HOV lane on US-101 was shielded by a proprietary crash attenuator. The crash attenuator was a SCI SmartCushion® SCI100GM crash cushion manufactured and marketed by Work Area Protection Corporation.[23] The crash cushion uses a hydraulic cylinder and cable assembly to provide a variable stopping force based on speed.[24] The crash cushion has 7 collapsible bays that use tubular steel frames that support 10-gauge steel side panels. The crash cushion is a redirective, non-gating attenuator that consists of a base, supporting frames, a sled, side panels, a wire rope cable, sheaves, and a shock-arresting cylinder. The base is anchored to the mounting surface and provides support for the frames that are mounted on it. The crash cushion (sled) telescopes rearward upon frontal impact. The crash cushion attenuators are slightly tapered from front to rear. This allows the side panel sections to collapse over the next section without stress or damage. During collapse, the parts are designed to move freely past each other so that they do not become wedged during the impact. The dimensions are 21.5 feet long x 31.8 inches wide at the rear x 33.4 inches high (see figures 6A and 6B). The SCI SmartCushion® SCI100GM attenuator weighs approximately 3,450 pounds.

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[20] http://aa.usno.navy.mil/data/docs/AltAz.php accessed November 8, 2018

[21] The altitude and azimuth values are for the center of the apparent disk of the sun. Based upon the Tesla Model X headway angle (117 degrees E of N), the sun at the time of the crash was about 6 degrees to the left of the driver and Tesla forward facing camera's view and 26.5 degrees above the horizon.

[22] See Highway Attachment 5, 2016 Traffic Volumes on California State Highways. The volumes reflect total traffic for both directions of travel.

[23] See www.workareaprotection.com accessed November 13, 2018.

[24] See Highway Attachment 6 – SCI Smart Cushion Design and Installation Manual

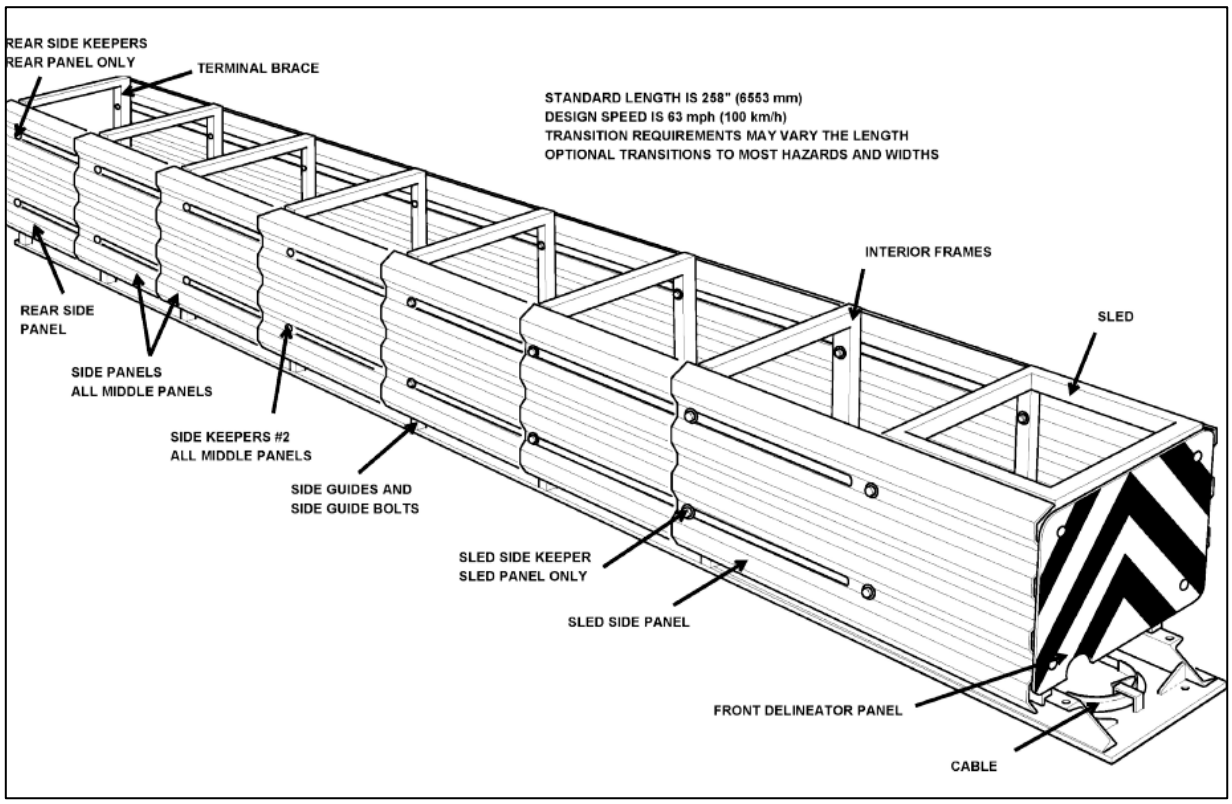


Figure 6A – Diagram depicting the components of the SCI SmartCushion® SCI100GM crash cushion.

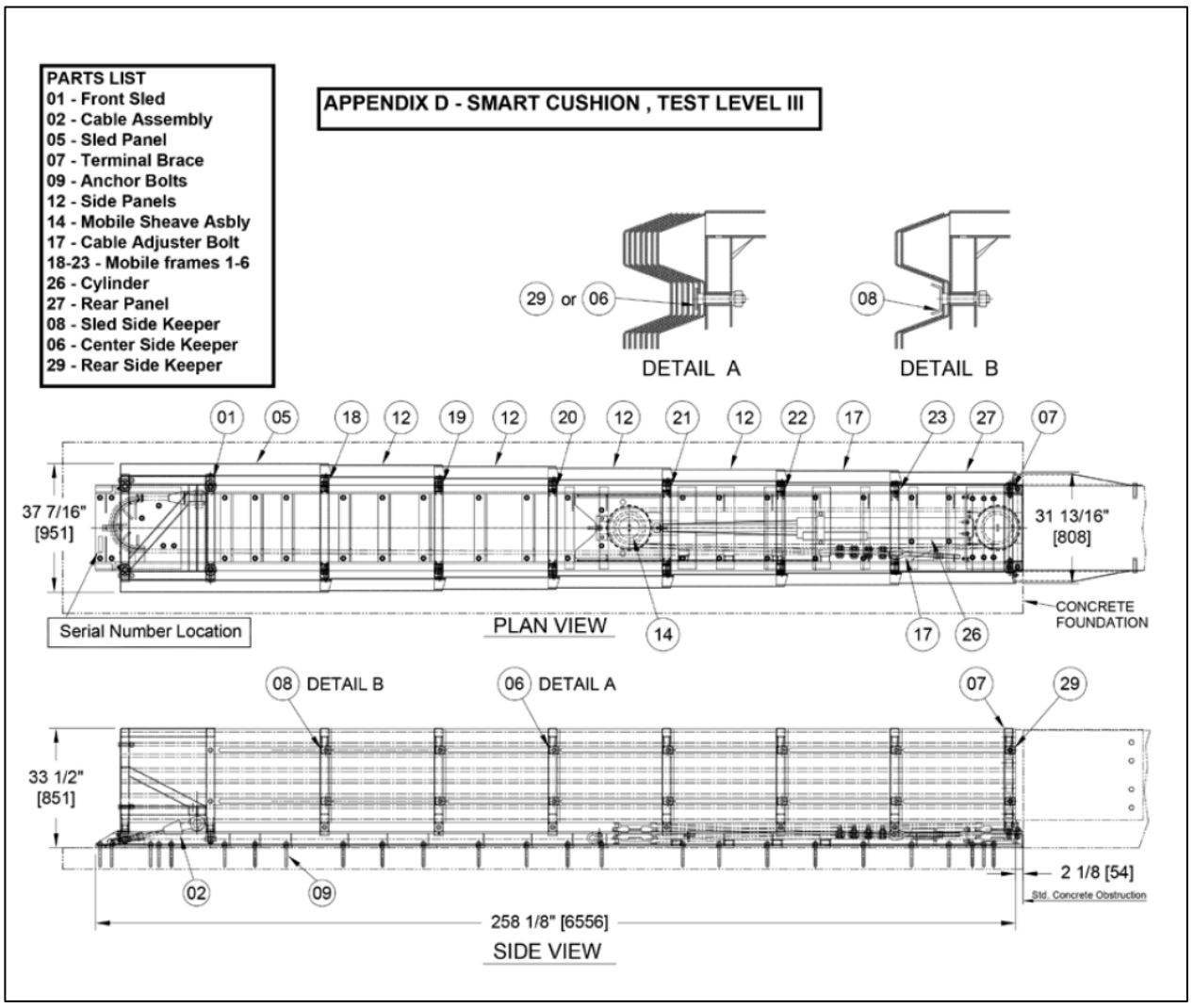


Figure 6B – Plan and side view schematic diagrams of the SCI SmartCushion® SCI100GM crash cushion.

Caltrans has installed the SCI SmartCushion® SCI100GM crash cushion at over 232 locations statewide.[25] Based upon collision experience, the approximate time to repair (reset) the attenuator is 15 to 30 minutes. The average repair cost for high impact locations is less than $100.

The SCI SmartCushion® SCI100GM crash cushion was tested to the MASH Test Level 3 criteria and was approved in the FHWA NCHRP 350 acceptance letter CC-85 and MASH acceptance letter CC-128 .[26] The letter of eligibility authorizes the use of the crash cushion on the National Highway System (NHS) as a Test Level 3 attenuator and makes the system eligible for reimbursement under the Federal-aid highway program.

[25] See Highway Attachment 7 – Severe Duty Crash Cushions Web Conference
[26] See Highway Attachment 8 – SCI Smart Cushion MASH Eligibility Letter

Following the crash, the crash cushion was fully compressed. The front delineator panel (with attached retroreflective object marker) and the sliding sled was compacted in an accordion-like manner over the seven collapsible bays to about 36 inches from the concrete median wall. Following the crash, Tesla Model X vehicle components were lodged inside the object marker and the hollow interior section of the crash cushion (see figures 6C and 6D).

Figure 6C – Postcrash picture of damaged crash attenuator with Tesla vehicle components lodged inside of the hollow interior section of the crash cushion.

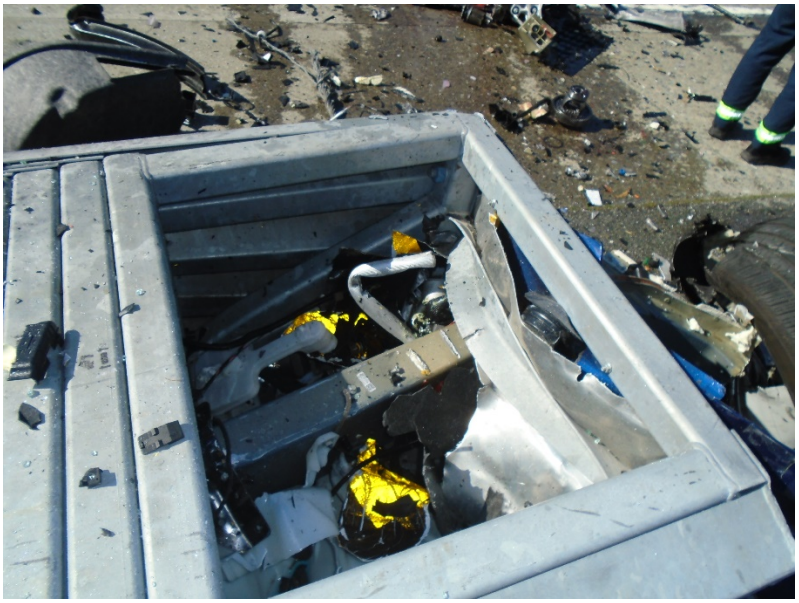


Figure 6D – Postcrash picture of damaged crash attenuator with Tesla vehicle components lodged inside of the hollow interior section of the crash cushion.

7. Crash and Maintenance History

As part of the NTSB's January 2016 investigation of a fatal motorcoach crash in San Jose, investigators collected information on maintenance performed on crash attenuators at all HOV left exits within Caltrans District 4.[27] Caltrans District 4 searched the Integrated Maintenance Management System (IMMS) database for maintenance performed on left HOV exit crash attenuators for the period from June 2006 to June 2016.[28] This review determined that the left exit attenuator at the crash location (US-101−State Route 85 interchange) was damaged/repaired more often than any other crash attenuator in Caltrans District 4 (see table 1).

Table 1 - Crash Attenuator Repairs at Left HOV Exits in Caltrans District 4 (06/2006 – 06/2016)

Location	City	County	Milepost	# of Repairs
US-101 S/B to SR-85 S/B	Mountain View	Santa Clara County	PM 48.385	9
US-101 N/B to SR-85 N/B	San Jose	Santa Clara County	PM 26.0	5
I-80 E/B to Richmond Pkwy	Pinole	Contra Costa County	PM 6.68	2
I-80 W/B to Cutting Blvd	Richmond	Contra Costa County	PM 2.191	1
I-880 S/B to SR-237 W/B	Milpitas	Santa Clara County	PM 8.784	1
I-80 W/B at Emeryville	Emeryville	Alameda County	PM 3.064	0
SR-237 E/B to I-880 N/B	Milpitas	Santa Clara County	PM 9.295	0
SR-85 N/B to US-101 N/B	Mountain View	Santa Clara County	PM 23.867	0
I-880 N/B to I-80 W/B	Oakland	Alameda County	PM 0.926R	0

[27] Caltrans District 4 is headquartered in Oakland, CA provides services to Sonoma, Napa, Solano, Marin, San Francisco, Contra Costa, Alameda, San Mateo, and Santa Clara counties.
[28] See Highway Attachment 9 – Caltrans District 4 Attenuator Repair Records for All HOV Left Exits

The traffic collision history was examined for US-101 southbound at the SR-85 interchange (milepost 48.38) for the three-year-period from March 23, 2015 to March 23, 2018. NTSB investigators reviewed information contained within the Caltrans Traffic Accident Surveillance and Analysis System (TSAS) and the CHP's Statewide Integrated Traffic Records System (SWITRS) to identify crashes in which the crash attenuator had been hit during the 3 years preceding the crash.

NTSB was able to identify six crashes prior to the March 23, 2018 accident in which a vehicle entered the gore area and collided with the crash attenuator.[29] Of the six crashes, one resulted in fatal injuries and four others resulted in injuries. In addition to the six prior crashes, the crash attenuator was hit again, two months after the subject crash, on May 20, 2018. Table 2 below summarizes the crashes between March 23, 2015 to May 20, 2018:

Table 2 - Summary of crashes at US-101−State Route 85 interchange involving impact with crash attenuator (03/23/2015 – 05/20/2018)

Date	Time	Report #	Fatal	Injuries	CHP Determined Cause
07/28/2015	11:25 p.m.	9330-2015-0194	0	1	Unsafe Turning Movement
09/29/2015	10:50 p.m.	9330-2015-0805	0	1	DUI (Alcohol) and Unsafe Turning Movement
11/14/2015	10:00 p.m.	9330-2015-3996	1	1	Unsafe Turning Movement
01/31/2016	10:50 a.m.	9330-2016-5193	0	2	DUI (Alcohol) and Unsafe Turning Movement
01/03/2017	7:40 p.m.	9330-2017-0017	0	0	Unsafe Turning Movement
03/12/2018	10:30 p.m.	9330-2018-0724	0	1	DUI (Alcohol) and Unsafe Turning Movement
05/20/2018	4:28 a.m.	9330-2018-1377	0	2	Unsafe Turning Movement

In examining the seven crashes in Table 2, in six of the seven crashes the involved-vehicle was initially traveling in the far left HOV exit lane to SR-85 southbound and turned right across the gore area and collided with the crash attenuator.

[29] See Highway Attachment 10 – Copies of Traffic Collision Reports

In addition to reviewing the collision history, NTSB also reviewed the Caltrans Integrated Maintenance Management System (IMMS) database for all work orders associated with repairs of the crash attenuator at the US-101−State Route 85 interchange (milepost 48.38) between March 23, 2015 to March 26, 2018.[30] Table 3 describes the work performed on the attenuator during this 3-year-period.

Table 3 - IMMS Work Order Reports of Repair/Replacement of Crash Attenuator

Date	Work Order #	IMMS Comments	Related Crash
08/18/2015	3703208	Needed to reset SMART Crash Cushion. Needed to get this fixed ASAP. Currently provides no protection. Created an emergency closure number: T101A from 2000 hours on 08/18/2015 to 0001 hours on 08/19/2015.	Possibly related to 07/28/15 crash. (TC Report #9330-2015-0194)
12/23/2015	3807796	Replaced damaged SMART Crash Cushion with new one S101 Carpool Connector to S85. TMC notification of damage 11/14/2015 at 2356 hours.	Related to 11/14/15 fatal crash. (TC Report #9330-2015-3996) See discussion regarding 11/14/15 fatal crash.
01/31/2016	3847208	Reset SMART Cushion Attenuator at S/B 101 and S/B 85 HOV connector.	Related to 01/31/16 crash. (TC Report 9330-2016-5193)
04/14/2017	4256817	Replacing totaled SMART Crash Cushion Attenuator. In a January 4, 2017 report by Ernesto Ramirez he advised "Smart Cushions completely demolished in CD." Made temp. repairs and will replace at a later date.	Related to 01/03/17 crash. (TC Report 9330-2017-0017)
03/26/2018	4607378	Replaced damaged SMART Crash Cushion that was not able to be reset at the gore point of South 101 carpool connector to S85 in Mt. View at PM 48.4.	Related to 03/12/18 crash and fatal Tesla crash on 03/23/18. (TC Report 9330-2018-0724) See discussion regarding 03/12/18 crash.

[30] See Highway Attachment 11 – Caltrans IMMS Work Order Reports

In reviewing maintenance records, it appears that in the two fatal crashes occurring on November 14, 2015, and on March 23, 2018, the crash attenuator was damaged during previous crashes and had not been repaired by Caltrans. These two crashes will be discussed in sections 7.1 and 7.2. After reviewing Caltrans maintenance records, NTSB investigators identified other examples of delayed repair of the crash cushion. Section 7.3 discusses an example of when the crash cushion was not repaired for over three months from January 2017 to April 2017.

7.1 Fatal Crash (November 14, 2015) CHP Traffic Collision Report #9330-2015-3996

On Saturday, November 14, 2015, at about 10:00 p.m., a 2008 Lexus RX350 SUV was operated by a 67-year-old male driver on US-101 southbound south of North Shoreline Boulevard.[31] The Lexus was traveling in the leftmost HOV exit lane to SR-85 southbound. The vehicle entered the gore area between the US-101 mainline lanes and collided with the crash attenuator. As a result of the crash, the driver died at Stanford University Medical Center in Palo Alto, California on November 15, 2015 at 5:15 a.m. The right front passenger also sustained injuries. Both occupants were wearing their lap/shoulder restraints at the time of the crash. The driver side front airbag, as well as the driver side knee bolster airbag, the driver side curtain airbag, the driver side seat airbag, and the passenger side front airbag all deployed.

NTSB investigators reviewed the circumstances of this crash and determined that the SCI SmartCushion® SCI100GM crash cushion at the location was non-operational at the time of the collision due to being compromised (compressed) in a prior collision. Additionally, the crash cushion was missing its black and yellow retroreflective object marker at the end of the attenuator. The precrash damaged condition of the crash cushion was not reported in the CHP Traffic Collision Report 9330-2015-3996. After the crash, the crash cushion was replaced on December 23, 2015 (39 days after the crash).

NTSB investigators made the determination that the crash cushion was in a damaged and collapsed condition prior to the November 14th crash based upon a review of Caltrans maintenance records, a review of Google Maps Street View imagery, and a review of photographs from the crash (see figures 7A and 7B). According to maintenance records, the crash cushion was repaired on August 18, 2015, and the next recorded maintenance was on December 23, 2015 when the crash cushion was replaced. Figures 7C – 7F depict images from Google Maps Street View of the crash cushion from September – December. All images depict the crash cushion being fully compressed and missing the retroreflective object marker during the months of October and November.

[31] See Highway Attachment 10 – Copies of Traffic Collision Reports

Figure 7A – Postcrash picture of 2008 Lexus SUV on November 14, 2015, after colliding with non-operational crash cushion on US-101 southbound at the exit ramp transition to SR-85.

Figure 7B – Postcrash picture of crash cushion on November 14, 2015, at the exit ramp transition to SR-85.

Figure 7C – Google Maps Street View image captured in September 2015 showing the crash cushion fully collapsed.

Figure 7D – Google Maps Street View image captured in October 2015 showing the crash cushion fully collapsed and missing the retroreflective object marker.

Figure 7E – Google Maps Street View image captured in November 2015 showing the crash cushion fully collapsed and missing the retroreflective object marker.

Figure 7F – Google Maps Street View image captured on December 23, 2015 showing the crash cushion being repaired by Caltrans.

7.2 Fatal Crash (March 23, 2015) CHP Traffic Collision Report #9330-2018-0839

The SCI SmartCushion® SCI100GM crash cushion was in a damaged and collapsed condition prior to the March 23, 2018 fatal crash. The crash cushion was damaged on March 12, 2018, at 10:30 p.m., during a solo vehicle traffic collision.[32] A 2010 Toyota Prius operated by a 31-year-old male driver on US-101 was traveling southbound south of North Shoreline Boulevard, entered the gore area, and collided with the crash attenuator. The solo occupant was wearing his lap/shoulder belt restraint and the driver's side airbag / knee bolster airbag deployed. The driver suffered a fracture/lacerated finger on his left hand and small tear of the intimal aorta.[33]

The CHP responded to the March 12th crash with two Sergeants and four Officers.[34] Caltrans maintenance personnel did not respond to the scene and there is no record in the dispatch log that Caltrans was notified of the damage to the crash cushion. A review of the CHP traffic collision report 9330-2018-0724 (page 2) states that Caltrans was notified of the buckled/crushed attenuator but there is no record to corroborate this claim.

Figure 7E depicts a dashcam image of the damaged attenuator on March 15, 2018 which was provided by a witness traveling through the area. There was no evidence (cones or barricades) that Caltrans had yet visited the scene.

Figure 7E – Witness dashcam image of the crash cushion on March 15, 2018 at about 5:03 p.m.

[32] See Highway Attachment 10 – Copies of Traffic Collision Reports (TC Report #9330-2018-00724)
[33] Refer to Survival Factors Group Chairman's Factual Report
[34] See Highway Attachment 12 – CHP Dispatch Log for March 12, 2018 Toyota Prius Crash

NTSB interviewed witnesses and obtained information from Caltrans to determine a timeline of events and the circumstances leading to the repair of the crash cushion.[35] The Caltrans Maintenance Supervisor for the Cupertino Area provided the following information:

- On March 20, 2018, at about 9:30 a.m., the maintenance supervisor for the Cupertino, CA facility was advised by two workers patrolling the area that the crash cushion at the southbound US-101 to the SR-85 southbound connector had been hit. The maintenance supervisor had no knowledge that the crash cushion had been damaged eight days earlier on March 12, 2018.

- Caltrans workers sent three pictures (see figures 7F to 7H) to the maintenance supervisor showing that resetting of the crash cushion was not possible due to a broken wire cable.

- The maintenance supervisor advised workers to put cones and barricades up until a new crash cushion could be located to replace the damaged attenuator.

- On March 20, 2018, there was no date scheduled for replacement of the crash cushion and a written work order was not prepared. The maintenance supervisor advised that this was because he had to locate a replacement crash cushion and identify employees and vehicles to perform the job.

- On March 20, 2018, the maintenance supervisor and his crew of 2 were repairing a center divider barrier hit on SR-85.

- The Cupertino maintenance area covers areas prone to slides during rain events. On March 21 and 22 they were assigned to storm patrol which requires 12-hour shifts.

- On March 23, the crew was off work because they had worked all night long on a 12-hour storm patrol.

- From March 20 to the morning of March 23, the maintenance supervisor was working on the center divider repair, storm patrol, and attempting to locate a new crash cushion.

- Since the supervisor did not have a replacement crash cushion at the Curpertino facility, he reported calling around to other maintenance facilities (San Francisco, Foster City, Gilroy and the San Jose Bernal yard) to locate an available crash cushion.

- Two crash cushions were located at the San Jose Bernal yard, but these were reserved for another location and waiting to be installed. A decision was made to

[35] See Highway Attachment 13 – Caltrans Maintenance Supervisor (Cupertino Area) Information

use one of these two crash cushions at the US-101-SR-85 crash location but it took two days receive approval to change the installation location.

- On March 23, 2018, the date of the Tesla crash, the supervisor and his crew were off work. The supervisor was called because the day shift needed to unlock the gate to obtain push brooms to help clear the scene. The supervisor advised that he was not informed that the crash cushion had been hit again.

- Even though he was off duty, the maintenance supervisor reported making several calls over the weekend (March 24 – March 25) to coordinate replacement of the crash cushion on Monday, March 26.

- Since the Cupertino maintenance area only had 2 employees, the supervisor had to locate crew and equipment. He added that a crash cushion replacement takes 10 employees and several trucks. A full lane closure, removal of the old crash cushion, and installation of a new crash cushion takes 9-10 hours. He had to locate other employees and vehicles, clearing availability with each supervisor, to fully staff the crew for the replacement on March 26.

- On Monday, March 26th, the new crash cushion was installed at the crash location. The emergency closure of the highway and crash cushion replacement was completed at 3:30 p.m.

Figure 7I depicts a dashcam image of the damaged crash attenuator on the morning of the crash, 1 hour and 17 minutes before the fatal Tesla crash. In the photo a Type 1 sawhorse barricade is laying in the gore north of the crash attenuator. There was also two orange traffic cones and a knocked down cone in the vicinity of the crash attenuator.

Figure 7F – Damaged crash attenuator photo taken by Caltrans worker on March 20, 2018.

Figures 7G and 7H – Photos taken on March 20, 2018 by a Caltrans worker depicting the damage to the crash attenuator and wire cable.

Figure 7I – Witness dashcam image of the crash cushion on March 23, 2018 at about 8:10 a.m. (1 hour 17 minutes before the fatal Tesla crash).

7.3 Delayed Repair of Crash Attenuator January 2017 to April 2017

The SCI SmartCushion® SCI100GM crash cushion was damaged in a collision on January 3, 2017 (CHP TC #9330-2017-0017) and was not replaced until April 14, 2017 (Caltrans work order 4256817). Figures 7J – 7L depict the collapsed crash cushion in Google Maps Street View images in January, February and April.

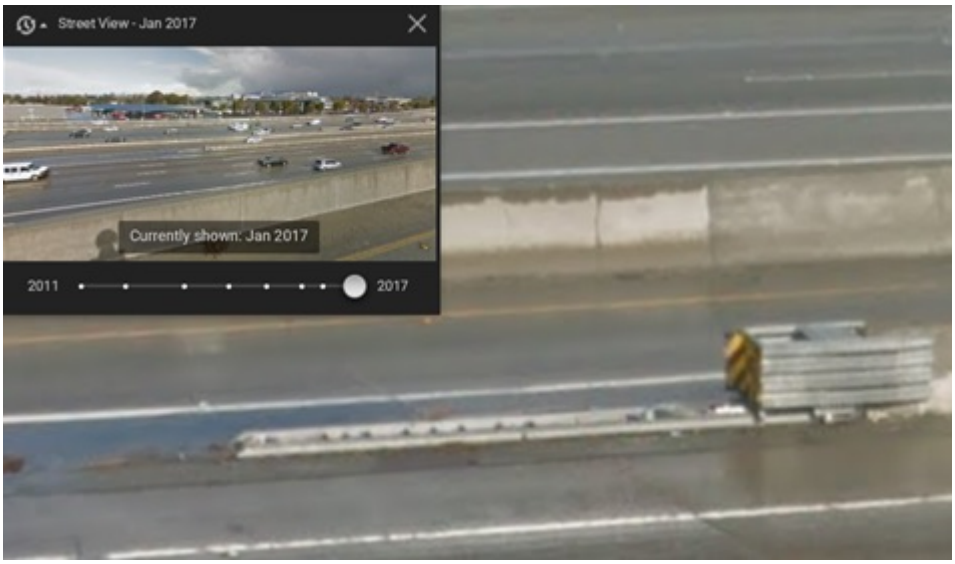


Figure 7J – Google Maps Street View image captured in January 2017 showing the crash cushion fully collapsed.

Figure 7K – Google Maps Street View image captured in February 2017 showing the crash cushion fully collapsed and the broken wire cable.

Figure 7L – Google Maps Street View image captured in April 2017 showing the crash cushion fully collapsed. Caltrans maintenance records show the crash cushion was replaced on April 14, 2017.

8. CHP and Caltrans Policy Regarding Damage to State Property

The California State Transportation Agency (CalSTA) is cabinet-level state agency focused on addressing the state's transportation issues.[36] CalSTA agencies and departments include the Office of Traffic Safety (OTS), Department of Motor Vehicles (DMV), CHP, Caltrans and others. The CHP and Caltrans have entered into joint operational agreements to enhance cooperation and understanding between the two Departments in matters of mutual concern.[37] The stated intent of the policy agreement is that "both Departments personnel at all levels work collaboratively, coordinate their efforts on behalf of the public, and cooperate in identifying and resolving mutual problems."

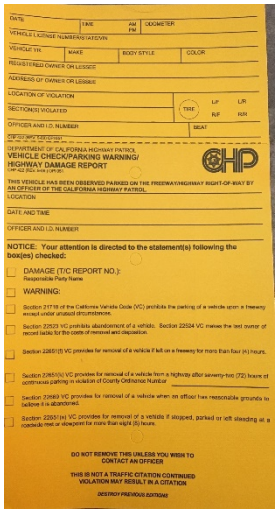
Annex A of the joint operational policy statement addresses traffic management and control on state highways. Regarding traffic collisions, policy states that "the CHP should notify Caltrans immediately when there are significant traffic impacts as a result of a traffic collision, or when there is damage to the highway facility. Caltrans personnel are responsible for the repair of the damage and restoration of the facility to normal operating conditions." The policy adds that "copies of collision reports on state highways are provided by the CHP to Caltrans for consideration of safety and operational betterments, repair, and maintenance. . . When frequent collision locations are recognized, Caltrans and the CHP should communicate to determine potential mitigations."

[36] See https://calsta.ca.gov
[37] See Highway Attachment 14 - CHP/Caltrans Joint Operational Policy Statement

The CHP and Caltrans also collaborated on the development of traffic incident management guidelines.[38] Section 2.2 of the guidelines state that "Caltrans shall be notified as soon as possible, or if after hours, the next day via the District's Emergency Operations Center/Traffic Management Center of any damage to the roadway. State property or appurtenances and any other incidents not identified as an immediate hazard." Section 7.8 of the guidelines add that "Caltrans should be notified immediately for "any sand barrel or other energy attenuator hits."

CHP guidance in the *Collision Investigation Manual* (HPM 110.5) requires officers record whether the owner or person in charge of the damaged property was notified on traffic collision investigation reports. The manual adds that "if the owner or occupant of the damaged property cannot be contacted, advise the communications center of the damage." The manual also states that a CHP 422 form (Vehicle Check/Parking Warning/Highway Damage Report – see figure 9A) should be prepared and attached to damaged state property.[39]

In a review of circumstances following the March 12, 2018 crash, NTSB investigators were advised by Caltrans that they were never notified by the CHP of the damage to the crash cushion.[40] Additionally, a CHP 422 form was not attached to the damaged attenuator. Caltrans first discovered that the crash cushion was damaged and non-functional on March 20, 2018. The crash cushion was not repaired until March 26, 2018, three days after the fatal Tesla crash.


DATE
TIME
AM PM
ODOMETER
VEHICLE LICENSE NUMBER/STATE/VIN
VEHICLE YR
MAKE
BODY STYLE
COLOR
REGISTERED OWNER OR LESSEE
ADDRESS OF OWNER OR LESSEE
LOCATION OF VIOLATION
SECTION(S) VIOLATED
TIRE
LF
LR
RF
RR
OFFICER AND I.D. NUMBER
BEAT
DEPARTMENT OF CALIFORNIA HIGHWAY PATROL
VEHICLE CHECK/PARKING WARNING/
HIGHWAY DAMAGE REPORT
THIS VEHICLE HAS BEEN OBSERVED PARKED ON THE FREEWAY/HIGHWAY RIGHT-OF-WAY BY AN OFFICER OF THE CALIFORNIA HIGHWAY PATROL.
LOCATION
DATE AND TIME
OFFICER AND I.D. NUMBER
NOTICE: Your attention is directed to the statement(s) following the box(es) checked:
DAMAGE (T/C REPORT NO.):
Responsible Party Name
WARNING:
Section 21718 of the California Vehicle Code (VC) prohibits the parking of a vehicle upon a freeway except under unusual circumstances.
Section 22523 VC prohibits abandonment of a vehicle. Section 22524 VC makes the last owner of record liable for the costs of removal and disposition.
Section 22651(l) VC provides for removal of a vehicle if left on a freeway for more than four (4) hours.
Section 22651(k) VC provides for removal of a vehicle from a highway after seventy-two (72) hours of continuous parking in violation of County Ordinance Number
Section 22669 VC provides for removal of a vehicle when an officer has reasonable grounds to believe it is abandoned.
Section 2251 (e) VC provides for removal of a vehicle if stopped, parked or left standing at a roadside rest or stopping for more than eight (8) hours.
DO NOT REMOVE THIS UNLESS YOU WISH TO CONTACT AN OFFICER
THIS IS NOT A TRAFFIC CITATION CONTINUED VIOLATION MAY RESULT IN A CITATION
DESTROY PREVIOUS EDITIONS

[38] See Highway Attachment 15 – Traffic Incident Management Guidelines

[39] The CHP 422 form is a yellow adhesive form that can be stuck on damaged property, abandoned vehicles, and as a parking warning. CHP HPM 110.5 states that CHP Form 422 need not be prepared when attaching the form to damaged property jeopardizes the safety of the officer or the public or when a Caltrans representative responding to the collision is provided with the necessary information by the officer at the scene.

[40] Dispatch records for the March 12, 2018 crash were checked and no evidence was found that the CHP notified Caltrans of the damaged crash cushion.

Figure 9A – Example of CHP 422 form (Vehicle Check/Parking Warning/Highway Damage Report) which can be affixed to damaged state property as a form of notification of the need for repair.

9. Maintenance of Traffic Safety Devices

The Caltrans Maintenance Manual, Volume 1 Section 3 provides guidance regarding the maintenance of safety devices.[41] Crash cushions are described as vehicle energy attenuators (energy dissipaters) in the manual. Crash cushions are "intended to protect the motorist from the consequences of collision with a fixed object. Routine surveillance should be performed to ensure that these devices remain functional. Detailed inspections should be made to ensure that the components are in satisfactory condition. Damage that impairs the functional integrity of attenuators should be repaired as soon as possible."

Levels of maintenance, including frequency and priority of action for severe damage (any damage that can affect the ability of the safety device from performing its intended function) are in included in the Maintenance Manual Volume 2.[42] Damage to a crash attenuator is considered a "safety" item with an immediate response required to remove crash cushion debris and spilled sand. Repair or replacement of damaged attenuators has a priority code of 1 requiring repair of crash cushions within one week.

On July 31, 2015, the Caltrans Chief of Maintenance sent out a policy memo to subordinate maintenance managers indicating a need to improve the maintenance of safety devices.[43] The policy memo states that the improved process will be incorporated into the Caltrans Maintenance Manual.[44] The policy lays out the following actions for every repair or installation of a safety device:

9.1 Documentation and Notification

Policy: "Each individual device must have the manufacturer's checklist signed off by the crew supervisor, and superintendent or District Safety Devices Coordinator after each repair. Each device repaired or installed must have its own checklist. The District Safety Devices Coordinator must be notified for every repair. This notification should be sent prior to closing the IMMS Work Order. The IMMS Work Order should not be closed until the District Safety Devices Coordinator has reviewed the location or received a copy of the checklist and approved the work. The coordinator may inspect any repair. This notification must be by e-mail and must include the IMMS Work Order number." NTSB investigators requested Caltrans provide information regarding the device checklists and oversight provided by the District Safety Devices Coordinator. Caltrans advised that the interim Traffic Safety Devices Coordinator is Saif Mamoon. Caltrans reported that

[41] See Highway Attachment 16 – Caltrans Maintenance Manual Volume 1, Section 3
[42] See Highway Attachment 17 – Maintenance Manual Volume 2, Attenuator Replacement
[43] See Highway Attachment 18 – Caltrans Chief of Maintenance Memo
[44] The information contained within the policy memo has not been fully incorporated into the Maintenance Manual. Caltrans has advised that the policy guidance in the memo is still applicable to current field maintenance operations.

"when damaged crash attenuators are repaired and replaced in kind, Maintenance does not contact the Safety Devices Coordinator. The checklist is approved by the Maintenance Supervisor. Only when they need a recommendation for a different kind, then they seek the Coordinator's recommendation."[45]

9.2 Material on Hand

Policy: "Every maintenance region is required to have a minimum of two of every type (or variation) of end treatment and crash cushion that is installed within its boundaries. The Region Manager should make the determination to have more on hand if the frequency of repair for that type of device is high."

NTSB investigators inquired whether adequate replacement crash cushions were in inventory. The Caltrans maintenance supervisor advised that there were two replacements available at the Bernal maintenance yard in San Jose. In order to locate these crash cushions, the maintenance supervisor needed to call around to other maintenance facilities to locate one. Upon locating the crash cushions, he was advised that the crash cushions were reserved for another location and waiting to be installed. The maintenance supervisor advised that it took 2 days to locate a new crash cushion and receive approval to change the installation location.

9.3 Response

Policy: "The local maintenance crew or district guardrail crew must respond immediately to all accident or vehicle collisions that involve any safety device. The CHP, local law enforcement, or local emergency response agency are not qualified to assess damage to safety devices. For those items that have a response time of one week, the crew supervisor must notify the area superintendent within two business days if the crew is not able to initiate permanent repairs within the one-week time frame. . . The CHP, local law enforcement, or local emergency response agency must notify Caltrans of any accident involving a guardrail, median barrier, or crash cushion, no matter how trivial the damage appears to them. What seems like minor damage may actually affect the performance of the device during the next incident. . . The use of emergency lane closure procedures needs to be considered in order to initiate repairs in a timely manner."

9.4 On-Call Contract

Policy: "All districts must have on-call contract(s) in place to be able to repair guardrails, guardrail end treatments, median barriers, and crash cushions. These contracts will augment Caltrans forces so that necessary repairs are initiated and completed within the prescribed times in the Maintenance Manual. The Division of Maintenance will have templates for these contracts. The contracts must be comprehensive and include all necessary labor, parts, and traffic control. Existing contracts should be amended to include all devices." NTSB investigators

[45] See Highway Attachment 19 – Caltrans Data Request Follow-up Response

found no evidence within the maintenance records that repairs and replacement of crash cushions are completed through on-call contracts.

E. DOCKET MATERIAL

The following attachments are included in the docket for this investigation:

LIST OF ATTACHMENTS

Highway Attachment 1 –	Video Drive Through of Crash Scene on March 27, 2018
Highway Attachment 2 –	FHWA 2007 Guidance Memo on Preferential Lane Traffic Control Devices
Highway Attachment 3 –	San Jose, California NTSB Crash Investigation
Highway Attachment 4 –	Safety Recommendation Letter to Caltrans
Highway Attachment 5 –	2016 Traffic Volumes on California State Highways
Highway Attachment 6 –	SCI Smart Cushion Design and Installation Manual
Highway Attachment 7 –	Severe Duty Crash Cushions Web Conference
Highway Attachment 8 –	SCI Smart Cushion MASH Eligibility Letter
Highway Attachment 9 –	Caltrans District 4 Attenuator Repair Records for HOV Left Exits
Highway Attachment 10 –	Copies of Traffic Collision Reports
Highway Attachment 11 –	Caltrans IMMS Work Order Reports
Highway Attachment 12 –	CHP Dispatch Log for March 12, 2018 Toyota Prius Crash
Highway Attachment 13 –	Caltrans Maintenance Supervisor (Cupertino Area) Information
Highway Attachment 14 –	CHP/Caltrans Joint Operational Policy Statement
Highway Attachment 15 –	Traffic Incident Management Guidelines
Highway Attachment 16 –	Caltrans Maintenance Manual Volume 1, Section 3
Highway Attachment 17 –	Maintenance Manual Volume 2, Attenuator Replacement
Highway Attachment 18 –	Caltrans Chief of Maintenance Memo

Highway Attachment 19 – Caltrans Data Request Follow-up Response

END OF REPORT

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